FOSS

Foss Hybrid Tug Development Project

Final Report

Project Name: **Foss Hybrid Tug**
Agreement No.: **C08299**

Technology Background and Comparison

During the first quarter of 2009, the Foss Hybrid tug, *Carolyn Dorothy*, entered service in San Pedro harbor. Foss Maritime Company received financial support from the Ports of Long Beach and Los Angeles as well as South Coast Air Quality Management District to help offset the cost to design build and commission the world's first hybrid tug. The concept of a hybrid tug had been discussed within Foss for several years prior to construction. The duty cycle of a harbor tug is ideal for a hybrid system that can provide enormous power for the very short duration that it's needed, but also provide efficient, cost effective low levels of power for transiting the harbor or awaiting a job. On a standard harbor tug, all motive power is provided by two large main engines, designed to provide all the propulsive power the boat will ever need. Unfortunately, as the harbor tug almost never uses all of its power and spends the vast majority of its time operating at less than 25% of max power, the engines run way below their design point, where they burn fuel inefficiently causing high specific fuel consumption and poor emissions profiles.

The hybrid propulsion system that Foss and its technology partner, Aspin Kemp and Associates (AKA), designed and installed on the newly-constructed harbor tug *Carolyn Dorothy* solves this problem by using a combination of different power sources to provide just the power the boat needs at any moment. The Energy Management System (EMS) of the boat will pick from two main engines (1800 hp each), two diesel generators (440 hp each) and a battery array (600 hp) to select the optimal combination of sources to provide the needed power, while the remaining equipment remains off.

For instance, to transit the harbor at up to 6.5 knots, the *Carolyn Dorothy* runs on one diesel generator which provides electrical power to both propellers via a motor/generator installed on each main shaft, as well as electrical power for the boat's hotel and navigational needs. During this mode of operation, both main engines and the other diesel generator are shut down and not

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operating. On a standard harbor tug, running at 6.5 knots would require both main engines to be running (one for each propeller) plus a diesel generator running to provide the boat's electrical needs. The fuel and emissions savings in this mode are obvious: the hybrid tug is doing the same job as a standard tug with only one engine running, as opposed to three. As required speed increases, the EMS will bring the second diesel generator on line to a maximum speed of 8.5 knots. Running at faster speeds require one or both main engines to start up and come on line. During an actual job, the *Carolyn Dorothy's* EMS can provide power from all five sources (main engines, diesel generators and battery array) to develop the same bollard pull as her sister boats.

Status

On March 2, 2009, the hybrid tug *Carolyn Dorothy* officially entered harbor assist and ship escort service in the LA/LB basin as a 60+ ton harbor tug. She has been working the harbor since then, with some minor work interruptions to tweak and refine her control logic and operating systems.

Entrance into service marked the end of tight and challenging design, build and commissioning period. Among the many challenges Foss faced on this project were such things as the original Nickel-Metal-Hydride (NiMH) battery manufacturer pulling out of the battery market half way through the design, necessitating a regrouping and redesign around a different battery technology (gel-cell lead acid) and a consequential shifting of the hybrid boat to a later hull than originally planned. There were also significant space allotment obstacles to overcome, as Foss had to fit more and more equipment into a small engine room while still providing safe access to equipment, and other general difficulties inherent in building the boat while it's still being designed.

Through much hard work, perseverance and ingenuity, Foss and AKA met the revised schedule for vessel completion in December of 2008, and began final commissioning and testing of the vessel in Long Beach/Los Angeles in mid January, 2009.

During the commissioning phase, Foss got its first glimpse of the actual fuel consumption and emissions reductions that the boat will deliver. In addition to being able to run on one generator while transiting the harbor, the boat also operates solely on batteries when awaiting harbor assist jobs in the area commonly known as "the Flats". As with the harbor transit scenario, while waiting in the flats, all other harbor tugs have both main engines idling and a diesel generator running to provide the electrical needs while the *Carolyn Dorothy* has no engines running. In this mode, the vessel is truly "zero emissions".

