FINAL REPORT ON BATTERY RE-INSTALLATION

CAMPBELL FOSS and CAROLYN DOROTHY

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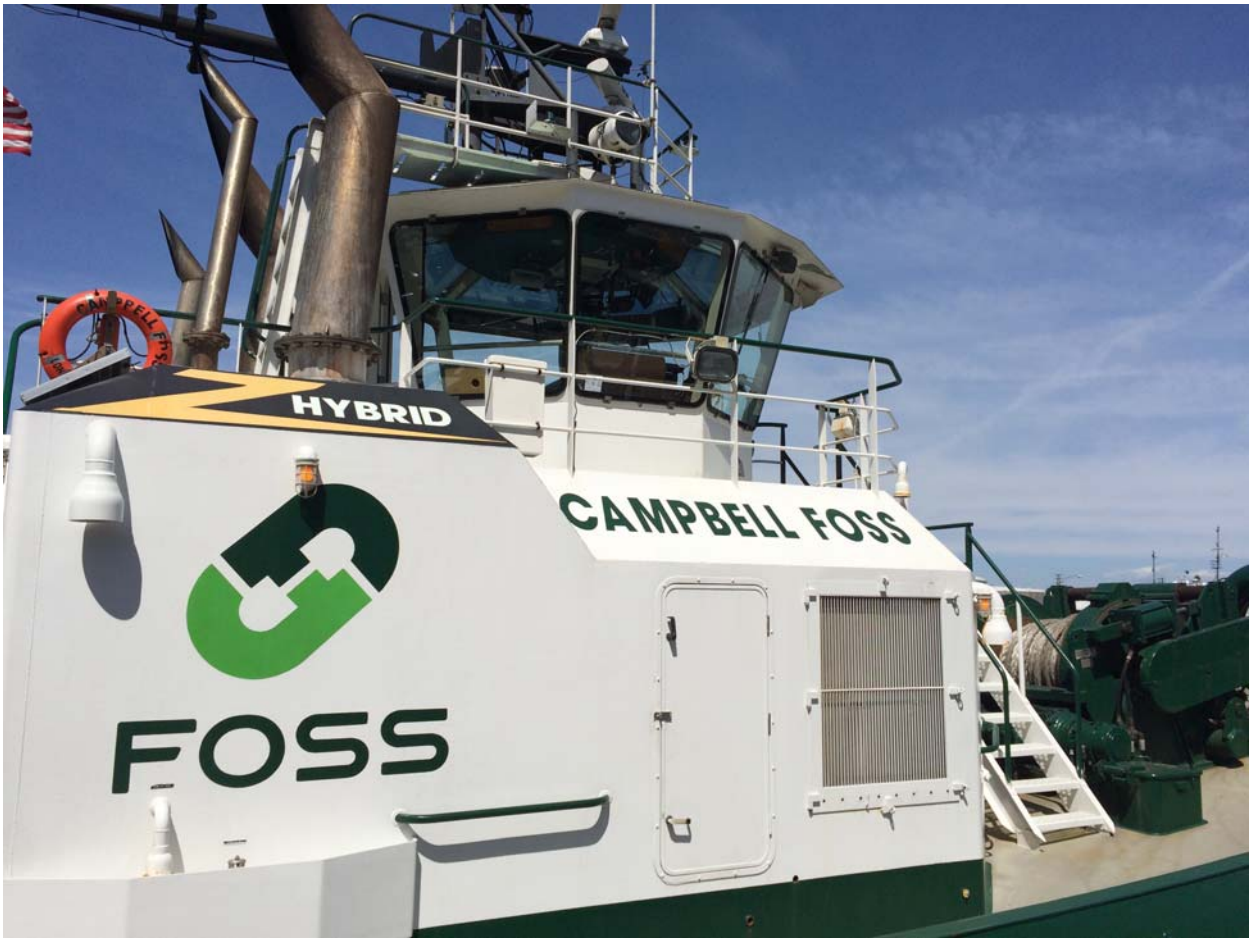


EXECUTIVE SUMMARY

Background

In August of 2012, an explosion and fire occurred in one of the lithium-polymer batteries on the Foss hybrid tug CAMPBELL FOSS. Subsequent to that fire, Foss removed the remaining batteries from the CAMPBELL FOSS and all of the lead-acid batteries on Foss' other hybrid tug, CAROLYN DOROTHY. CAMPBELL FOSS was returned to service in diesel configuration without batteries, and CAROLYN DOROTHY was returned to service in a modified hybrid configuration that did not require the use of batteries.

At the time of the fire on the CAMPBELL FOSS, Foss was applying for MARAD Maritime Environmental and Technical Assistance (META) program funding to help pay for the hybrid conversion of a sister vessel, the ALTA JUNE, from conventional propulsion to a hybrid system similar to the one installed on the CAMPBELL FOSS. Foss was awarded META funding from MARAD for the conversion. After the fire, Foss decided not to pursue the hybrid retrofit until such time as the battery installation could be proven to be safe.

