EVS26
Los Angeles, California, May 6-9, 2012

Electric Propulsion in Short Sea Shipping

Paul Windover[1], Bryan Roy, Joseph Tario[2]
[1]*New West Technologies, 414 Trenton Ave, Suite 2D; Utica, NY 13502*
[2]*New York State Energy Research and Development Authority, 17 Columbia Circle; Albany, NY 12203*

Abstract

Short sea shipping, the movement of freight along coasts and inland waterways, is more efficient and environmentally friendly for transporting large quantities of product. While marine transport may displace numerous diesel trucks, conventional propulsion systems still rely on petroleum fuels and the old engines found in most freight vessels produce harmful exhausts. An investigation was undertaken to determine the technical, economic, and environmental potential for an electric propulsion system in short sea shipping operations within New York State where numerous waterways provide a marine highway option that can be used for freight transport. Duty cycle information obtained from tugs during real-world operations in the New York City Harbor was used in the analysis. Three drivetrain configurations, a series hybrid-electric tug with energy storage, a series hybrid-electric tug with plug-in capability, and a series hybrid-electric tug with exchangeable energy storage capability were analyzed using the acquired load profiles. Modeling results indicate that the fuel savings is highly dependent on the application. The plug-in configuration is likely to be the most cost effective concept based on the large increase in additional fuel savings for the minimal cost to add this capability. This study shows the value of modeling with real-world duty cycles to estimate system benefits. An ongoing study evaluating the potential benefits of electric propulsion for New York State Canal Corporation maintenance vessels may identify a favorable application for this technology due to the low power requirements and regular recharging opportunities within their operations.

Keywords: marine, electric drive, data acquisition, modeling, energy consumption

1 Introduction

According to the U.S. Energy Information Administration, New York State (NYS) is the fifth largest energy user of all the states. The State's transportation sector in 2009 was responsible for 77 percent of petroleum consumption (all of which must be imported because there are no petroleum refineries in the State) and 40 percent of greenhouse gas (GHG) production, the single largest sector in either category [1]. While automobiles are the primary contributor, energy use and GHG emissions from freight transportation have grown at roughly twice the rate of passenger transportation emissions over the last 15 years.

In January of 2011, Governor Andrew M. Cuomo reaffirmed Executive Order No. 24 (2009), which set a goal to reduce NYS greenhouse gas emissions in 2050 by 80 percent below the levels emitted in 1990. The Executive Order also created the New York Climate Action Council with a directive to prepare a Climate Action Plan that will assess how all economic sectors can reduce GHG emissions and adapt to climate change.

The New York State Energy Research and Development Authority (NYSERDA) is a public benefit corporation to help New York meet its energy goals: reducing energy consumption, promoting the use of renewable energy sources, and protecting the environment. NYSERDA strives to facilitate change through the widespread development and use of innovative technologies to improve the State's energy, economic, and environmental wellbeing. NYSERDA's transportation programs are designed to provide funding opportunities for innovative research projects, and product development initiatives that reduce emissions, improve air-quality, and reduce our dependency on imported oil. The programs are designed to promote NYS business development, protect the environment, increase energy reliability, and enhance a competitive transportation-energy market.

New West Technologies has been awarded multiple NYSERDA contracts to investigate the feasibility of advanced transportation concepts, demonstrate new technologies that have not been validated in real-world conditions, and assist in the commercial acceptance of underutilized systems that have not been previously deployed in NYS to any significant extent. To advance waterborne freight transport, New West Technologies completed an All-Electric and Hybrid-Electric Short Sea Shipping Assessment for NYS in 2010 and an Evaluation of Electric Propulsion for Tug Operations in New York City (NYC) Harbor in 2012. NYSERDA also recently awarded a follow-on project to New West Technologies to study the feasibility of electrifying NYS Canal Corporation maintenance vessels.

1.1 Short Sea Shipping

Economies rely on the transportation of freight to maintain the flow of goods from manufacturers to consumers. The trucking industry accounts for about 70 percent of all transportation domestic freight tonnage [2]. An alternative to trucking, which could ease the burden on the highway system, is commercial vessel or tug and barge operations that transport freight on inland waterways. These operations, termed short sea shipping, have traditionally moved freight that could not effectively be transported on the highway because of height, width, or weight restrictions. Because of slower operating speeds, waterborne cargo is typically not time sensitive. In addition to their ability to transport difficult loads, marine vessels also have an inherent efficiency advantage. A barge can transport 514 ton-miles per gallon of fuel while trucks can only transport 59 ton-miles per gallon of fuel [3].

Short sea shipping provides significant economic savings for transporting dry or liquid products in bulk quantities because a typical ship or barge will have at least 60 times more capacity than a single truck and can load or unload that amount of cargo much more effectively. The expansion of marine transport often requires little infrastructure investment and could have a direct effect on alleviating highway congestion with routes along existing highways [4]. Additional freight will have to be moved with economic growth and increases in population growth, for which trucking will only further burden a highway system that has reached maximum capacity around many cities. For coastal cities or those served by a major inland waterway, short sea shipping is a logical alternative transportation mode for freight that is either distributed to rural regions from an international port or brought into the densely populated urban area for consumption.

