APPENDIX A

MARAD Alternative Fuel Test Plan

U.S. Department of Transportation

Maritime Administration (MARAD)

Alternative Fuel For Marine Application Test Plan

8/23/11

Revised DRAFT

Performed in cooperation with the U.S. Navy and Great Lakes Maritime Academy

1. Introduction

The Maritime Administration (MARAD) is participating in the U.S. Navy's ongoing efforts to test alternative fuels for marine use. MARAD will be testing alternative fuel provided by the Navy on the T/S STATE OF MICHIGAN which is owned by MARAD and operated by the Great Lakes Maritime Academy in Traverse City, Michigan. This testing is being performed in conjunction with the component testing, full-scale testing, and demonstration projects currently being conducted by the Navy using a hydro-treated algae based fuel. A combination of underway and pier side testing will be accomplished over a three month period. The test fuel will be a 50/50 blend by volume of algal fuel provided by the U.S. Navy and Ultra Low Sulfur Diesel (ULSD) purchased by MARAD. This test plan provides the details of the equipment, vessel, and operational tests that will accomplished to evaluate the performance of the test fuel against ULSD on the same engine. Performance and emissions data will be collected both underway and pier side.

2. Ship Description

The vessel selected for the test program is the T/S STATE OF MICHIGAN, which is a retired Stalwart Class (T-AGOS 1) Modified Tactical General Ocean Surveillance Ship built by Tacoma Boat. The vessel was commissioned in August 1985 as PERSISTENT (T-AGOS 6) and was struck and transferred to Great Lakes Maritime Academy in 2002 and renamed the T/S STATE OF MICHIGAN. The vessel is an electric drive vessel with 4 propulsion generators and two propulsion motors. In 2009-2010 the control system was upgraded and the tankage was modified during a yard period. Figure 1, shows the vessel.

Figure 1. T/S STATE OF MICHIGAN

3. Test Engine Description

The T/S STATE OF MICHIGAN has four main propulsion diesel generators that are electrically interconnected via a bus to drive two 1,600 kW propulsion motors and provide electrical power for the ship. Each propulsion diesel generator is a Caterpillar D398 Engine that is :

- 12-Cylinder, V-12, 4-Stroke Configuration
- 6.25 in bore, 8.00 in stroke, 2,945 cu in displacement
- 600 kW (800 hp) – fuel rate 47.6 gph
- Turbocharged, aftercooled configuration

The Navy currently uses this engine on their remaining T-AGOS 1 Class vessels in service as well as Emergency Diesel Generator (EDG) service on some older ships in the fleet. Figure 2 shows the engine configuration and Figure 3 shows the engines as they are currently installed on the ship. Figure 4 provides the cut sheets for the engine as provided by Caterpillar.

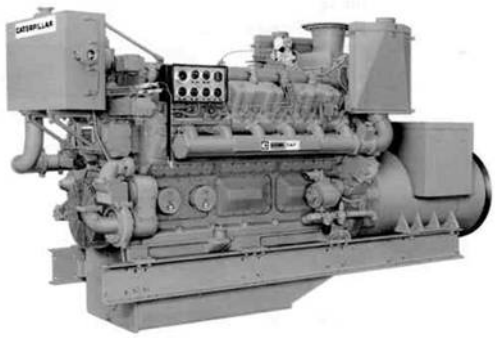


Figure 2. Caterpillar D398 Generator Set

Figure 3. T/S STATE OF MICHIGAN Engine Room – D398 Generator Sets

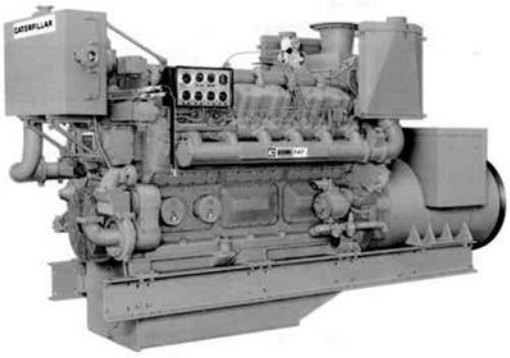
CATERPILLAR
MARINE GENERATOR SET

D398

600 kW 60 Hz | 500 kW 50 Hz

Features

- Durable, Reliable — conservative ratings . . . big displacement
- Compact, Easy to Maintain — components readily accessible . . . large inspection openings
- Marine Societies Works Approval — assurance of high quality standards for materials, procedures and workmanship
- Product Support — worldwide parts and service availability



Shown with Accessory Equipment

Standard Equipment

- Air Intake — single stage, dry panel type air cleaner with service indicator; air cleaner inlet adapter
- Cooling — lubricating oil, auxiliary sea water pump, jacket water pump, expansion tank, thermostats, watercooled turbocharger shield, watershielded exhaust manifold
- Exhaust — 12″ dry flange
- Flywheel and SAE #00 Housing
- Fuel — filter, priming and transfer pumps, flexible lines
- Governor — Woodward
- Instruments and Gauges — left side instrument panel with fuel pressure, intake manifold temperature, lubricating oil pressure and temperature, pyrometer, tachometer, water temperature gauges
- Lubricating — emergency connections, filter, manual sump pump
- Mounting — floor type rails
- Protection Devices — oil pressure and water temperature contactors, hydra-mechanical oil pressure, water temperature and overspeed shutoffs; intake manifold temperature contactor (SWAC)

Accessory Equipment

- Air Intake — air cleaner rain cap
- Cooling — heat exchanger, emergency jacket water connections, auxiliary sea water pump
- Exhaust — flexible fitting, 90° elbow, muffler
- Fuel — duplex filter, double wall fuel lines
- Instruments and Gauges — tachometer, magnetic pickup, ammeter, right mounting standard premium panel, exhaust pyrometer and thermocouples
- Lubricating — duplex filter
- Mounting — engine and generator length rails
- Power Takeoffs — front accessory drive, auxiliary drives, flexible coupling, coupling hub, front enclosed clutch, front end stub shaft, pulley
- Protection Devices — explosion relief crankcase valve, electrical shutoffs, remote manual shutoffs
- Starting — air, electric