The role of batteries in the hybrid system is not well understood; however, the risk of fire from lithium batteries in various platforms from computers, airplanes to tugs has been well documented. Anecdotal evidence suggests that the use of batteries in a hybrid tug system poses an impediment to more widespread adoption. Therefore, Foss requested to use the funds from MARAD to put batteries back into the two existing hybrid tugs after completing a risk assessment and incorporating lessons learned from the CAMPBELL FOSS fire. The revised project plan also included emissions testing with University of California Riverside (UCR) to quantify the benefits of moving from a Tier 2 to a Tier 3 auxiliary generator in this same hybrid application.

There is no doubt that hybridization is an excellent way for vessels with variable duty cycles, such as harbor tugs, to reduce all emissions as well as fuel and maintenance costs. The hybrid technology used in the CAMPBELL FOSS was verified as a diesel reduction technology by EPA in 2012 but has yet to gain widespread acceptance in the United States. This project further quantifies the benefits from hybrid technology and serves to promote the adoption of this emissions reduction technology for the public benefit. MARAD agreed and awarded Foss $600,000 in funding to help offset the costs for this project.

Risk Assessment

In October of 2014, Foss hired Elliott Bay Design Group (EBDG) to perform a risk assessment study on the hybrid boats with respect to reinstalling batteries. The risk assessment, included as Attachment 1 to this document, showed that with a properly designed and installed battery system, with structural separation from occupied spaces, proper explosion protection and correct and functioning battery control and shutdown protocols, the hybrid boats would be able to realize their full potential in performance, emissions and fuel consumption reductions. Conversely, the cost and risk of <u>not</u>

reinstalling batteries was high, based on increased fuel consumption and emissions, and decreased usability of the CAROLYN DOROTHY due to lower bollard pull. The lower bollard pull is a direct result of the fact this vessel has smaller main engines than her sister tugs; therefore requiring a large array of batteries to supplement the installed diesel power in high load conditions.

In order to proceed with reinstalling the batteries, two key decisions needed to be made as a result of the risk assessment findings. The first was whether or not to move the battery compartment outside of the engine room and the second was to select a battery manufacturer.

Two alternative locations for the battery compartment outside the engine room were examined, the deck locker and the stern void/ballast space. Although the deck locker provided easier access to install the batteries it complicated the engineering of the ventilation system. The stern void space was ultimately chosen because it offered the safest alternative and simplified the engineering of the ventilation system.

Aspin Kemp and Associates (AKA), the company Foss partnered with to develop the existing hybrid control and management systems, Foss and EBDG evaluated two battery manufacturers who met the technical and performance criteria established for the project. The two manufacturers chosen for consideration were Corvus Energy and Energy Storage Technologies (EST). AKA has worked with both manufacturers on different projects and Corvus Energy is the same brand previously used onboard the CAMPBELL FOSS.

Both manufacturers use cells produced by Dow Kokum in Korea, and assemble them into battery modules. Corvus Energy uses parallel connections for the cells while EST does not connect the cells in parallel. Measuring the voltage across parallel cells means measuring the voltage of a group of cells, where the loss of voltage indicated by a failed cell will be masked by the voltage of the remaining cells. This is a risk because the module will suffer from reduced capacity, and a failed cell may eventually explode without a warning from a low/high voltage reading. When cells are connected in series, it is impossible for a failed cell to remain undetected. The EST lithium-polymer batteries along with their attendant control system and hardware were chosen for this project on the basis of their technical and safety merits.

Acting on the EBDG recommendations, Foss developed a team of engineers, naval architects and operators to refit the hybrid tugs with new batteries. This team was led by Foss project engineers and team members included EBDG, AKA and Energy Storage Technologies (EST). EBDG was tasked to design the modifications required to the vessels to accommodate the batteries and AKA worked to integrate the new batteries into the existing control system.

During the design phase of the project, the team determined that CAMPBELL FOSS would require ten of the EST batteries acting in a single string, and the CAROLYN DOROTHY would require (28) of the same batteries, acting in two separate strings of (14) batteries each. With this determined, EBDG designed a separate battery compartment in the stern void tank of each vessel. EBDG also designed the ancillary systems and modifications required to support battery operations, such as ventilation, explosion protection via rupture discs, HVAC systems and installed firefighting systems.

Project Summary

Foss began physical modifications to the CAROLYN DOROTHY in May of 2015. While these modifications were being performed, EST informed the team that the batteries could no longer be shipped via air freight, and required shipping via cargo ship which resulted in a delay of approximately six weeks. With this in mind, Foss continued with the structural modifications on the vessel through July, and then put her back into service in non-battery hybrid mode while awaiting the delivery of the batteries. Foss took the CAMPBELL FOSS out of service in early September to begin the physical modifications. In addition, in September the first set of batteries arrived while the work on the CAMPBELL FOSS was proceeding. Foss finished the modifications to the CAMPBELL FOSS in October, installed the batteries and began testing of the newly reconfigured system.