Interest in short sea shipping increased considerably in 2010 when U.S. Transportation Secretary Ray LaHood identified a national network of marine corridors, connectors, projects, and initiatives for further development as part of "America's Marine Highway Program." The Eastern Seaboard and the Eastern United States in general, figured prominently in the program due to high population densities and an abundance of coastal and inland waterways.

1.2 Waterways in New York State

NYS has a network of waterways which are currently used, to a limited extent, for commercial shipping operations. These waterways include the NYC Harbor, Hudson River, New York State Canal System, St. Lawrence Seaway, Lake Champlain, and Great Lakes. The Port of New York and New Jersey is the third largest U.S. port by cargo volume, handling almost 150 million tons in 2009 [5]. The NYS Canal System is 524 miles long with 57 locks and 20 lift bridges. It is a critical component of a successful waterborne freight system in NYS, because it links the Port of New York and the Hudson River to the Great Lakes. Partially due to reduced commercial demand, the canal is only open seasonally and other methods of transport must be used during the coldest months. The Great Lakes provide cost-effective trade routes to the Midwest and Canada.

Figure 1-1 illustrates the marine highway routes that are created by the waterways in NYS.

Figure 1-1: NYS Waterways (shown in light blue)

2 Feasibility Assessment

While short sea shipping has efficiency and economic benefits that warrant its use for freight transport, marine vessels are reliant on petroleum fuels. This non-renewable resource is costly and must be imported which is a drain on the local economy. In addition, the combustion of petroleum fuels emits harmful emissions that have negative effects on the environment and contributes to bad air quality that is injurious to human health. One potential solution to address these concerns is an electric propulsion system that would reduce or eliminate petroleum consumption. Using similar approaches that are being commercialized in the automobile industry, the shipping industry could reduce emissions and clean up the air and water around highly populated port areas. Electric propulsion systems have the capability to be more efficient, conserving energy during idling and potentially having more power for the small intervals of acceleration and steering. At port, the vessel could connect to utility power to recharge the on-board energy storage system. Switching to electrical power generated in NYS has both petroleum and emission reduction benefits because the primary sources of that power which include Nuclear (27%), Natural Gas (26%), and Hydro-electric (18%). New West Technologies performed an assessment of the technical, economic, and environmental aspects of an electric propulsion system for use in a short sea shipping operation on NYS waterways.

2.1 Electric Marine Propulsion

Electrical propulsion for the marine industry is not new. It was used years ago when steam engines were on ships to generate electricity and can be found on modern nuclear powered vessels. Most current electric propulsion applications are utilized for added power (icebreakers) or quiet operation (stealth submarines), and have limited use for increasing efficiency. A few hybrid tug concepts have been deployed recently for harbor tugs that may idle and perform only small maneuvers for long periods between jobs. While these vessels have proven beneficial and show efficiency improvement, the limited energy storage does not provide fully-electric propulsion capability. A series hybrid-electric propulsion system with a large, plug-in capable energy storage system and back-up generators may be able to provide significant petroleum reductions and increase the economic benefits of short sea shipping.

The series hybrid-electric configuration provides propulsion power for the vessel using diesel generators (gensets), on-board electrical energy storage, or a combination of both. In this concept, the gensets would become “range extenders” that would operate at their most efficient speed when additional energy is required. The system design includes several diesel gensets (for redundancy and the ability to only produce as much power as needed) connected to banks of energy storage and electrically driven propulsors through an electrical control cabinet, or switchboard, which controls the source and flow of power. The primary power source is the electrical energy storage that would be charged from shore power and allow the vessel to operate almost exclusively on electric power for a period of time. This arrangement is shown in Figure 2-1.

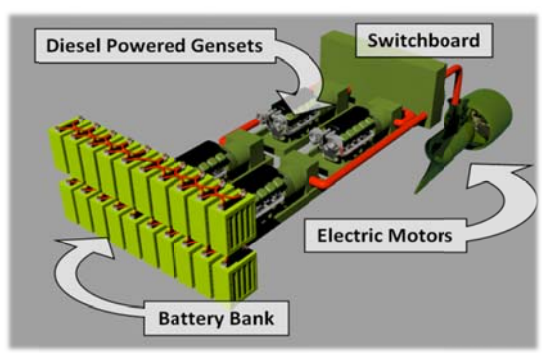


Figure 2-1: Series Hybrid-Electric Propulsion System with On-Board Energy Storage

2.2 Potential Application: New York City Harbor

The Port of New York and New Jersey is the largest system of ports and terminals on the East Coast of North America. In the port there are terminals that are able to handle most forms of cargo, from bulk, break-bulk, containerized, liquid, roll-on/roll-off, automobiles, and large project pieces. The port is the primary destination of cross-ocean freight voyages, with the majority of freight coming into the Port of New York and New Jersey and later being distributed to other locations via short sea shipping, rail, or truck. Within the port there are six terminals as shown in Figure 2-2; Port Newark Container Terminal, APM Terminals, Maher Terminals, New York Container Terminal, Global Marine Terminal, and Red Hook Container Terminal. Tug boats and other cargo vessels tend to make numerous short trips between terminals and frequently dock at their home port or one of the cargo terminals. This provides significant potential for electric propulsion vessels because there are regular opportunities to charge the on-board energy storage system and short routes that may be completed primarily using electric power.