Specifications

16 Cylinder, 4-Stroke-Cycle Diesel

Bore — in (mm)	6.25 (159)
Stroke — in (mm)	8.00 (203)
Displacement — cu in (liter)	2,945 (48.3)
Rotation (from flywheel end)	Counterclockwise
Engine Weight, Net Dry (approximate) — lb (kg)	
Jacket Water Aftercooled (JWAC)	14,800 (6727)
Separate Circuit Aftercooled (SCAC)	14,925 (6739)

SR 4 Brushless Generator

- revolving field, single-bearing
- permanent magnet excitation system
- volts-per-hertz regulation
- reactive droop compensation
- piloted shaft reduces linear vibration
- stator temperature detectors, space heater
- voltages (adjustable +10%, −5%)
  60 Hz 440, 600 50 Hz 380, 480
- SR 4 Generator (approx) net wt, lb (kg) . . 5,590 (2536)

Dimensions

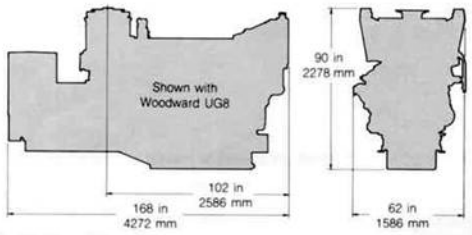


Figure 4. D398 Cut Sheet (Sheet 1 of 2)

D398 Marine Generator Set — 600-500 kW

CATERPILLAR

Performance Data

Jacket Water Aftercooled

60 Hz
Prime Power, 1200 rpm

600 kW @ 0.8 pf 750 kV•A	% Load	100	75	50	25
	kW	600	450	300	150
Fuel Rate	gph	47.6	35.7	25.0	14.9
	L/h	180.2	135.1	94.5	56.5

50 Hz
Prime Power, 1000 rpm

500 kW @ 0.8 pf 625 kV•A	% Load	100	75	50	25
	kW	500	375	250	125
Fuel Rate	gph	39.5	29.1	19.5	11.4
	L/h	149.7	110.3	73.8	43.0

Note: Caterpillar Marine Engines and Generators are approved by Marine Classification Societies. Consult your Caterpillar Dealer for specific ratings and approvals.

Rating Definition

Prime Power

For continuous electrical service

Rating Conditions

Ratings are based on SAE J1349 standard conditions of 100 kPa (29.61 in Hg) and 25 °C (77 °F). These ratings also apply at ISO 3046/1, DIN 6271 and BS 5514 standard conditions of 100 kPa (29.61 in Hg), 27 °C (81 °F) and 60% relative humidity.

Fuel Rates are based on fuel oil having an HHV of 19,590 Btu/lb (45 570 kJ/kg) and weighing 7.076 lb/U.S. gal (848 g/liter).

Materials and specifications are subject to change without notice.

The International System of Units (SI) is used in this publication.

LEHM4132 (5-84)
Supersedes LEHM0286

Printed in U.S.A.

Figure 4 (Continued). D398 Cut Sheet (Sheet 2 of 2)

4. Fuel System Overview

Based on the anticipated operating hours underway and pier side anticipated for this test we will require at least 13,000 gallons of test fuel and 5,000 gallons of ULSD will also be provided. A portion of the fuel will be required for each tank due to tank suction location configuration. According to the Chief Engineer, each service tank typically can fuel about 7,000 gallons, however, fuel is never allowed to go below 1,500 gallons before it is filled again. Figure 5 shows the fuel tank capacities. The ship has a port and starboard service tank that supplies fuel to the engine. The other fuel storage tanks on the ship store the fuel. Fuel is transferred out of the storage tanks and run through a purifier before being pumped into the service tanks. Figure 6 provides the fuel oil system details. Figure 7 shows the fuel oil service system that provides fuel to the propulsion diesel generators