During this testing, the team found that the batteries could be charged and discharged at high rates with excellent results when the vessel was not moving. Unfortunately, as soon as the vessel's motor generators on the shafts were energized, the resulting electro-magnetic interference (EMI) caused the battery system communications to shut down, causing the breakers to open and the batteries to stop charging as a fail-safe mechanism. Consequently, Foss returned the vessel to normal service in its original diesel configuration and pulled the CAROLYN DOROTHY back out of service to finish installing the batteries and begin commissioning.

After completion of the installation of the batteries and ancillary systems on the CAROLYN DOROTHY, the hybrid system was tested. On the CAROLYN DOROTHY, the EMI was found to be much less than on the CAMPBELL FOSS and allowed the batteries to properly communicate and operate while in hybrid propulsion mode. However, AKA had difficulties getting the hybrid system to integrate both strings of batteries into the system as required. It was determined that 12 batteries supplied by EST for the CAROLYN DOROTHY were defective as well as four of the ten batteries for the CAMPBELL FOSS.

Consequently, EST removed and tested all the batteries from both vessels at the end of January 2016. The defective batteries were rebuilt by EST on site at the Foss location in Long Beach. The rebuilt batteries were re-installed on both vessels during the first week of February 2016. During this same time the DC/DC converters on the CAROLYN DOROTHY were replaced by AKA in order to solve the system integration issues.

After the repairs were accomplished, both vessels underwent Foss acceptance testing and sea trials. The CAROLYN DOROTHY was returned to full hybrid status with all batteries functioning and integrated into the system on February 8, 2016 and the CAMPBELL was accepted and returned to full hybrid status on February 16, 2016.

Design

Design for this project was broken into two portions, "Battery Design" and "Vessel Modification". Descriptions of what each portion entailed are below. In general, AKA was responsible for the Battery Design, with input from EST and review by Foss. The Vessel Modification design was done by EBDG based on physical requirements of the battery components and ancillary equipment.

Battery Design—

This task covered the hardware and software modifications and additional equipment required to modify the existing hybrid system of both vessels to integrate the controls, monitoring and power specifications of the new batteries. This portion of the Hybrid Design was accomplished by AKA.

In addition to supplying the new lithium polymer batteries, EST also provided the hardware and software design for monitoring and controlling the batteries, as well as the physical boxes where the batteries are housed and the interconnecting power and communications cables. They worked with AKA to determine the interfaces between the two systems (hybrid energy management system (EMS) and battery management system (BMS)) and provided direction during the installation.

Vessel Modifications—

This task covered the design of the modifications required to the existing boats' structural, mechanical and electrical systems to accommodate the new battery compartments. EBDG was hired to provide the structural design and perform all necessary structural, stability and heating load calculations.

Foss and EBDG agreed that the stern void directly aft of the engine room provided the best and safest location. The stern void was chosen because, of its size, its separation from normal working areas, and its proximity to the stern of the vessel. New vents were installed at the stern to prevent harm to personnel should a battery catch fire or explode.

The vessel modifications include:

- Installation of bulkheads, inserts, structure and doors to create the new battery compartments
- Installation of rupture discs between the battery compartment and the adjacent void, and the void and the exterior of the boat. In the event of a battery explosion, these discs would blow out at a low pressure to allow the escaping gasses to expand without damaging the structure of the compartment
- Installation of air conditioning and air handling units to keep the compartments cooled to approximately 65F
- Installation of FM200 fire suppression systems to smother any potential battery fires
- Containment boxes in stern bulwarks to direct any potential flame ball or hot escaping gasses out the stern of the vessel and away from personnel.
- Insulation of new battery compartment surfaces.

Design Challenges—

Other than typical challenges associated with designing vessel modifications, the design portion of this project went smoothly with no exceptional challenges or issues. There were a few obstacles however that bear mentioning in this report:

- Quantity of Batteries—
    - The total quantity of batteries required by the CAMPBELL FOSS was not an issue – the team simply replaced the quantity of Corvus batteries (the batteries which were installed on the CAMPBELL FOSS when the fire occurred) with the same number of EST batteries, to achieve essentially the same power and energy. As CAMPBELL FOSS does not use batteries for rapid bursts of energy as the CAROLYN DOROTHY does, there was less risk in simply replacing the old batteries with the new.