Figure 2-2: Port of NY and NJ Terminals [6]

2.3 Potential Application: NYS Canal

The Erie Canal, the longest of the four waterways of the New York State Canal System, allows marine vessels to transport freight between Albany and the Great Lakes, or any point in between. The volume and type of freight is often limited due to its seasonal operation, barge size restriction, speed limit, and required closure at night. However, the canal plays a vital role in transporting large items, such as huge turbines and bridge trusses that would otherwise not be able to be shipped in their assembled form. With the smaller sized barges, restricted drafts, calm waters, and slow speeds, the propulsion power requirements are reduced. In addition, locks and lift bridges are regularly spaced along the route where the vessels typically spend 30 minutes or more getting through. These factors present an interesting application for electric propulsion in which series hybrid-electric tugs could recharge or swap energy storage modules while being lifted or lowered in the lock. Many of the locks were constructed with hydro-electric generation capability that are still operating or could be re-commissioned to provide power to the charging station. The limitation of this concept is the extensive infrastructure costs to establish fast charging capability at every lock, which would serve a small number of vessels operating only during the warm seasons.

An additional electric propulsion option associated with the New York State Canal System is the fleet of vessels required to carry out the operation and maintenance of the canal. The tugboats, tenders, and buoy boats perform the necessary tasks of placing, maintaining and removing buoys, moving dredges, taking soundings, and various other jobs. These vessels are used daily, returning to a Floating Plant or lock at night. During the day there are periods when the tenders and buoy boats tie onto the hydraulic dredges, derrick boats, gradalls, or quarter boats between tasks. All of this equipment has generators for on-board power that may have excess electricity that can be used to charge the energy storage on a series hybrid-electric vessel. Overnight, low-cost slow chargers should be sufficient to fully recharge the on-board energy storage. Given these opportunities to plug into electrical power and the lower propulsion requirements it is possible that these canal vessels may operate entirely on electricity.

3 NYC Harbor Tug Evaluation

The feasibility assessment indicated that a series hybrid-electric tug utilizing a large energy storage system could potentially provide significant energy and emissions savings when used for an in-harbor barge route. This result was determined using an assumed duty cycle for a tug transporting a rail car float across the NYC Harbor. The original conceptual design integrated the energy storage module into a railcar or container on the barge that was being transported, with a power cable run to the tug to supply it with electricity. The envisioned advantage of this concept was that the energy storage module could quickly be swapped with another one for the next transport while the depleted module could be moved to a charging location where it could wait for off-peak electricity before recharging and be ready by the following day.

It was clear that a second project phase would be necessary to further prove the viability of this concept using real-world tug data. Support from a specialized marine engineer was required to address the technical barriers of the concept and develop an outline of the system components, including the series hybrid-electric tug, energy storage modules, and electrical management system. A more detailed evaluation using commercially available equipment and actual operational duty cycles would result in more accurate estimates of the efficiency gains, environmental benefit, and market potential. The project team sought to establish a partnership with existing tug operators to develop a commercially acceptable pre-prototype conceptual design and identify potential barriers to a successful deployment of the electric propulsion system.

3.1 Investigated Marine Operations

The two selected applications are both tugboats primarily utilized for inter-harbor operations and consequently rarely travel beyond NYC Harbor. Daily duties within the harbor generally consisted of barge transports between cargo terminals, construction sites, and refuse transport. A Global Positioning System (GPS) was used on one of the tugs to trace its routes and stops. An example GPS trace over several days is shown in Figure 3-1. The frequency, duration, and location of stops were used to determine the tugs potential for plugging in to electrical power to recharge the energy storage module.

Figure 3-1: Typical Routes for NYC Harbor Tugs

3.1.1 Moran Towing Corporation

Moran Towing Corporation began as a small towing company operating in the New York Harbor 150 years ago. Throughout the years, Moran's expansion and diversification enables them to provide a wide range of services that includes ship docking, contract towing, Liquefied Natural Gas (LNG) activities, and marine transportation. Their tug service includes the East Coast, Great Lakes, inland waters along the U.S. Eastern Seaboard, and the Gulf of Mexico, with occasional trips outside of U.S. waters. Currently, Moran's fleet consists of 95 tugs and 30 barges stationed throughout their ports of operation. Customers served at these port locations include shipping companies, energy and power generating companies, barge companies, minerals and commodity corporations, government agencies, and the U.S. Navy. Moran is a proponent of advanced technology and is increasingly adopting Z-drive and articulated tug and barge units to increase performance [7].

The Moran Towing vessel used in this analysis is an Atlantic IV class articulated tug and barge. This vessel is propelled by two EMD turbocharged, diesel v-12 engines, model number 12-645F7B. These engines are rated at 2,550HP (1900kW) peak each for a total of 5,100HP, and power the mechanical drive system through a reduction gearbox. Power is routed through Lufkin 4.5:1 ration reverse reduction gears to two 115 inch Rolls Royce five blade stainless steel propellers. The auxiliary loads are powered by a John Deere RG6081 engine coupled to a genset. The tug has redundant gensets for safety and security with only one operating at a time. An example of this class of Moran tug is shown in Figure 3-2. [7]

Figure 3-2: Moran Class Atlantic IV Tug

3.1.2 Reinauer Transportation

Reinauer Transportation Companies (RTC) began local operations in the New York and New Jersey harbor area in 1923 using fishing vessels which were converted to large tank vessels. Since their beginning, RTC has grown to now operate more than 75 vessels, including numerous 2,000 hp to 3,000 hp tugs and articulated tugs up to 7,200 hp. RTC began significant utilization of articulated tug and barge operations in the 1990s resulting from the shift to double-hulled vessels required by the Oil Pollution Act of 1990. Through the years they have also acquired other operations including Boston Towing and Transportation, SENESCO Marine, and REICON Construction to create a comprehensive transportation company. RTC also acquired the Erie Basin Barge Port, which includes sheltered water areas and upland warehouse areas, totaling 87 acres all together. Their headquarters are on Staten Island where both corporate offices and vessel maintenance are located [8,9].

