Program Progress Performance Report for University Transportation Centers
Marine Engine Testing and Emissions Laboratory (METEL)
Led by Maine Maritime Academy

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Recipient Identifying Number or Account Number: Not Applicable

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Report Term or Frequency: This report covers the period from October 1, 2014 to March 31, 2015, per the Grant Deliverables and Requirements for UTCs instructions

Signature of Submitting Official: 

1. ACCOMPLISHMENTS

What are the major goals of the program?

The Marine Engine Testing and Emissions Laboratory (METEL) focuses on research and development of practical and commercializable emissions reductions technologies and engine efficiency enhancement technologies for marine and related power plants (US DOT strategic goal focus area of environmental sustainability).

METEL also provides maritime transportation workforce development and educational opportunities for undergraduates, graduate student as well as middle and high school students (Through its STEM activities).

METEL has four projects as the focus of the UTC funded activities which are:

- Project 1: Field Testing of Diesel/Glycerin Emulsion fuels as a low cost, low emissions, drop-in fuel for marine diesels. This fuel is being developed and commercialized by the startup SeaChange Group LLC
- Project 2: At Sea testing of a hydrogen injection system on MMA Work Vessel for emissions reduction. This system is being developed by Global Marine Consulting
- Project 3: Development and engine testing of Forest Biomass fuel derivatives being developed at UMaine's Chemical Engineering Department and Forest Bioproducts Research Institute.
- Project 4: Development and testing of an exhaust heat recovery thermoelectric generator(TEG) for marine engine efficiency improvement using current advances in thermoelectric materials.
- Project 5: Development of a Marine Engine Continuous Emissions Monitoring System which operates on actual at-sea vessels
- Project 6: Studies the capability of particular Algae strains to produce Glycerin fuel for use as a low cost low emissions transportation fuel.

All of the projects work with commercial partners and have the potential to be practical solutions which can be implemented into the maritime industry in a timely, cost effective manner. Testing at METEL is a vital step toward proving out these technologies for practical use in the real working environment for which they would be subjected.

What was accomplished under these goals?

Major Activities and Specific Objectives

General METEL accomplishments:

- Hardware and Software for Continuous Emissions Monitoring System has been completed, some refinements are ongoing.
- Development of the Lab Dyno using a 4 Cylinder CAT generator, load bank and Variable Frequency Drive is complete.
- Instrumentation of the *Quickwater* with fuel flow meters, torque sensors and RPM sensors has been completed sufficiently to collecting data; refinements are ongoing.
- Blending skid for Diesel/Glycerine Emulsion has been delivered, installed and has blended test batches of fuel.

A primary activity for METEL over its third six month period of operation focused on development and refinement of the test infrastructure to support the various research projects. Base line testing of diesel fuel and testing of alternative fuels will be conducted over the next reporting period. The following summarizes the tasks for each project which were accomplished over the reporting period:

Project 1: Diesel/Glycerine Emulsion fuel project

The summarized accomplishments for the reporting period are:

- Blending skid for Diesel/Glycerine Emulsion has been delivered, installed and has blended small batches of fuel.
- Development of the Lab Dyno using a 4 Cylinder generator, load bank, Variable Frequency Drive (VFD) and fuel consumption measurement is complete.
- *Quickwater* has been outfitted with a secondary fuel system to accommodate testing of fuels, fuel flow meters, torque sensors and RPM sensors to measure power and efficiency. The Continuous Emissions Monitoring System was installed onboard. Reliability and repeatability is being tested. Baseline data with diesel fuel has been established.
- SeaChange has delivered a small quantity of Glycerin-diesel emulsion fuel. Run-ability testing on board *Quickwater* is ongoing. Emissions and efficiency testing is expected during within the next quarter.
- successfully tested blends of Diesel/Glycerine Emulsion fuel using the Lab Dyno

A test of the glycerol emulsion fuel was conducted using MMA's sonolator fuel blending system. The blend used in this test was a 28 percent glycerol and 7 percent water mixture with the certified diesel. The emissions were measured using the continuous monitoring system and the results of the test are shown below [Figure 1,2&3]. As can be seen, there was a significant reduction in NOx production, but also an increase in the carbon monoxide produced and residual hydrocarbons in the exhaust. An investigation into how to reduce the carbon monoxide levels will have to be performed.