Photo: Batteries installed in CAMPBELL FOSS

    - On the CAROLYN DOROTHY, batteries are needed for providing top-end power to the propellers, which requires rapid draw down of many batteries to supply the needed power. The vessel is required to have a minimum of 60 tons of bollard pull which meant

batteries were needed to supply supplemental power due to the smaller size of the vessel's main diesel engines. The team then needed to decide on a battery configuration to ensure the required power could be supplied to the hybrid system in the time frame needed without exceeding the current capacity of the cables and power sharing equipment. The other consideration on battery quantity was the physical space available to house them – more batteries require more space, and these Dolphin class tugs are small to begin with.

In the end, the team settled on (28) total batteries, provided in two separate strings of (14) batteries each. This allows the batteries to supply over 400 additional horsepower

to the hybrid system without overloading the equipment and cables.

Photo: CAROLYN DOROTHY battery compartment

- Tonnage Requirements—

    - A vessel "Registered tonnage" (GRT) is a way of measuring the cargo capacity of a vessel. The USCG requires certain crew manning and levels of safety depending on the vessel's registered tonnage. Both the CAMPBELL FOSS and CAROLYN DOROTHY are designed and crewed to have registered tonnage of less than 150 GRT – if the tonnage measurements show the boat could exceed 150 GRT, additional modifications and crew would be required.

      The aft void spaces in which Foss planned to put the battery compartments are exempted from tonnage calculations. Before this modification, both vessels had GRTs in the 144-145 range. However, adding battery compartments to these aft voids reduces the exempted amount, thereby increasing the vessel's tonnage. EBDG had to create battery compartments on both vessels that not only could fit the required number of batteries, but also NOT reduce the volume in the aft void tanks to the point where the calculated tonnage exceeded 150 GRT. In the end, both vessels stayed below 150 GRT.

- Battery Delivery Method—

    - The original schedule for the project anticipated being able to ship the lithium-polymer batteries via air freight, with batteries available overnight if need be (in addition to clearing US Customs). Foss had received a quote from EST's freight forwarder that provided this option. However, in May of 2015, commercial airlines put restrictions on transporting lithium polymer batteries through the air, and the quantity of batteries required for this project exceeded the allowable. As a result, EST had to ship the batteries via commercial shipping, which increased delivery time for the batteries by approximately six weeks. This had a ripple effect through the schedule as the first batteries could not arrive until mid August.

Construction

Foss performed the modification work on both vessels at the Foss berth on Pier D in the Port of Long Beach. Foss hired Biltmore Metal Fabricators (BMF) to perform the structural and system modifications to the vessels, in accordance with the design drawings created by EBDG. Foss hired DeMaria Electrical to pull the required electrical cables for the hybrid and battery systems, in accordance with electrical one-line drawings and cable lists supplied by AKA and EST.

Modifications to the CAROLYN DOROTHY occurred first, starting in mid May and ending in late July. Modifications to the CAMPBELL FOSS took place in September, ending in early October. The scope of work on the CAMPBELL FOSS was significantly less than on the CAROLYN DOROTHY due to the lower number of batteries. This combined with the learning curve realized by BMF and DeMaria allowed for a more efficient construction period and lower project costs.

Construction Challenges

Similar to the Design phase of the project, the construction of the vessel modifications proceeded as planned, without any major issues or challenges. The confined working area in the stern void was a challenge for BMF to gain access to all required areas for welding and painting, and there were some layout and minor structural issues that came up during the course of the modifications, but nothing particularly difficult or challenging.

Photo: Rupture disc on CAMPBELL FOSS

Testing and Commissioning

CAMPBELL FOSS-

After completion of the modifications to the vessel and installation of the batteries, the team began commissioning the battery system. EST technicians arrived onsite and performed the initial system checks and start-up protocols, working with AKA technicians to confirm that all communications and alarms were being properly transmitted to the energy management system. All systems checked out fine; the team confirmed all alarms and shutdowns were functioning properly, and then began using the batteries to supply power to the vessel's non-propulsive electrical needs (e.g., ventilation fans, AC units,

lights and the bow winch). The team also confirmed the batteries could be charged from either a shore power connection or the boat's diesel generator. All operations went according to plan.

The next step consisted of using the batteries to start turning the propulsion shafts. However, as soon as the team tried this the internal battery communications became erratic and unreliable and the batteries shut down. One of the safety features of the EST control system is a requirement that the batteries communicate with the system software on a nearly continuous basis. If the communications are dropped or interrupted for even a short period of time, the physical contactors to the batteries open. While the contactors are open the batteries are effectively shut down and are isolated from the rest of the hybrid system components. This is an important fail-safe for the system and this testing proved that the fail-safe was working correctly.

Investigation into the cause of this communications failure showed very high levels of electromagnetic interference (EMI) when the motor generators on the shafts were energized electrically, which caused the battery communications to become erratic. The team took a two-pronged approach to address this issue – (1) reduce the level of EMI developed by the power converting equipment (the variable frequency drives and the DC/DC converter), and (2) insulate the battery communications to make them less susceptible to the EMI. These solutions were implemented by both AKA and EST which resulted in solving the problem.