The Kristy Ann Reinauer, a square bow pushboat, was used to establish a duty cycle for developing a comparable series hybrid-electric tug. This tug is not suitable for open water transports and stays relatively near its home base, resulting in short transits and significant waiting periods spent at RTC's dock. The tug in its current configuration is shown in Figure 3-3. This test vessel is powered by two MTU 8V 4000 M60 diesel engines producing 880 kW (approximately 1,200 HP) each [10]. These engines are generally synchronized. However, during maneuvering, control can be split to allow for more precise control. Power is routed through a mechanical drive system into twin fixed Kort nozzles and flanking and is directed with standard rudders. The tug is also equipped with two 75 kW auxiliary gensets (for redundancy), which operate one at a time, to supply on-board electrical power.

Figure 3-3: Kristy Ann Reinauer

3.2 Data Collection

Moran provided basic pre-recorded data for this analysis to evaluate the dynamics of the vessel's operation. Three months data was provided at one minute sampling periods. Parameters included; port side main engine speed, starboard side main engine speed, port side main engine fuel rate, starboard side main engine fuel rate, and fuel consumption rates for both gensets. A 200 minute section of the data is shown in Figure 3-4 to demonstrate the highly variant nature of the vessel's operation.

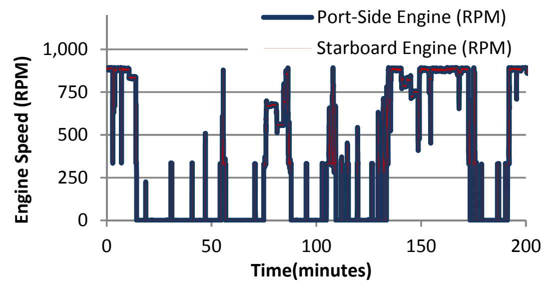


Figure 3-4: Moran Tugboat Operational Profile

To obtain operational data on the Kristy Ann Reinauer, a data logging system was installed on-board to record engine parameters and vessel activity. Data was retrieved from the tugs two engines' diagnostic connectors. Captured parameters later used in the analysis included; percent engine load, fuel rate, and engine rotational speed. Additional information collected by the data logging system included engine oil pressure, engine coolant temperature, exhaust gas temperature, and engine oil temperature. A GPS unit also recorded latitude, longitude, and speed data. The actual recorded engine test data is shown in red on Figure 3-5 projected over the power curve for the engines in the Kristy Ann Reinauer.

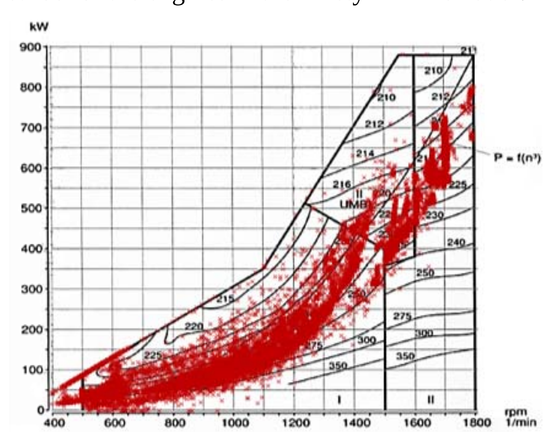


Figure 3-5: MTU 8V 4000 M60 Diesel Engine Map

Duty cycle information obtained from the selected NYC tugs during real-world operations was used to establish baseline operating parameters for these applications. The overall power profiles are shown in Figure 3-6.

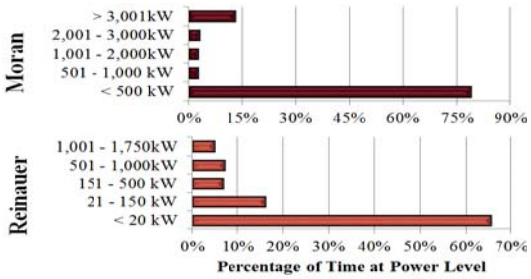


Figure 3-6: Power Usage Profiles for Selected Tugs

The significant portion of time at the lowest power level indicates a lot of stationary periods utilizing only the auxiliary genset. GPS data on the Kristy Ann Reinauer showed that much of this occurred while the vessel is at its home port. These tugs spend only a small fraction of their time at high power, which generally occurs in short periods during barge transport.

3.3 System Design

Three electric propulsion system configurations were evaluated to determine the value of advanced hybrid-electric systems compared to a conventional direct diesel drive tug. The hybrid-electric tug (HET) layout utilizes diesel engines to generate electric power for the propulsion motors and is mechanically decoupled from the propulsion system. The conceptual layout of this system can be seen in Figure 3-7. The gensets (shown in green) supply power, when needed, to the electrical control cabinet which routes power either directly to the propulsion motors (also shown in green) or to recharge the battery pack (positioned just behind the control cabinet).