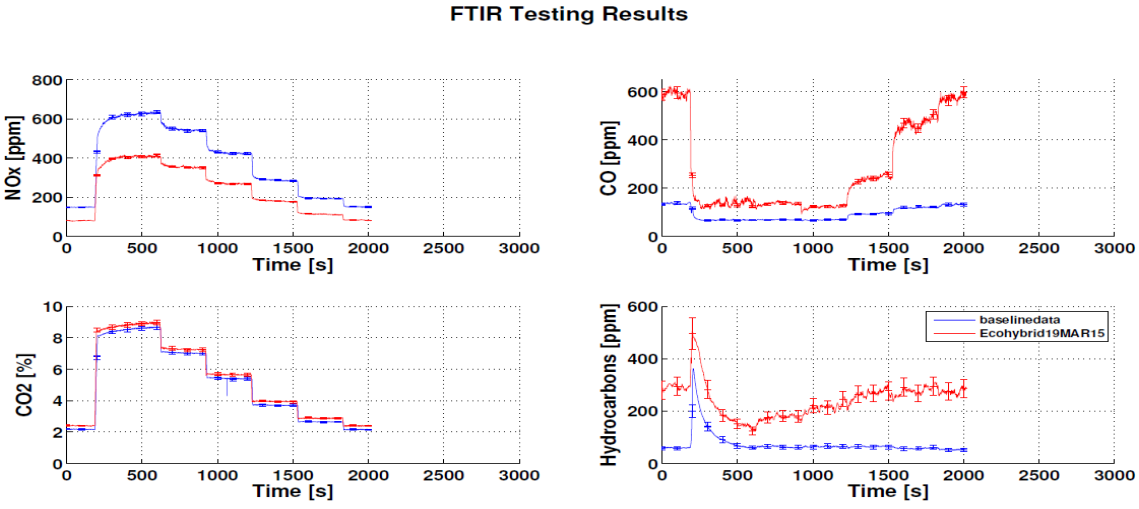


Figure 1: FTIR Results from 28% Glycerol Emulsion

This test shows that the particle count results were elevated. The particle size distribution will also have to be measured in order to make a clear determination on the effects on the soot from the glycerol emulsion fuel. A scanning mobility particle size spectrometer (SMPS) is recommended for the determination of particulate matter emission on a mass and volume basis.

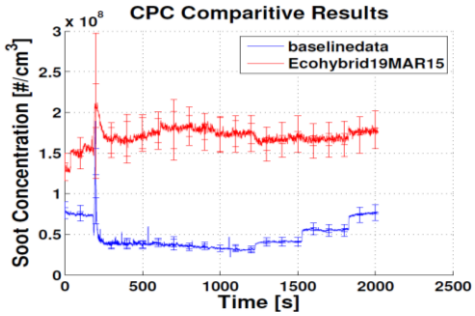


Figure 2 CPC Results from 28% Glycerol Emulsion

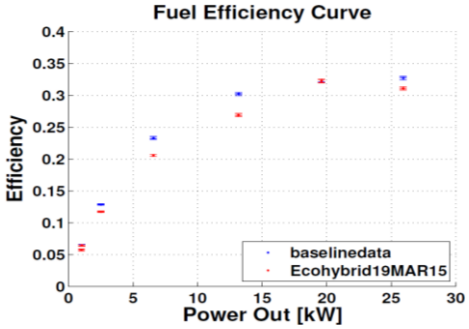


Figure 3 Fuel Efficiency from 28% Glycerol

Project 2: Hydrogen Injection Fuel Project

The summarized accomplishments for the reporting period are:
The installation of the Hydrogen Injection System supplied by Global Marine Solutions in the Quickwater's air intake systems is in its final stages of installation. Run-ability, emissions and efficiency testing with this system is expected to begin during with next quarter.

Testing of the Hydrogen Injection System on the Lab Dyno has begun. The hydrogen production system was connected to the suction side of the turbocharger of the Caterpillar C2.2 genset engine test dynamometer (Lab Dyno), where the test was conducted following the guidelines outlined in CFR title 40 part 1065. The exact flow rate of the hydrogen was not determined, but will be measured in the next iteration of testing. The initial test results did show an approximate 10% reduction in NOx, but also showed a slight increase in carbon dioxide. The next iteration will monitor the amount of hydrogen introduced to the engine's intake, as well as the power required to produce the hydrogen. This data will be incorporated into the efficiency calculation to determine the exact efficiency of the system and will better show the optimal amount of hydrogen flow to reduce the engine's emissions.