After the defective batteries on the CAMPBELL were replaced, the vessel successfully completed sea trials and acceptance testing on February 16, 2016.

CAROLYN DOROTHY—

Like the CAMPBELL FOSS, the EST technicians boarded the boat after the batteries were installed and hooked up and performed the initial system checks and start-up protocols. They worked with AKA to establish proper communications between the systems and tested all alarms and shutdowns. The team has confirmed proper operation of the batteries with the hybrid system, ensuring the batteries would support the vessel's electrical loads and that the batteries could in turn be recharged from the hybrid system.

The team also found that the CAROLYN DOROTHY did not have the same problem with EMI that the CAMPBELL FOSS did and that the batteries could be used to turn both shafts with no loss of communications. However, during this testing AKA found some issues with the DC/DC converters. These converters on the CAROLYN DOROTHY were replaced in February 2016 and the vessel successfully completed acceptance testing and sea trials on February 8, 2016.

Emissions Testing

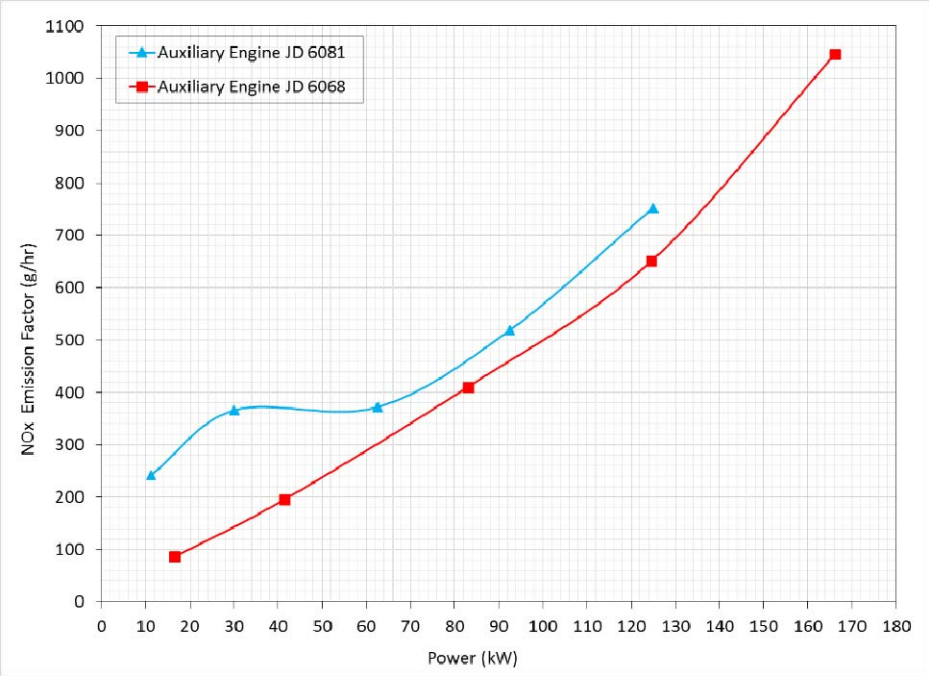
Concurrent with the physical conversion project, the University of California, Riverside (UCR) undertook a project to quantify the emissions benefit of repowering one of the auxiliary engines on the CAMPBELL FOSS from Tier 2 to Tier 3. (Attachment 2) UCR completed the original emissions testing of the CAMPBELL FOSS when it was converted from a conventional to hybrid configuration.