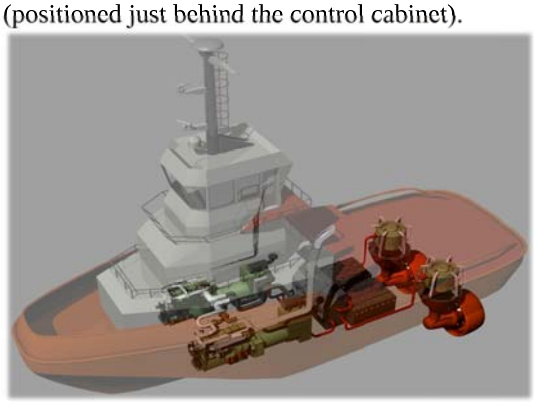


Figure 3-7: Series Hybrid-Electric Tug (HET) Concept Cutaway

With the addition of plug in capabilities, the HET-PI concept could receive a significant portion of its propulsion energy from the grid. This would offset the diesel genset run time required and the overall fuel consumed. In addition to the HET components, this concept requires on-board and off-board transformers along with some form of cable management dockside. One potential layout, which is similar to what is currently utilized for cruise ship cold-ironing applications, is shown in Figure 3-8.

Figure 3-8: Series Hybrid-Electric Tug Concept with Plug-In Capabilities (HET-PI)

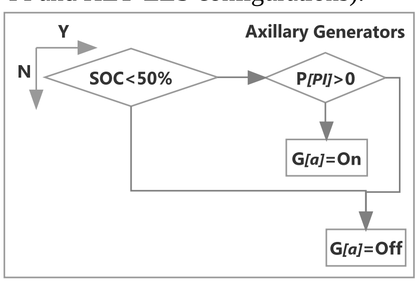
The hybrid-electric tug concept could be further modified with exchangeable energy storage (HET-EES) that can be switched with a fully charged module once it is depleted. The design of the battery switching infrastructure could vary widely; however, some form of large, onshore crane or lift would be required to move the large battery modules as shown in Figure 3-9. This system would also allow the vessel to have a shore power connection to maintain charge and support hoteling loads while stationary at the port. A module placed on-board the vessel is shown here.

Figure 3-9: Series Hybrid-Electric Tug with Exchangeable Energy Storage (HET-EES)

3.4 Modeling

The modeling of the hybrid-electric propulsion systems was completed in separate modules (termed sub-models); primary gensets, auxiliary gensets, energy storage modules, and grid connectivity. These were combined into a comprehensive system operating model. The modeling technique is utilized to determine the energy usage profiles of each of the system components, as well as the overall system interaction. These profiles were then utilized to create total power, fuel consumption, emissions, and cost savings estimates associated with each technology. Similar sub-models were used for the HET, HET-PI, and HET-EES configurations; however, some aspects were eliminated to simulate the variations between these concepts. Data retrieved from the tugs was the primary driver for the modeling analysis which provided real-life applicable results.

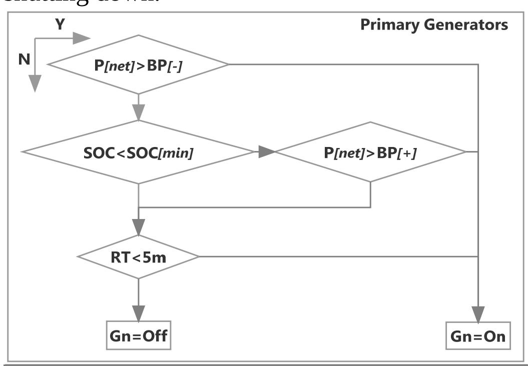
The first sub-model is for the auxiliary genset. As shown in Figure 3-10, this module simply references the state of charge (SOC) and maintains a minimum of 50% charge by turning the auxiliary genset on and off to ensure that power for all on-board equipment is available when needed. This module is programmed to keep the auxiliary genset off when the vessel is plugged into and receiving power from grid (for HET-PI and HET-EES configurations).



G[a]	*Auxillary generator state (on/off)*
P[PI]	*Power received when plugged into the grid*
SOC	*Battery State of Charge*