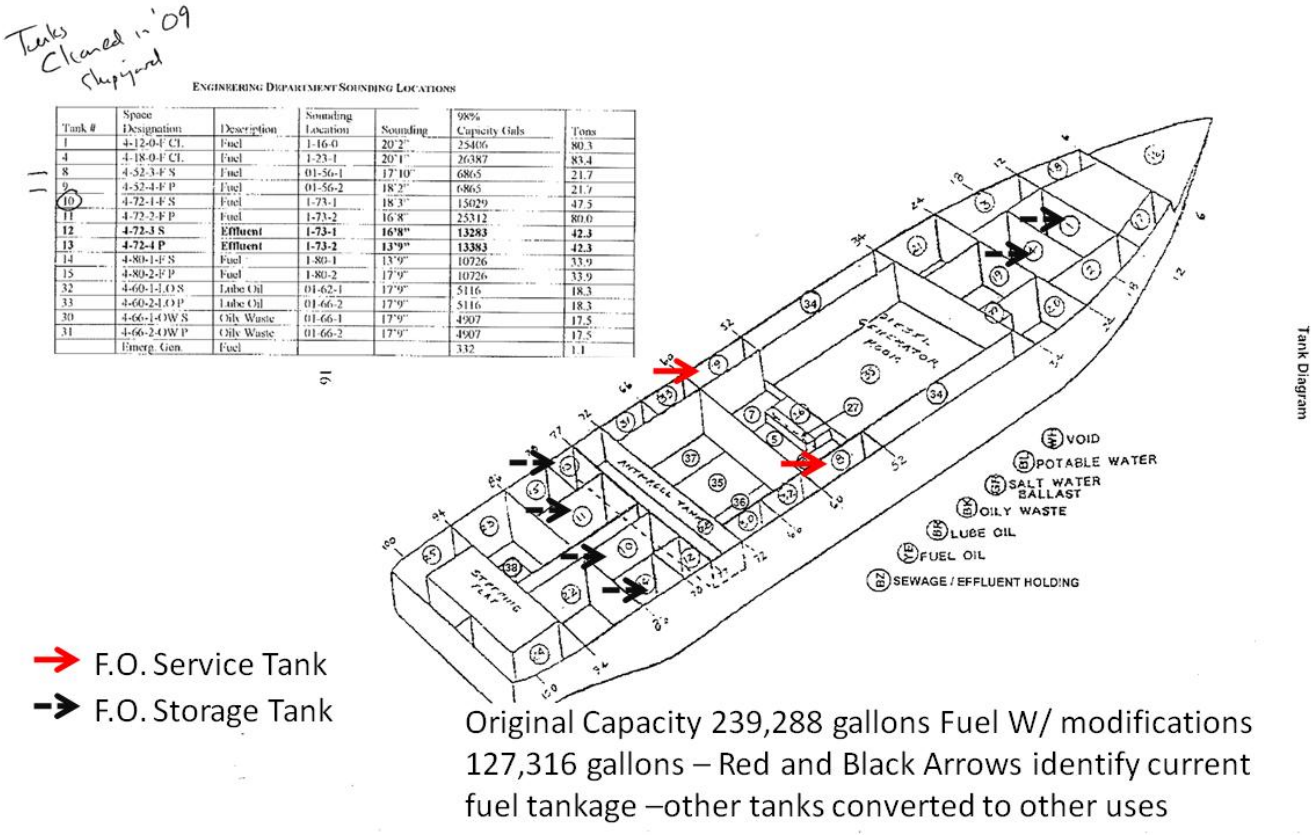


Figure 5. Fuel Oil Tank Capacity

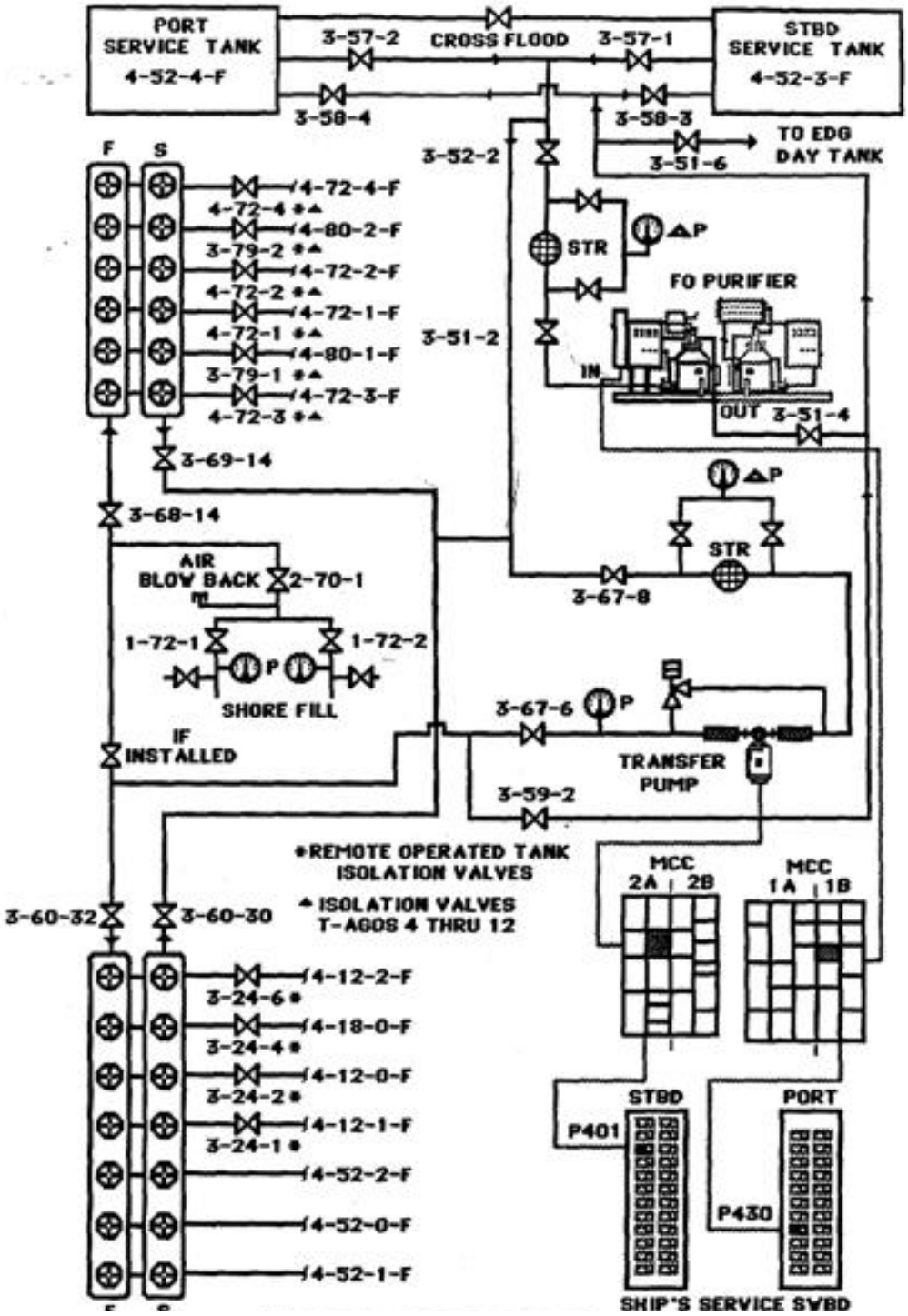


Figure 6. Fuel Oil System

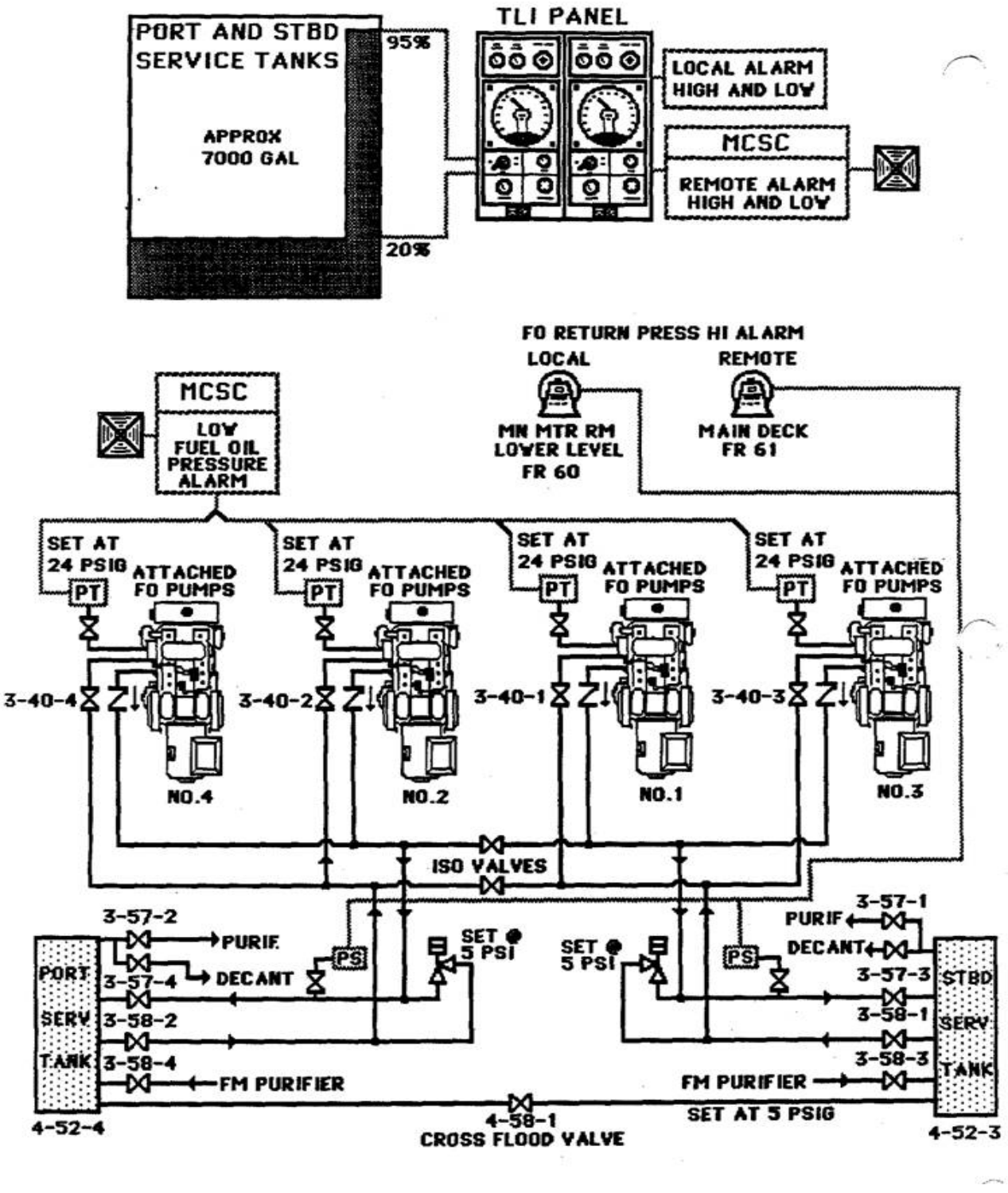


Figure 7. Fuel Oil Service System

5. Test Fuel Requirements

Table 1 provides the estimated fuel requirements based on the estimated operating hours for both underway and pier side operation. To ensure enough test fuel would be on hand to complete the test, 13,000 gallons of blend fuel will be provided to the ship. This means that 6,500 gallons of Algal fuel and 6,500 gallons of ULSD will be blended together. An additional 6,500 gallons of the same batch of ULSD will also be provided to provide sufficient fuel for the baseline testing and running other diesel generators during the blend fuel testing.

Table 1. Estimated Fuel Requirements

	Hours	GPH*	Gallons
Service Tank Minimum			1500
Underway (@75% load)	168	35.7	5997.6
Pier Side (@25% load)	248	14.9	3695.2
Total**			11192.8

* GPH from Cat Cut Sheet - Figure 4

**Chief Estimated 40 gph - adds another 800 gallons

6. Fuel Blending and Storage Plan

Crystal Fuel Energy is a local fuel sales company in Traverse City. They will be purchasing around 11,500 gallons of ULSD and will receive the 6,500 gallons of hydro-treated algal fuel from the Navy. The current plans are for them to lease a Frac tank with the volume to handle the mixing of 13,000 gallons of fuel. They also have identified additional pump gear to help ensure the fuel is blended if required. At this point the plan is for them to receive the 11,500 gallons of ULSD and split it into 6,500 and 5,000 gallon portions with 6,500 gallons being placed in the Frac tank for mixing with the Navy alternate fuel. They will also be adding a lubricity additive to the fuel mixture in sufficient volume to ensure that it covers both the ULSD and algal fuel. The lubricity additive will be provided by MARAD for the project as specified by the Navy – Lubrizol 539D. A sample of fuel will be drawn from the ULSD batch and readied to ship to NAVAIR for testing.