Project 3: Forest Biomass Diesel fuel project

UMaine is exploring multiple forest biomass processing routes for the commercial production of liquid transportation fuels. These materials are projected to displace fossil fuel consumption and reduce greenhouse gas emissions within the transportation industries. Two candidate processing routes explored through this center project are formate assisted pyrolysis (FAsP) and thermal deoxygenation (TDO). A summary of accomplishments for each processing route is provided below.

FAsP Accomplishments

Summary of Accomplishments:

- Two semi-batch processing runs for FAsP oil production in the 50 L TDO reactor were carried out. Initial conclusions were that this processing method would not be effective at producing oils because of the higher temperatures required to carry out reactions observed in the fast pyrolysis reactor.
- A manuscript entitled "Calcium-catalyzed pyrolysis of lignocellulosic biomass components" was accepted for publication in *Bioresource Technology* (Elsevier).
- Dr. Paige Case successfully defended her thesis, "Fundamentals of pyrolysis of pretreated biomass." She has accepted a position at the SAPPI-Westbrook Tech Center in Westbrook, ME.
- A fast pyrolysis system to operate at pressures up to 150 psi was designed and fabricated

Background: Formate-assisted pyrolysis (FAsP) is a biomass thermochemcial conversion scheme which has been demonstrated to improve bio-oil quality by pre-treating biomass with alkaline-earth formate salts prior to thermal processing. Under pyrolysis conditions, the pre-treated biomass undergoes additional *in situ* deoxygenation and hydrogen transfer reactions which yields a more stable bio-oil with favorable physicochemical properties for upgrading to transportation fuels.

Accomplishments: To increase the production capacity of FAsP bio-oil, two semi-batch reactions were performed at the 50 L scale. This processing concept would theoretically increase the daily output of FAsP bio-oil by an order of magnitude and enable more rapid interfacing with upgrading and engine systems. Semi-batch processing is fundamentally different from traditional fluidized-bed processing as reactant residence time is significantly increased and products are evolved over a broad range of reactor temperatures during heating. Experiments performed at the UMaine Forest Bioproducts Research Institute's Technology Research Center (TRC) demonstrated that biomass volatilization was achieved, but solids carry-over was detrimental to reactor materials handling. No further reactions were performed.

Another processing pyrolysis reaction scheme under investigation is high pressure pyrolysis. Recent reports by the USDA and others suggest that fast pyrolysis at elevated pressures under reducing environments may improve bio-oil yields and quality. This is a significant result with implications for FAsP processing. The University of Maine is investigating the effects of pressure on FAsP processing by designing and building a high pressure pyrolysis reactor capable of achieving 150 psi, utilize a wide variety of feedstocks and reactive gas species. The unit has been designed and fabricated. Commissioning of the reactor is expected in May 2015 with initial experimental results anticipated for September 2015.

TDO Accomplishments

Summary of Accomplishments:

- Produced 2.5 L of TDO bio-oil for fuel processing and characterization.
- Produce 1.5 L of TDO bio-oil co-feeding sulfuric acid with traditional TDO feed for characterization

- Produced 800 mL of TDO bio-oil co-feeding furfural with traditional TDO feed for characterization
- Evaluated 2-Stage TDO processing scheme at the 300 mL and 4 L scale in a semi-batch reactor
- A manuscript entitled "hydropocessing of Bio-Renewable Thermal Deoxygenation Oils" was accepted for publication in *Energy & Fuels* (American Chemical Society).
- Presented research results
    - American Institute of Chemical Engineers (AIChE) Annual Meeting, Atlanta, GA.
    - Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products (TCS2014), Denver, CO.

Accomplishments: Co-processing experiments were conducted at the 50 L scale to identify opportunities for process intensification by co-feeding simulated process streams in the TDO reactor. Co-feeding of process streams has the opportunity to reduce overall process complexity, lower overall processing costs and improve oil yields. Three experiments were completed; the first used traditional TDO processing feedstock to develop a baseline, the second charged dilute sulfuric acid with the TDO feedstock to simulate co-feeding sulfuric acid used in the up-stream biomass acid hydrolysis process, the third charged stoichiometrically produced furfural to simulate co-feeding furfural process streams. Bio-oils produced from the experiments were sent to Galbraith Laboratories in Knoxville, TN for independent characterization of bio-oil physicochemical properties.