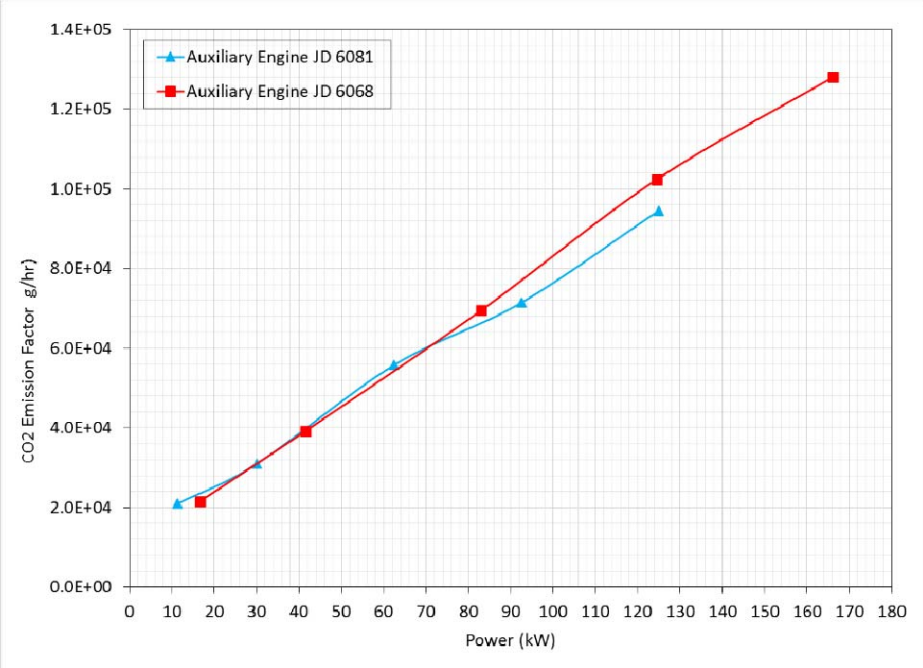
In the intervening years between the original conversion and the current project, Foss replaced the John Deere model 6081 auxiliary engine meeting EPA Tier 2 standards with a John Deere model 6068 auxiliary engine meeting EPA Tier 3 standards. The John Deere 6081 engine was rated at 125kW (168 hp) and was replaced by a John Deere 6068 rated at 166kW (223 hp) so there was more power in the replacement engine than the originally installed engine. The purpose of the UCR study was to quantify the emissions benefit as a result of the repowering.

Photo: John Deere 6068 Tier 3 engine

The emissions rates in grams per hour as a function of the engine load for both NOx and CO2 are shown in the graphs below. As expected, the NOx output for the Tier 3 engine (model 6068) is less than the Tier

2 model 6081 engine while the CO2 rates were essentially the same. Similar charts are not included in this report for PM $_{2.5}$ emissions because of the confidential nature of the data. The $PM_{2.5}$ emissions factors were measured in previous UCR projects for the model 6081 engine and the data for the model 6068 engine was obtained from John Deere. However, this $PM_{2.5}$ emissions data is considered business confidential by John Deere so only the overall factors are included in the UCR report.





UCR followed the same methodology established in the emissions studies done for both the CAROLYN DOROTHY and CAMPBELL FOSS. The activity profiles were calculated from these previous two studies and emission factors were calculated at specific load points. This analysis then combined engine histogram and emission profile data to determine the in-use emissions for the CAMPBELL FOSS with the higher tier engine.

As expected, the study showed that the majority of the emissions benefits are realized when a conventional tug is converted to hybrid operations. The repowering to a higher EPA tier rating showed minimal overall improvement in emission benefit. The chart below shows the percentage reduction of NOx, and $PM_{2.5}$ when compared to a conventional tug configuration, reductions with a Tier 2 engine and reductions with the Tier 3 engine. Because the conversion from Tier 2 to a Tier 3 auxiliary engine did not impact fuel consumption, the CO2 reduction remained the same when comparing the Tier 2 and Tier 3 results.

	Conventional Tug Configuration	Hybrid Tug with Tier 2 Auxiliary Engine	Hybrid Tug with Tier 3 Auxiliary Engine
NOx (g/hr)	3773	2433	2418
% NOx reductions		35.51%	35.91%
$PM_{2.5}$ (g/hr)	36.80	19.47	17.81
% $PM_{2.5}$ reductions		47.10%	51.61%
CO2 (kg/hr)	233.77	140.45	140.44
% CO2 reductions		39.92%	39.92%

Another way to look at this data is in terms of absolute emissions reductions on a tons per year (tpy) basis. Based on the assumption of 8,000 operating hours per year, the NOx reduction from the conversion of a conventional tug configuration to hybrid is 11.8 tpy and for repowering the hybrid tug configuration to a Tier 3 auxiliary engine, the additional reduction is 0.13 tpy.

For $PM_{2.5}$, the reduction through conversion from conventional to hybrid is 0.15 tpy and the additional reduction through the Tier 2 to Tier 3 auxiliary engine replacement resulted in an additional 0.015 tpy reduction.

Financial Results

The EBDG Risk Analysis report provided a rough order of magnitude (ROM) estimate for this project of $870,000 for using EST batteries and creating a battery compartment in the stern void. When Foss looked at the actual expected costs associated with implementing this project as the design progressed, that figure rose substantially based on actual quotes received from AKA, EST and EBDG for their services and materials, and Foss experience with performing this type of work on these vessels at the Foss berth in Long Beach. Foss is estimating the final cost of the project to be just over $1,500,000 with over 95% of these funds spent to date.