When the algal fuel arrives a sample will be drawn from one of the tank trucks before it is added to the Frac tank that has the 6,500 gallons of ULSD. The algal fuel will be added to the ULSD and the appropriate dosage of lubricity additive (Lubrizol 539D). At this point the fuel should be sufficiently mixed, however, to ensure it is mixed the fuel mixture will be circulated with a pump system. When the ship is ready for the fuel, two tank trucks will be used to transport the fuel to the ship. Each tank truck will be steam cleaned before the first batch of blend test fuel is loaded.

A third sample will be drawn as the blend test fuel as it is loaded on the ship. The three samples will be forwarded to NAVAIR for testing.

The Chief Engineer will have drawn down the fuel both service tanks to as low as possible, well below the typical 1,500 gallon mark and strip with a stripping pump. The port service tank will be filled with the initial blend test fuel through the vent. The remainder of the blend test fuel will be added to fuel storage tank 4-72-1-S that has been emptied of other fuel. Approximately 5,000 gallons of ULSD fuel will be added directly to the starboard service tank via the tank vent. The final amount of ULSD to be will loaded into the starboard service tank will be determined by the Chief prior to the scheduled lift. The port service tank will be initially isolated from the fuel service system for the first day of baseline underway operation. As the port service tank uses fuel, the blend test fuel stored in the storage tank will be transferred via the purifier to the port service tank.

The final two fuel samples will be drawn during the test program The next sample will be drawn of the blend fuel near the conclusion of the underway tests. The final sample will be drawn at the end of the pier side testing. Both of these samples will be sent to NAVAIR for testing. In all five samples will be drawn and tested – one of algal fuel, one ULSD, one of the blend at the beginning of the tests, midway blend fuel, end of test blend fuel.

7. Engine Test Plan

The alternative fuel test will be comprised of a combination of testing ULSD and the blend test fuel on the same engine. The purpose of this is to ensure that the engine – to –engine variability is removed from the test. Figure 8 shows the propulsion system layout. During the July meeting with T/S STATE OF MICHIGAN operational staff, Navy, and MARAD it was determined that Ships Service Diesel Generator (SSDG) #4 would be the best candidate to perform the testing. The fuel service system (Figure 7) is capable of being isolated to run on either service tank and can be split to operate SSDG #2 and #4 on the port service tank and SSDG #1 and #3 on the starboard service tank. The fuel is isolated by closing the valves circled in red on Figure 7.

To perform this test MARAD has contracted with Great Lakes Maritime Academy to crew and operate the ship for the duration of underway testing. Pier side testing will be performed as a normal function of the daily routine, however, instead of using shore power the ship will be running their generator at dockside. MARAD also has contracted with Life Cycle Engineering (LCE) to provide overall test management, subcontracting of various other test team members and services, and provide on-site test support. Included in the LCE scope will be the procurement of the fuel, Caterpillar service support, TMS controls system support, and a local fabrication shop to make modifications to the exhaust stack to enable exhaust gas measurement. MARAD will also be contracting directly with an exhaust emission measurement team because of the specific nature of the services. MARAD will also contract DLA to ship the hydro-treated

algal fuel from Puget Sound storage facilities to the Crystal Energy Facilities in Traverse City, Michigan