Project 4: Thermoelectric Exhaust heat recovery generator (TEG) project

Summarized accomplishments:

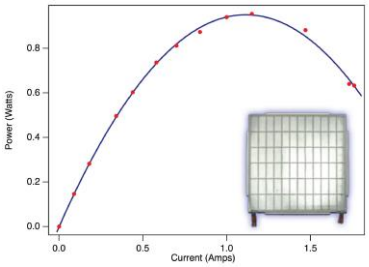
- Modification of diesel generator set (Caterpillar C2.2) exhaust to measure waste heat transfer coefficient completed
- Individual thermoelectric module characterization setup completed
- Initiation of thermoelectric material and device fabrication project with University of Maine at Orono's Laboratory for Atomic and Surface Science Technology (LASST)

Description of accomplishments for the TEG project: The first step in the construction of a useful thermoelectric generator (TEG) for marine diesel engines is extracting waste heat without compromising engine performance. The heat extracted $Q = h\ A\ \Delta T$, is directly proportional to the temperature difference across a surface (ΔT), the area of the surface (A) and the heat transfer coefficient (h). The experimental setup is shown in Figure 4. The load on the engine is controlled

Figure 4: TEG Exhaust Test Apparatus

by an electronic dynamometer system that features a variable frequency drive (Allen Bradley Powerflex 700) and a resistive load bank (Avtron Freedom). Experiments are underway to determine the heat transfer coefficient for a flat plate heat exchanger under variable exhaust conditions. The crank on the top of the box attached to the exhaust allows the exhaust profile to be varied continuously. Constriction of the exhaust improves heat transfer, but also increases back-pressure on the engine, which decreases engine efficiency and increases emissions. The exhaust line has been instrumented with a piezoelectric pressure transducer at the turbo exhaust and a differential pressure transducer across the heat exchanger.

a.



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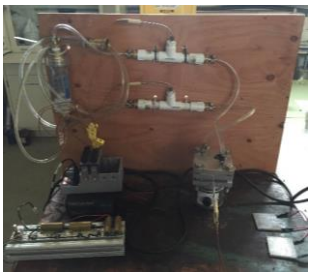

Figure 5 a. Individual power curve for Hi-Z module (inset) measured at constant temperature differential with b. home built load bank and acquisition setup.

To demonstrate the tradeoff we are using commercial-off-the-shelf thermoelectric modules from Hi-Z Technologies, Inc., whose performance is shown in figure 5. We intend follow this work with devices and modules fabricated at the University of Maine's Laboratory for Atomic and Surface Science Technology (LASST). LASST, established in 1986, is a national leader in materials research and possesses significant materials and device fabrication and characterization capabilities. LASST is interested in the synthesis and characterization of new thermoelectric materials and is working with METEL to put those materials into devices and modules tailored to the waste heat energy that can viably be extracted from our test engine. This spring METEL and LASST submitted a brief (requested) on our collaboration to NASA's EPSCOR program for seed funding to advance initial thermoelectric material synthesis and device fabrication.

Project 5: Marine Engine Continuous Emissions Monitoring System

The summarized accomplishments for the reporting period are:

- Current hardware for continuous emissions monitoring system finalized
- LabView control, monitoring, and data logging program finalized for both the CAT diesel generator test stand (Lab Dyno) and Quickwater
- Repeatable diesel baseline emissions data collected
- All measurement uncertainties fully quantified
- EPA g/kW-hr emissions calculations for post processing completed per 40 CFR 1065.655
- Performance and emissions data collected for private party fuel products on CAT genset
- Performance and emissions data collected for glycerol diesel emulsion fuels on CAT genset
- Preliminary diesel baseline performance and emissions data collected on Quickwater

The current version of the continuous emissions monitoring system hardware is finalized with real time LabVIEW control, monitoring, and data logging for both the CAT diesel generator and Quickwater. Considerable effort was spent quantifying measurement uncertainties and finalizing test protocol standards to ensure accurate and repeatable data. With the continuous emissions monitoring system and testing fully characterized, several emissions tests were conducted. Progress on the summarized accomplishments is outlined below.