Figure 3-10: Auxiliary Genset Sub-model Diagram

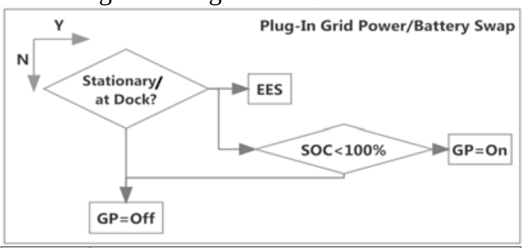
Modules used for each of the primary gensets were similar which allowed for the scalability of the model to accept designs with different number of gensets. The modules are numbered sequentially (genset 1, genset 2, etc.…) and analyzed in numerical order, after the auxiliary genset, in the comprehensive model. The module's logic path, as shown in Figure 3-11, begins by referencing the net power demanded by the tug and comparing it to the maximum power capabilities of the on-board energy storage. The net power refers to the total power, demanded by the tug, minus power provided by the auxiliary genset or lower numbered primary gensets. If the power required is higher than what can be provided by the energy storage, the genset is automatically turned on. If it is not, the system looks at the SOC to determine if it is below a predetermined threshold. This threshold is based on battery specific characteristics and varied for each of the gensets, allowing them to be brought online incrementally if required. This SOC threshold is also utilized to specify charge-sustaining and charge-depleting modes. Charge-sustaining is accomplished by starting the generators earlier and not allowing the SOC to drop as low. It is used on the HET tug to protect battery life and provide sufficient power when needed. Charge-depleting is used on the HET-PI and HET-EES to optimize the use of grid power. It allows the SOC to drop much further before the gensets are brought online. If the SOC is below this threshold, the system checks to ensure that the power the genset provides will not overcharge the battery (which can cause damage) due to other gensets that may be operating. Once on, the gensets operate for a minimum of 5 minutes before shutting down.



P[net]	*Net power demand*
BP[-]	*Maximum battery power (discharging)*
BP[+]	*Maximum battery power (charging)*
G[n]	*Primary Generator State (n=1,2, ect…)*
SOC	*Battery State of Charge*
SOC[min]	*Predetermined Low state of charge threshold*
RT	*Run time*

Figure 3-11: Primary Genset Sub-model Diagram

The grid connectivity sub-model accounts for the displacement of petroleum by grid power and its impact on the overall value of these concepts. This module is not included for the HET concept model but provides grid connectivity simulation for both the HET-PI and HET-EES. To determine if the vessel is able to plug in to grid power or swap battery packs, it is necessary to verify that the vessel is stationary and docked at a location where this capability is possible. This is ideally determined using geo-fencing techniques. However, when GPS data was not available, it was assumed that if the vessel was not active for more than 2 hours, then it was at a dock and could be plugged in. When the vessel is docked and the SOC is under 100%, the vessel will charge the on-board energy storage until mobile. Battery-swapping capability with the HET-EES was only modeled if GPS data could verify that the vessel was at its home port. When that occurred, the vessel swapped battery packs and the SOC was reset at 100%. Shore charging is enabled on the HET-EES to allow auxiliary loads to be provided by grid power even after a battery swap as shown in the diagram in Figure 3-12.

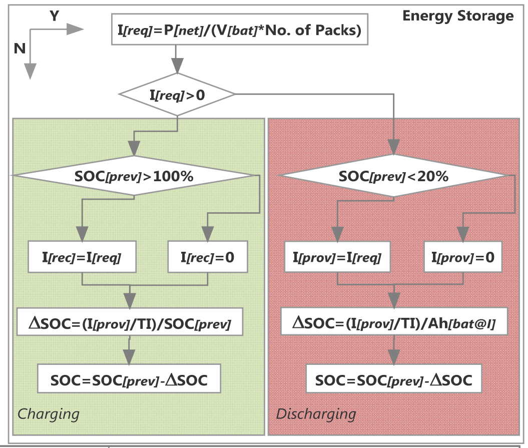


SOC	*Battery State of Charge*
GP	*Grid power (specified at 250 kVA)*
EES	*Exchangable energy storage swapped with fully charged unit*

Figure 3-12: Grid Connectivity Sub-model Diagram

Two types of energy storage technology were analyzed for this study to evaluate the difference between lower-priced, low power dense absorbed glass mat (AGM) technology, and higher-priced, high power dense lithium Polymer (LiPo) technology. Each of these battery technologies exhibit widely different charge/discharge characteristics and require varied control logic for optimal operation of the hybrid electric propulsion system.

The energy storage sub-model diagram is shown in Figure 3-13. The overall power requested from the battery pack is first converted to amp-hours per pack and then split up into separate algorithms for charging or discharging. The charging state is identified by the flow of current into the battery, which automatically accounts for the grid power when plugged in. Charging can only occur if the SOC is below 100%. The discharging state is identified by the flow of current out of the battery, which ensures that the SOC does not drop below 20% to prevent damage to the energy storage system. If the SOC is above 20%, the requested current is provided and the energy storage discharges. With AGM batteries, the rate of discharge determines the energy capacity of the energy storage system (higher power = lower capacity), so the equivalent SOC lost per increment is calculated based on specific battery data. However, with LiPo battery technology, the rate of discharge does not detrimentally affect the energy storage capacity of the system. The current SOC of the battery is continually updated by subtracting or adding the incremental change in SOC from the previous time period.



I[req]	*Requested current (amps)*
I[rec]	*Received current (amps)*
I[prov]	*Provided current (amps)*
P[net]	*Net power demand*
V[bat]	*Battery Voltage (DC)*
TI	*Time increments per hour*
Ah[bat@I]	*Maximum batter amp-hours at discharge rate*
SOC	*Battery State of Charge*
ΔSOC	*delta SOC (change in SOC)*
SOC[prev]	*SOC from the previous incremental time period*

Figure 3-13: Energy Storage Sub-model Diagram

3.5 Results

The completed analysis revealed significant potential fuel savings for both tugs with different propulsion system configurations. These savings varied significantly with the vessel duty cycle and energy storage technology.