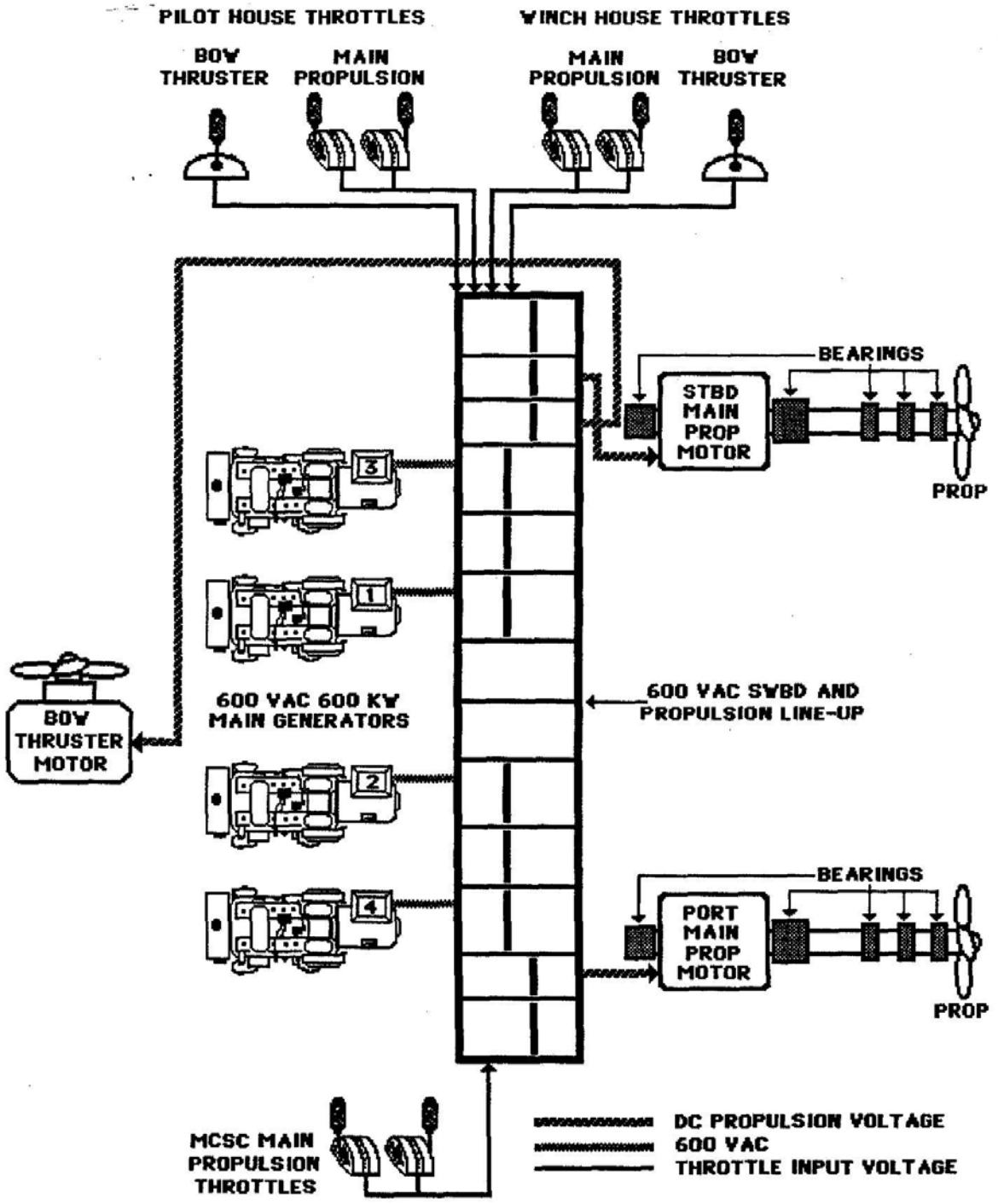


Figure 8. Propulsion System Layout

7.1 Operational Plan

During the June visit to the ship, it was determined that there is a window of operation available between now and the onset of winter in Traverse City, Michigan which is located on Lake Michigan. The layout of the pier and docking basin at Great Lakes Maritime Academy requires significant maneuvering to get out to sea. Due to water depth and lake topography, full propulsion motor thrust is not possible until the vessel is out into the bay. Through the combination of bow thruster and light propulsion motor use, the ship is pulled away from the dock and out into the bay. Any high wind conditions make it impossible to pull the ship out into the bay. This creates some operational restrictions that must be dealt with in the test plan. Additionally, the onset of winter creates an operational window because of ice, snow, and windy conditions on the lake.

It was determined that during the month of September there is an opportunity to take the ship into Lake Michigan for underway performance tests. U.S. Coast Guard requirements for crewing help to dictate the total time the vessel can be underway daily without having an impact on the crewing requirements. It was agreed that a series of daily 12-hour voyages would be possible with minimum crewing and still meet the objectives of this program. The current plan is to operate the ship at sea for about 168 hours, or 17 days underway. This daily 10 hour operation would include maneuvering out of and back into the dock. For two of the underway days a specific operational protocol will be established to accommodate ULSD versus blend test fuel performance and exhaust emission comparison. The balance of the days underway will include operating SSDG #4 on blend test fuel with either PDG #1 or #3 on ULSD in normal navigational operation runs.

The SSDG #4 will also be tested with the blend test fuel while the vessel is pier side using the electrical power generated to replace the shore power normally used daily for 268 hours. The shore power connection is 450 volt, 3 phase, 400 amp service. Typically, 200 amps of the 400 amp service is used which is roughly between 12-20 percent of generator load. The plan is to run the generator for roughly 31 days (8 hour days) once the underway testing is complete.

We anticipate that some operational flexibility will be required to accomplish this testing before the onset of winter. For example, we anticipate that we will not be able to run 17 straight days, Monday through Sunday underway at sea testing because of weather, crew, or operational issues. For those days not at sea during the underway test period we plan to run the engine and collect hours as part of the pier side tests and then when next available get underway to go to sea. There also may be days where weather or operational commitments require the ship be underway for less than 10 hours. This test plan calls for running the engine with the alternative blend fuel for 436 hours of underway and pier side operation in combination. This will provide an operational assessment of the test fuel in actual shipboard situation.

7.2 Pre-Test Preparation

Several pre-test activities must occur to ensure that the test will be accomplished in accordance with the objective and goals of this project. In addition to the fuel blending and shipboard husbandry required, engine pretest inspection and exhaust stack modifications will be required.

Caterpillar will be contracted to perform test/inspection of several fuel wetted engine components. These will include:

- Inspection and test of fuel nozzles
- Inspection and test of fuel pump while installed on the engine and verify fuel pump timing
- Measure and reset valve clearances to specification requirements
- Cylinder inspection through fuel nozzle hole in head using bore scope
- Turbocharger blade inspection
- Change out and provide spare fuel filters.

Caterpillar will document the results of their pre-test inspection and also be responsible for installation of fuel flow meters on the engine fuel supply and return lines. They will also ride the ship during the first two days of testing to ensure the engine is performing properly and to assist as required in exhaust emission testing. They will also be responsible for collecting a lube oil sample from the sump before the commencement of the alternative fuel portion of the test, sending out for testing, and reporting the results.

The planned exhaust emissions testing will require a modification to the existing exhaust pipe to include an additional test port that will be installed into the line. The exhaust emission contractor will determine the necessary modifications which will be drawn up in sketch form and submitted to ABS for approval. Once approved, a local repair shop will be contracted to make the modification per the approved sketch.

7.3 Test Protocol

As stated in Section 7.1, operational flexibility will be required in order to successfully complete this test. This section will provide an overview of the test protocol that is designed to accomplish all of the testing in serial fashion, however, because of the operational uncertainties we anticipate doing a combination of underway and pier side operation until we successfully accomplish all of the underway testing. Once the underway testing is complete, the remainder of the evaluation will consist of pier side operation.

After all of the pre-test inspections and modifications are accomplished testing can commence. The first week of testing will include more rigorous operational requirements because of the

exhaust emission and performance mapping activities that will be accomplished. Table 2 provides the underway portion of the testing and the anticipated operating tempo that will be required to accomplish the tests for the 168 hours anticipated.