Emissions Reductions Results

Foss has an MOU with the California Air Resources Board (ARB) for emissions testing of the hybrid tug. Foss, ARB and the University of California-Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT) have developed a tugboat test cycle and test the in-use emissions of both a hybrid and conventional tugboat using this cycle. The final report by UCR was posted on CARB's website entitled Evaluating Emission Benefits of a Hybrid Tug Boat . A copy of the report is attached. A side by side comparison of two Foss Maritime dolphin-class tugs the *Carolyn Dorothy* and a conventional tug named the *Alta June*, showed these significant emissions reductions:

- 73% reduction for PM
- 51% reduction for NOx
- 27% reduction for CO2

Benefits

The benefits of this hybrid technology are many, and can be broken down into three groups: Environmental, Lifecycle Costs and Operational:

- Environmental Benefits—
  The boat exceeded the originally estimated PM/NOx reductions of 44% as highlighted above. Additionally, as the engines are running significantly less time than in a conventional harbor tug, there is a significant reduction in ALL emissions, including CO and CO2 just based on engine running time alone. This reduction in emitted pollutants is the main reason this boat was constructed, and these benefits have exceeded expectations.

  Additionally, the boat is in general quieter than her sister boats, helping to reduce the noise levels within her working sphere. This is especially appreciated by the crew, but also has an impact on the waterfront businesses and wildlife adjacent to where she is working.

- Lifecycle Cost Benefits—
  Lifecycle costs for the *Carolyn Dorothy* are expected to be significantly lower than her sister tugs. Under current market conditions, these savings should pay back the initial incremental cost required to build a hybrid boat relative to a conventional one in less than 10 years. The expected cost savings come from the following sources:
  - Fuel savings: Initial indications show a potential savings of 100,000-150,000 gallons per year, which could equal $200k-$300k or more savings per year

- Reduced maintenance costs: Routine maintenance and overhauls of the diesel engines are based on running hours. As the engines, especially the mains, are now operated 50% less than on a conventional tug, the intervals for maintenance and overhauls will increase three to four fold. This means a $250k major engine overhaul will now be performed every 10 to 15 years, versus every 2.5 to 5 years on a standard boat.

- Operational Benefits—
  In addition to the overall reduction in noise noted in the Environmental Benefits above, the boat's extra weight (due mainly to batteries) causes the boat to sit deeper in the water. The captains who run the boat report that it digs in deeper when pulling in indirect mode during a job, while still maintaining the same maneuverability and agility that its sister boats have.

  Additionally, the varied sources of propulsive power provide considerable redundancy, and make the boat more reliable than her conventional sisters, as any single failure may diminish the pulling capability of the boat, but will not prevent the boat from safely finishing her work before heading back to dock. In a standard harbor tug, loss of a main engine for instance would require the boat to take immediate action to disengage from a job and get assistance back to dock. On the *Carolyn Dorothy*, loss of one main engine would cause the other power sources to compensate for the loss in power, but the boat would still be fully capable with both propellers at a diminished capacity.

Project Costs

The final cost to design, build, test and commission the *Carolyn Dorothy* was approximately $8,000,000. This figure represents an overage of approximately $1,000,000 over the initial budget, due largely to the fact that Foss and AKA was designing the hybrid systems concurrent to construction of the boat. Additionally, the change from NiMH to Lead Acid batteries in the middle of construction required considerable re-design and rework to accommodate the different battery arrays and their appurtenances.

This final cost represents an incremental cost over a conventional Dolphin tug of approximately $2,500,000. On future hybrid projects, both new-build and retrofit, Foss would expect this incremental cost to drop significantly due to lessons learned during the development of the prototype *Carolyn Dorothy*.