3.5.1 Moran Savings

Due to the size and overall duty cycle profile associated with the Moran vessel, the benefits of hybrid-electric propulsion are somewhat limited. As shown in its operational profile (Figure 3-6), this vessel utilizes higher power levels and spends significant time (approximately 14% of the total time) at maximum power. While the energy storage is limited in its overall energy capacity, this application is most demanding on the power capabilities of the specified batteries. This meant that LiPo battery technology was a better fit because of its high power density. Because GPS data was unavailable for this vessel, an accurate evaluation of the HET-EES concept was not possible.

The overall percentages of fuel savings expected by the Moran tug for both AGM and LiPo battery technology are shown in Figure 3-14. While percentage-wise these savings appear minimal, the sheer volume of fuel consumed by the baseline tug results in significant fuel savings over the course of a year.

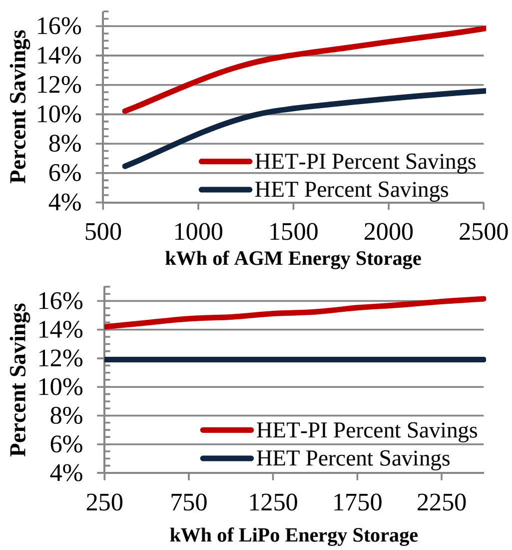


Figure 3-14: Moran Tug Fuel Savings Potential

Emission savings for the Moran vessel are incrementally greater than its fuel savings because the engines used to power the gensets are operated at their most efficient load. The predicted emissions savings of a Moran HET-PI vessel equipped with two battery packs is shown in Figure 3-15.

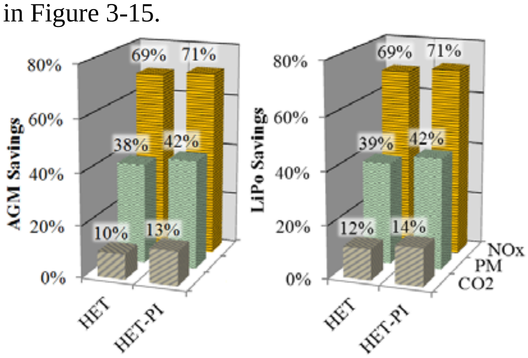


Figure 3-15: Potential Moran Tug Emissions Reduction

3.5.2 Reinauer Savings

The duty cycle data collected from the Kristy Anne Reinauer shows significant potential for the successful adoption of hybrid-electric propulsion technology. The majority of this vessel's operation is not at peak power and it spends considerable time at idle and low power cruising. When high power operations are conducted, they are generally quite short. This varied operation allows the vessel to utilize mostly electric power (stored in on-board batteries) and use the gensets only when operating at high power. Excess power from the gensets quickly recharges the energy storage.

The model predicts that hybrid propulsion system configurations, including HET, HET-PI, and HET-EES, can provide significant fuel savings potential for this vessel. The overall estimated fuel saving potential is shown in Figure 3-16.

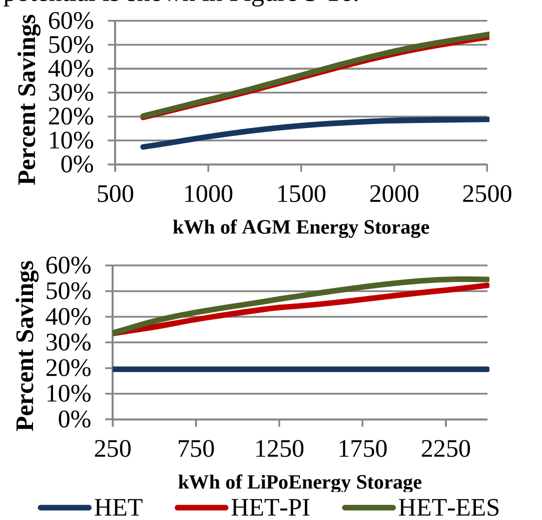


Figure 3-16: Reinauer Tug Fuel Savings Potential

The potential emission savings realized from the adoption of an electrified propulsion system follow similar trends as the fuel savings. However, because the gensets are operated at their cleanest power level, emission savings can be even more significant, as shown for two battery packs in Figure 3-17.

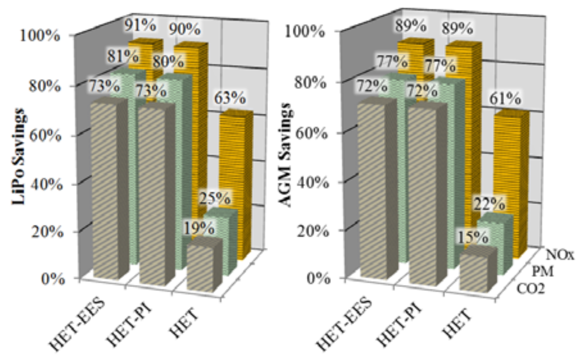


Figure 3-17: Reinauer Tug Emissions Reduction Potential

3.6 Conclusions

During this evaluation, factors influencing the effectiveness of marine vessel hybridization were found. First and foremost, minimal energy storage levels are optimal for purely hybrid vessels, unless shore power charging is available. It was also found that maintaining the baseline power levels with the diesel generators was necessary for these tugs to meet their expected performance. While smaller vessels may be able to offset a portion of the installed power with electrical energy storage, the level and duration of the tug's power demand is too great for continuous supplemental battery power. The final factor revealed is that real world, real time data is crucial when evaluating hybrid electric propulsion systems. Simple power profiles and power level operational data is helpful in a broad sense for identifying components but does not provide the level of operational detail required to accurately predict equivalent performance and benefits of an advanced hybrid propulsion concept.