Table 2. Underway Test Schedule

Day	Activity Description
1	Install and calibrate the exhaust emission test equipment. Port Service tank will be isolated and Starboard Service Tank will be used to run the engines on ULSD for 2-4 hrs pier side to ensure test equipment, data collection tables, and routines are understood.
2	10-hour duration - Run the engines on ULSD, conduct emission tests out at sea to establish the baseline emissions. With TMS on-hand disable the load limiter and load up SSDG #4 to nearly 100 percent load. Perform emission and performance runs.
3	10 hour duration – Close cross connect valves in supply and return lines and isolate SSDG #2 and #4 to Port Service Tank filled with blend test fuel. Isolate SSDG #2 to ensure blend test fuel only provided to SSDG #4. Run PDG #4 engine on blend test fuel for entire day at sea.
4	10 hour duration - Run SSDG#4 engine on blended test fuel, conduct endurance and emission and performance tests runs out at sea. Remove the exhaust emission test equipment.
5 -17	8-10 hour duration Conduct additional tests at sea using SSDG #4 fueled with blend test fuel and SSDG #1 or #3 online with ULSD. Operational profile to be determined with crew.

Upon award of the emissions testing contract and through further discussions with the crew at Great Lakes Maritime Academy we will prepare an better defined load profile for the underway operation. Section 7.4 covers the data we anticipate we will be able to collect and Section 7.5 provides the emission testing.

During the first few days of underway testing the periodicity of data collected will be greater because of the availability of additional test personnel on board and also the types of test being performed. We anticipate recording critical engine functions every 15 minutes by hand through preprinted log sheets. The ship is also equipped with a data collection system in the engine room that permits trending and records faults and alarms. Technical Marine Servie (TMS) will be aboard to show us how to collect much of the data electronically. Figure 9 provides a view of the touch panel screen located in the engine control room. Additional data collection will be required from the two fuel flow meters locally installed on the engine. Bell data and power monitoring is also available from the control system. After the initial days of rigorous testing, the remainder of the underway test data will be recorded and dumped from the control system.

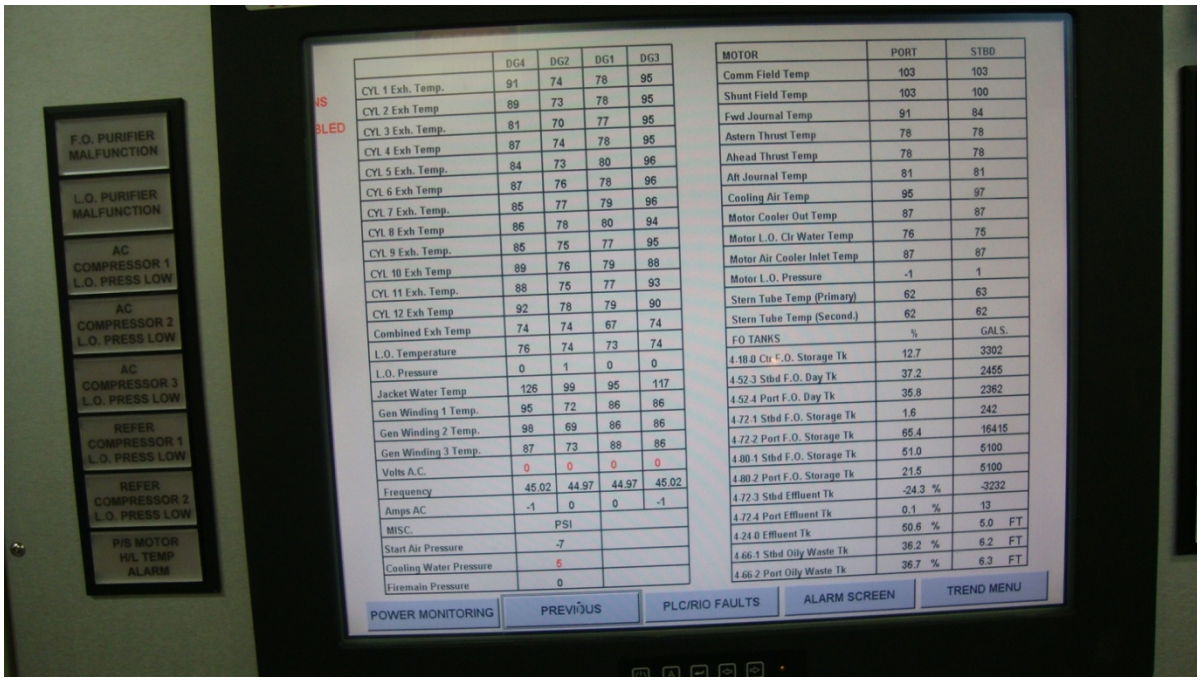


Figure 9. Engine Room Control Station Touch Screen

The next phase of testing will be the pier side tests. These tests will be conducted as unobtrusively as possible to the ship's crew as the load will be applied as the ship normally operates with shore power. The duration of this testing is anticipated to be 8 hours daily and all data will be recorded using traditional shipboard logging techniques and through dump of the control system trending data.

7.4 Data Collection

Data will be collected as discussed in Section 7.3 on paper and in electronic format from the machinery control system. Typical engine parameters will be monitored as well as alarms and alerts. Pressures, temperatures, and loads will be recorded to permit future comparison and evaluation and to determine performance. Exhaust emission data will be collected separately, however, the required operating parameters will be recorded via the ship control system. Additional data will be collected and recorded periodically including:

- Instantaneous fuel consumption – using supply and return line flow rates measured locally
- Fuel consumption through tank ullage measurement at the conclusion of daily testing
- Lube oil consumption via dipstick measurement at start and finish of daily testing
- Atmospheric conditions – temperature, humidity, etc.
- Weather, sea temperature, and sea conditions
- Visual stack smoke observations

7.5 Emissions Test

The exhaust emission tests will be performed in conjunction with the initial underway at sea testing discussed in Section 7.3. Exhaust emission tests will be conducted on SSDG #4 using ISO 8178 guidelines and MARPOL Annex VI NOx Technical Code for CO2, CO, PM (2.5), NOx and SOx emissions. During our original meeting we were told that the engines could only be run at a max. ~50% of MCR - sampling may be conducted at 50%, 25%, maneuvering and idling modes. After communicating with the control system designers we determined that this load limiting function can be removed to permit a higher loading (nearly 100 percent loading). To ensure safety and equipment health, MARAD will be contracting with Technical Marine Service (TMS) to send an engineer to the ship during the exhaust emission portion of the testing.