Photos

Photo 1: Under Construction before launch

Photo 2: Engine room under construction

Photo 3: Unveiling in January 2009

Photo 4: Working a ship assist job in San Pedro Harbor

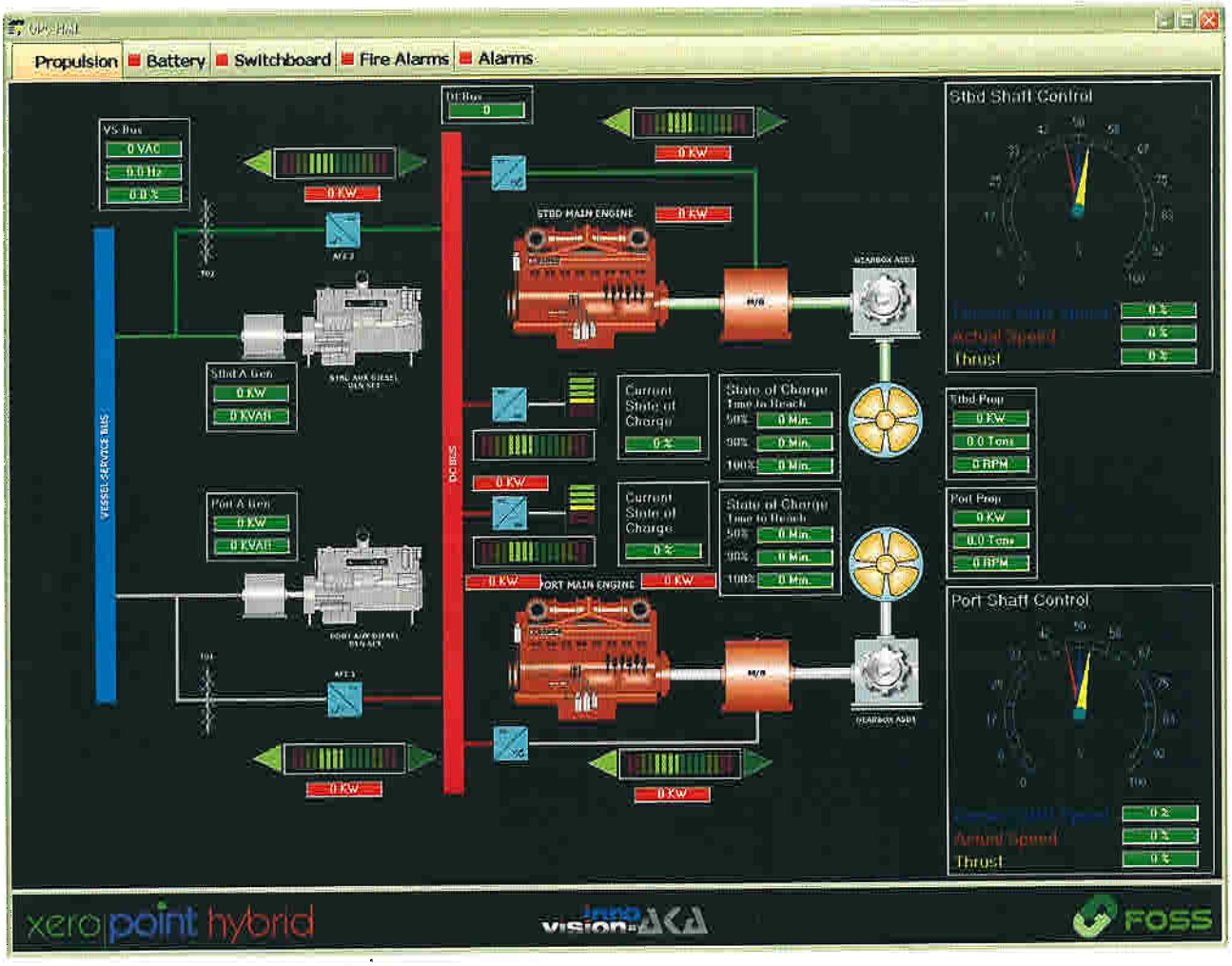

Photo 5: One of the display screens of energy management system

Photo 6: Transiting in San Pedro Harbor