Schedule

The original proposed schedule had this project complete in August of 2015, with the final report delivered to MARAD in September of 2015. Due to a variety of circumstances and events both within and outside of Foss' control, Foss requested an extension for submittal of the final report. The following is a summary of the extenuating circumstances and delays that caused the need for this extension:

- Fire to CAROLYN DOROTHY's starboard diesel generator destroyed a large portion of the existing hybrid system and cabling, requiring months of rework. The fire occurred in March, just before Foss was planning to take the CAMPBELL FOSS out of service to begin the modifications on that vessel. With the fire, Foss rearranged the schedule to do the modifications on the CAROLYN DOROTHY first while the vessel was out of service for the fire repairs. The repairs were not completed until the end of July

- The delivery of the batteries was delayed by approximately six weeks due to changes to commercial airline policy regarding shipping lithium polymer batteries via air freight. Foss and EST had established that air freight was allowed at the beginning of the project and based the schedule on that fact; however, in May when the batteries were ready to be shipped, the policy change took effect requiring the batteries to be shipped via ocean freight.

- Repair work on other Foss vessels in the Long Beach harbor during the month of August required both the CAROLYN DOROTHY and the CAMPBELL FOSS to be working to meet the needs of Foss' customer base. This created an unplanned month of no modification work in the middle of doing the modifications.

- Testing and commissioning difficulties due to EMI and hardware and software glitches at the end of the project on both vessels delayed final testing and sea trials until February 2016.

Task Summary

This section provides a description of the work performed on the major individual tasks outlined in the project scope:

Perform Risk Assessment of Reinstallation of Batteries

Description of Actions Performed:

Foss hired Elliott Bay Design Group (EBDG), a well-known naval architecture and marine engineering firm in Seattle, to perform a risk assessment on reinstalling batteries on the two Foss hybrid boats, CAMPBELL FOSS and CAROLYN DOROTHY. The result of this study is the "CAMPBELL FOSS & CAROLYN DOROTHY Hybrid Tug Battery Reinstallation Risk Assessment Report", attached to this report as Attachment (1).

During the study, EBDG reviewed the events that led to the battery fire on the CAMPBELL FOSS in 2012, and analyzed the risks associated with reinstalling batteries on the hybrid boats as well as the commercial, financial and operational risks of NOT reinstalling batteries on the boats.

The result of their analysis is a recommendation to reinstall batteries on the boats, but in separate, environmentally-controlled compartments in the stern voids of the boats with proper explosion prevention and mitigation safeguards in place.

This report formed the basis for design and construction of the new battery compartments and purchase of the new batteries and control systems.

Redesign of Compartments and Systems

Description of Actions Performed:

1. Battery Compartments, Venting Containment, and Fire Protection Systems—
    - Subsequent to the risk analysis, Foss hired EBDG to perform the necessary structural and system design to create a separate compartment for the new batteries. The design includes the following features to enhance the safety and correct operations of the batteries:
        - Ventilation system terminating in confined compartments in stern bulkwark to direct any potential flame or explosive gasses away from personnel to a safe location
        - Rupture discs in battery compartment bulkheads and stern void to immediately release potential explosion gasses into the adjacent void and out the stern bulwark and prevent structural damage
        - Dual air conditioning systems to maintain battery compartment temperature at 68F for optimal battery life and operation
        - Structural insulation to help maintain battery compartment temperature and to protect adjacent deck and spaces from extreme heat in the event of a fire

        - Vibration isolated battery racks to protect batteries from hull-borne vibrations and vessel impacts
        - FM200 fire suppression system to smother any potential fire. Can be energized manually from one of two pull stations or automatically from heat and smoke sensors installed in the compartment
    - In addition to designing the modifications and systems required to be performed on the boats, EBDG also performed stability and tonnage calculations and reviews to make sure that the vessels continued to operate within the original requirements of the vessels prior to modification. These studies confirmed that the vessels would only be minimally impacted by the modifications from a stability and tonnage perspective, and these impacts would not affect vessel operational or regulatory parameters.
2. Battery Control System
    - Based on the recommendations of the Risk Analysis Report, Foss and AKA selected EST headquartered in the Netherlands to provide the batteries and the battery control system. The EST batteries use the same lithium-polymer chemistry and cells provided by Kokum in Korea as the batteries supplied by Corvus Energy, who supplied the batteries that failed on the CAMPBELL FOSS. However, the EST series cell configuration and controls methodology are more straight forward and safer than those that Corvus had in place at the time of the fire, and are in compliance with the recommendations of the Risk Analysis.
    - Having selected EST to supply the batteries, Foss and AKA attended factory testing in the Netherlands to gain assurance that the batteries and control/alarm/communications systems hardware and software designed by EST would be compatible with the AKA-supplied energy management system, and meet the safety requirements of the Risk Analysis Report. After this testing, all parties agreed that the batteries and control systems would perform as desired.
    - The EST batteries are type-approved by Lloyds Register and DNV. As part of the Class approval process, EST hired KEMA, an outside laboratory, to vet the batteries and controls for safety, durability and operation.