The engines will first be run on ULSD and sampled to determine the baseline, and then switched over to run on blend test fuel (50% Algal and 50% ULSD). The emission test contractor selected will visit the ship to survey the machinery space for setting-up the test instruments 2 or 3 weeks prior to the actual tests – the ship visits shall be coordinated with MARAD. At the end of the tests, all the test data will be compiled and a separate emission test result report will be prepared. The report will show the test results and compare them with the baseline data. The data will include the percent reduction/increase of CO2, CO, PM (2.5), NO_x, and SO_x at all the test modes.

7.6 Post Test Inspection

Upon completion of the underway and pier side testing, several post test inspection activities will take place. Final fuel tank level measurements will be taken and recorded. Additionally, final fuel blend test fuel samples will be collected and sent to NAVAIR for evaluation.

Caterpillar will come aboard to provide post test inspection and test services. Caterpillar will document the results of their post-test inspection and also be responsible for removal of the fuel flow meters on the engine fuel supply and return lines. They will also be responsible for collecting a lube oil sample from the sump before the commencement of the alternative fuel portion of the test, sending out for testing, and reporting the results. Their field notes and condition assessment will be included in the Final Test Report.

8. Test Schedule

Figure 10 provides the anticipated testing schedule. This is based on an 8 August 2011 start date for all of the subcontracting required to perform the program.

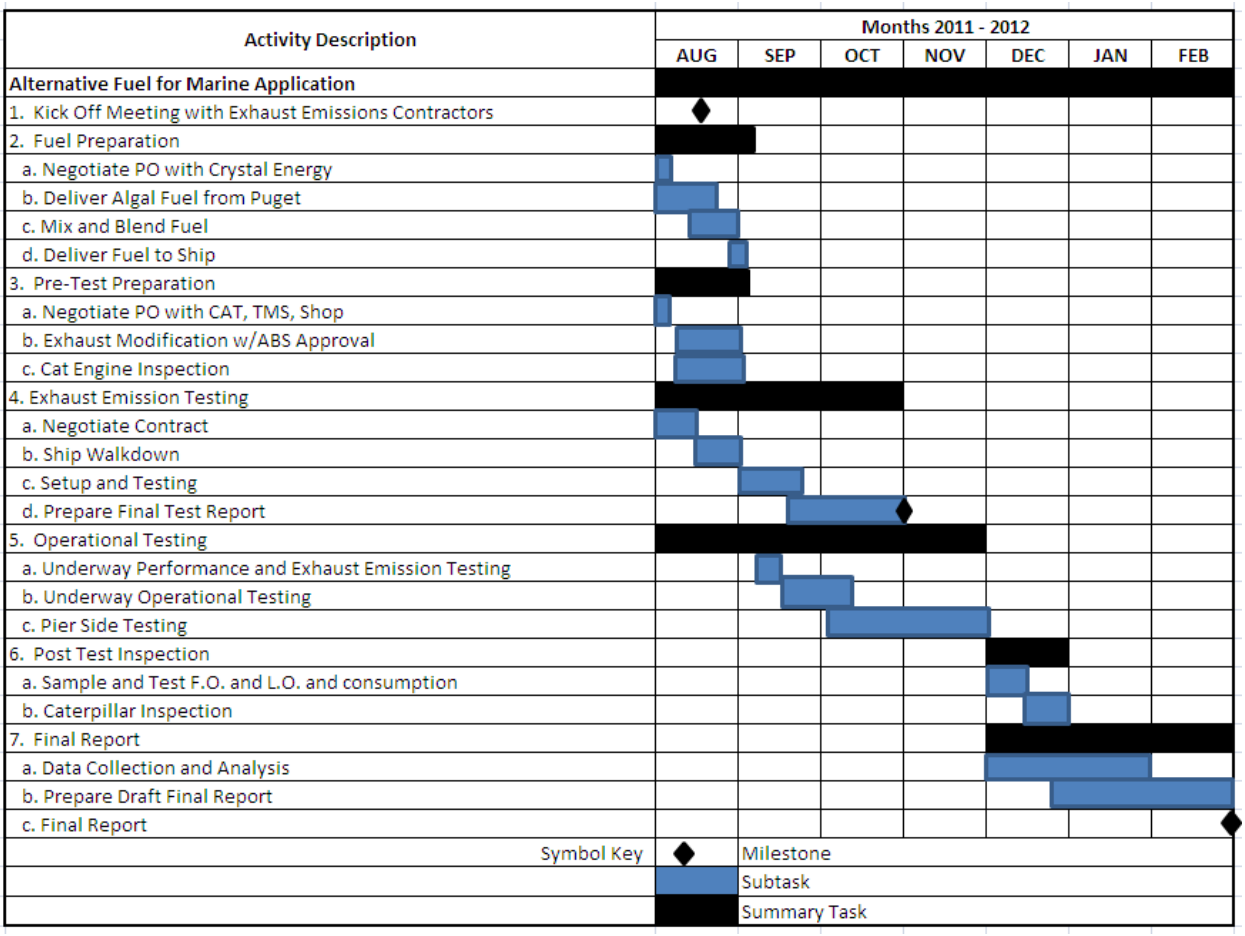


Figure 10. Project Schedule

9. Final Test Report

A final test report will be prepared to document the entire test including results of performance and emissions tests, engine condition inspection, operational data, and a summary of findings and conclusions. Additionally, a technical paper will be prepared to report to the maritime community about the results of this alternative fuel test program.