Continuous Emissions Monitoring System Hardware

The complete continuous emissions monitoring system (CEMS) is shown in 6 installed aboard Quickwater during diesel baseline testing. The MKS 2030 Fourier Transform Infrared (FTIR) spectrometer for gaseous emissions measurements is shown on bottom with heated sample lines per EPA test standards. The soot particle measurement case is shown in the center, housing the BMI Condensation Particle Counter (CPC) for measuring soot particle number concentration. All control hardware is shown housed in the top gray box. Future improvements to the CEMS include the addition of a scanning electrical mobility particle size spectrometer for full soot particle size distribution information and an estimate of total particle mass emissions. Modifications to the CPC are also planned to eliminate device malfunction due to pitch and roll during field-testing on board vessels.

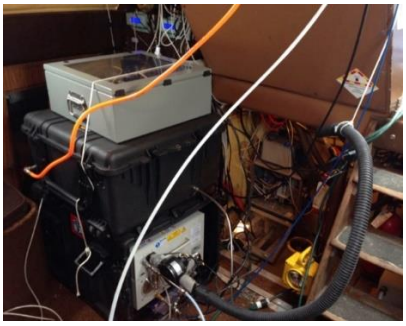

Figure 6: CEM system on Quickwater

Continuous Emissions Monitoring System Software

The finalized LabVIEW VI for the CEMS including hardware control and data logging is shown in Figure 7 and 8. The software is modular allowing any measurement device to be initialized or taken offline for testing. Individual tabs give a snapshot of subsystems including engine parameters, particle measurements, gaseous measurements, temperature control, etc. The software syncs all incoming data and saves to a single file for post processing. Future work will focus on implementing a tab for real time EPA g/kW-hr emissions measurements per 40 CFR 1065.655

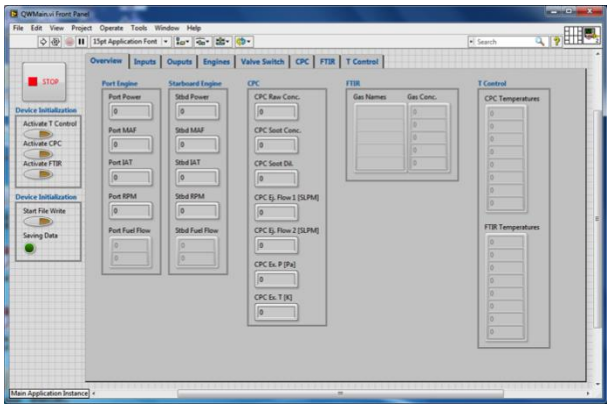

Figure 7 Control, monitoring, and data logging LabVIEW vi for engine performance and emissions data on board Quickwater.

Figure 8 Computer running CEMS LabVIEW vi placed in the cabin aboard Quickwater during testing.

CAT Generator Diesel Baseline Data (Lab Dyno)

Diesel baseline performance and emissions measurements were conducted on a CAT 2.2L diesel generator. After a 1-hour warm-up period, the test duty cycle consisted of:

- Starting idle (1 kW)
- Five load settings in gear per 40 CFR 1042.505
    - 100% power (25.9 kW) ,75% power (19.6 kW),50% power (13.2 kW), 25% power (6.6 kW), 10% power (2.5 kW)
- Return to idle (1 kW)

The average soot particle concentration from three diesel baseline tests is reported in Figure 9 for the duty cycle described above. Total soot particle number concentration measurement uncertainty is 13% and shown as the black error bars in Figure 9. A data repeatability study was also conducted and reported as grey error bars. Soot concentrations were found especially sensitive to engine thermal equilibrium. The individual baselines exhibited good repeatability after identifying a sufficient warm up time of 1-hour for the engine to reach thermal equilibrium.

Mole fractions of NOx, CO, CO2, and Total Hydrocarbons (THC) are shown in Figure 10 for the duty cycle described above. Overall concentration uncertainties defined by ASTM D6348 MDC#3 are approximately 2.5% for NOx, 5% for CO, and 3% for CO2. Measurement uncertainty bars are shown in black in Figure 10. THC is a multicomponent estimated quantity shown primarily for order of magnitude studies and trend analysis. The measurement uncertainty bar is estimated for THC by accounting for all individual component measurement uncertainties. Gaseous emissions were found much less sensitive to engine thermal equilibrium. Gaseous emissions concentrations reached equilibrium within 20