4 NYS Canal Fleet Evaluation

A subsequent detailed evaluation will collect and analyze operational data from NYS Canal Corporation vessels to determine the potential energy, environmental, and economic gains from installing electric propulsion systems. Over the next decade, the NYS Canal Corporation will likely need to replace many of the engines in their maintenance vessels that are reaching their end of life, while the vessels themselves will likely be around for another half century. This study will provide the NYS Canal Corporation a decision basis for repowering their vessels with electric propulsions systems that include on-board energy storage and grid recharging capability.

Vessels with smaller engines and shorter single day trips are likely the best candidates for electrical propulsion to minimize the amount of on-board energy storage. For the NYS Canal Corporation fleet this includes their dredge tenders (Figure 4-1). Some of their tugboats might also have operations that are favorable for regular electrical recharging despite their higher power requirements.

Figure 4-1: NYS Canal Corporation Dredge Tender

Using collected data, the duty cycle of the vessels will be analyzed to determine the typical power requirements that must be matched by a comparable series hybrid-electric system. Electric propulsion technology is emerging for the marine industry and an evaluation of commercially available systems that meet the required demand of the Canal fleet will be down-selected to determine which is best suited for this application. While electric propulsion systems can have increased energy efficiency, even when solely powered by the diesel gensets, the most significant economic and environmental savings occur when the vessel can recharge its energy storage system with grid power or excess electricity from gensets on other canal equipment vessels. Therefore, all recharging opportunities will also be thoroughly investigated and evaluated using GPS data and operational logs. If the results from this evaluation are promising, then an actual repower of a Canal Vessel to electric propulsion with on-board energy storage will be pursued to demonstrate and quantify its real-world performance and benefits.

References

[1] NYSERDA (2011), *Patterns and trends 2009; New York State Energy Profiles: 1995-2009*, www.nyserda.ny.gov/Publications/~/media/Files/Publications/Energy-Analysis/1995_2009_patterns_trends_rpt.ashx, accessed on 2012-01-23

[2] American Trucking Association (2008), *Trucking and the Economy*, www.truckline.com/Newsroom/Trucks%20Are/Trucking%20and%20the%20Economy.pdf, accessed on 2012-01-24

[3] U.S. Department of Transportation Maritime Administration (1994), *Environmental Advantages of Inland Barge Transportation*, www.ingrambarge.com/images/ingrambarge/pdf/environmental_advantages.pdf, accessed on 2011-09-05

[4] Stephen Flott (2004), *Building a U.S. Waterborne Intermodal System*, Presented at the Journal of Commerce Short Sea Shipping Conference, Hilton Head Island, SC

[5] American Association of Port Authorities (2009), *U.S. Port Rankings By Cargo Tonnage*, http://aapa.files.cms-plus.com/Statistics/2009US_PORTRANKINGS_BY_CARGO_TONNAGE.pdf, accessed on 2012-01-24

[6] *Port Authority of New York and New Jersey*, www.panynj.gov/port/ocean-shipping-schedules.cfm, accessed on 2012-01-24

[7] *TugboatInformation.com*, www.tugboatinformation.com/tug.cfm?id=564, accessed on 2012-01-30

[8] Tugboat Information.com, *Reinauer Transportation Companies*, www.tugboatinformation.com/company.cfm?id=33, accessed on 2011-12-27

[9] *Reinauer Transportation Companies*, www.reinauer.com, accessed on 2011-12-27

[10] Tugboat Information.com, *Kristy Ann Reinauer*, www.tugboatinformation.com/tug.cfm?id=17, accessed on 2011-12-27

Authors

Paul Windover, a recent graduate from SUNY IT with a degree in Mechanical Engineering Technology, is a project engineer at New West Technologies, LLC. His areas of proficiency include system and technology modeling, concept development and technology evaluation, advanced transportation technology data collection and analysis, and economic analysis.

Bryan Roy, an engineer and project manager, has over 7 years of research and engineering in the renewable energy field with a focus on advanced transportation technologies. His expertise covers alternative fuels, transportation electrification, and petroleum use reduction for fleets. Mr. Roy has a B.S. in mechanical engineering from Union College and an M.S. in mechanical engineering and North Carolina State University.

Joseph D. Tario is a Senior Project Manager with NYSERDA's Transportation Research Department; managing projects focused on advanced transportation infrastructure and intelligent transportation systems. A graduate of Rensselaer Polytechnic Institute, he holds an M.E. in environmental engineering, a B.S. in civil engineering, and is a licensed professional engineer in NYS. Mr. Tario also serves on the Board of Directors for the Intelligent Transportation Society of NY.