Develop and Award Shipyard Contracts for Modifications

Description of Actions Performed:

For this task, Foss contracted with Biltmore Metal Fabricators (BMF) in Long Beach to provide the labor and materials to perform the required vessel modifications. All modifications were performed pier-side at Foss' facility at Berth 49 on Pier D, Long Beach CA. Prior to awarding the work to BMF, Foss reviewed the EBDG drawings with BMF and a competitor, Oceanwide Construction, to obtain pricing quotes. Foss has extensive experience working with both vendors, and was confident that either could perform the work in the time allotted. In the end, BMF provided a lower cost estimate to perform, and Foss selected them as the main contractor on this project.

Foss issued a purchase order on May 15, 2015 BMF to perform the modification work in accordance with the EBDG drawings.

CAMPBELL FOSS Shipyard Period

Description of Actions Performed:

The original schedule called for the CAMPBELL FOSS to be the first boat modified. However, in March of 2015, the CAROLYN DOROTHY suffered a major failure of one of the diesel generators, causing a fire in the engine room that required extensive repair and rework of the hybrid electrical systems. Since this put the CAROLYN DOROTHY out of operation for an extended period, Foss chose to proceed with the modifications to the CAROLYN DOROTHY first.

As a result of switching the order of the modifications, as well as operational constraints that required both boats to be in service for the month of August, modifications to the CAMPBELL FOSS did not begin until September 4, 2015. Modifications were completed one month later, on October 13, 2015

CAROLYN DOROTHY Shipyard Period

Description of Actions Performed:

CAROLYN DOROTHY modifications were started before the CAMPBELL FOSS due to a fire on the starboard diesel generator. Modifications began on the CAROLYN DOROTHY in mid May, 2015, and were completed in the end of July 2015.

The CAROLYN DOROTHY had significantly more work to be done compared to the CAMPBELL FOSS, due to the boat receiving 18 more batteries than the CAMPBELL FOSS. Additionally, the work had to be done in coordination with the ongoing repair work required by the generator fire. These challenges caused the duration of the modifications to be longer than originally anticipated.

Due to an operational requirement that both the CAMPBELL FOSS and the CAROLYN DOROTHY be performing ship assist services in the harbor for the month of August, the CAROLYN DOROTHY was put back in service at the end of July without batteries. CAROLYN DOROTHY was then pulled back out of service for final commissioning and testing after the CAMPBELL FOSS modifications and testing were complete, in early November 2015.

Delivery Acceptance Testing – CAMPBELL FOSS

Description of Actions Performed:

Once the batteries were installed and commissioned, the Foss/AKA/EST team began testing of the hybrid system in concert with the battery system. Initial testing went very well, with the hybrid system able to charge and discharge the batteries as needed depending on the vessel's non-propulsive electrical requirements. However, once the team went to the next step and attempted to turn the propellers using electricity from the hybrid system, the battery control system lost communications with the batteries and caused that system to shut down as a fail-safe mechanism. The subsequent investigation into why this happened revealed significant sources of electromagnetic interference (EMI) on the vessel that distorted the communications signals of the battery management system when the shafts are turned via the hybrid system.

Foss, AKA and EST solved this problem, by both reducing the amount of EMI created by the hybrid system as well as shielding the battery communications systems to make them less susceptible to EMI distortion.

Delivery Acceptance Testing – CAROLYN DOROTHY

Description of Actions Performed:

Once the CAROLYN DOROTHY's batteries were commissioned by EST, Foss, EST and AKA began testing of the hybrid system with support from the battery system. In this case, the team did NOT see the same level of EMI that exists on the CAMPBELL FOSS, and in fact was able to run the vessel's propellers using power from the batteries as intended. However, several other hardware issues occurred during this testing, including problems with the DC/DC converters that caused one of the battery strings to stop working after approximately one hour.

During troubleshooting in December 2015, it was determined that several of the batteries in both vessels were defective. All batteries were removed from both vessels and tested in January 2016. The defective batteries were rebuilt and re-installed on the vessels in early February 2016 and the DC/DC converters were replaced in the CAROLYN DOROTHY. After completion of the battery reinstallation, both vessels successfully completed acceptance testing and sea trials and were returned to full hybrid service in mid-February 2016.

Closing Note

Foss thanks MARAD for helping to offset the cost of this project. The Foss hybrid tugs need to have batteries to allow them to live up to their full potential as industry-leading examples of how environmentally friendly concepts like fuel savings and emissions reductions can exist in full synergy with business-friendly concepts like reduced operating and maintenance costs. Foss fully believes that this technology is on the cusp of becoming widespread, and is proud to have been at the tip of this revolution.

Although this project took somewhat longer than originally anticipated, it resulted in a successful conclusion. Both the CAROLYN DOROTHY and the CAMPBELL FOSS are operating in San Pedro harbor in full hybrid mode with batteries functioning and fully integrated into the system. These hybrid vessels continue to show a significant reduction in emissions compared with the conventional tugs operating in this same harbor.