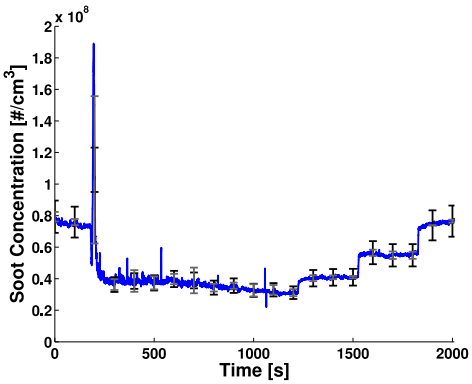

Figure 9: Soot Particle concentrations

minutes of the engine warm-up period. The magnitude of repeatability uncertainty between the three diesel baseline tests is very small for gaseous emissions and is represented by the grey error bars in Figure 10.

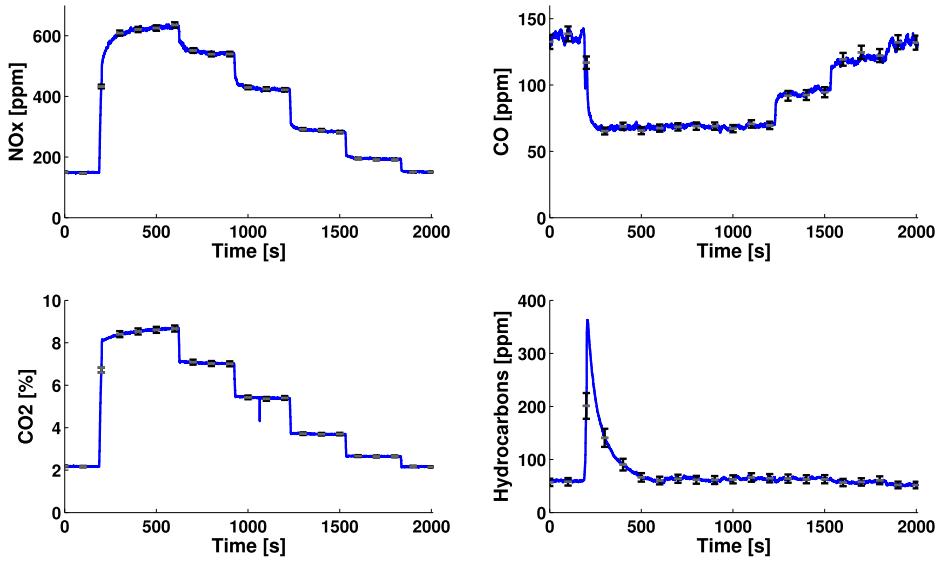

Figure 10 FTIR calculated gaseous emissions of NOx, CO, CO2, and Total Hydrocarbons (THC).

Quickwater Diesel Baseline Data

Preliminary diesel baseline performance and emissions measurements were conducted on the port engine of the 41 ft Maine Maritime Academy utility vessel Quickwater. After a 1-hour warm-up period, the test duty cycle consisted of:

- Starting idle in gear (5 kW, 750 engine RPM)
- Four load settings in gear per 40 CFR 1042.505
    - 100% power, maximum test speed (272 kW, 2616 engine RPM)
    - 75% power (204 kW, 2050 engine RPM)
    - 50% power (136 kW, 1735 engine RPM)
    - 25% power (68 kW, 1386 engine RPM)
- Return to idle in gear (5 kW, 750 engine RPM)

Soot particle concentration is reported in Figure 11 for the duty cycle described above. Total soot particle number concentration uncertainty is 13%. Of particular note is the equilibrium time required to achieve steady particle number concentration especially when applying 100% load from idle and returning to idle to complete a test. Note that transients are also captured during load changes.

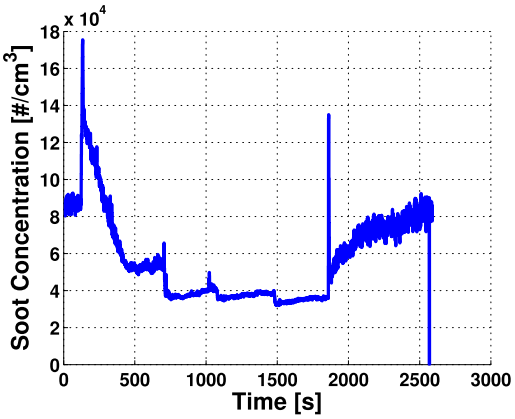

Figure 11 Soot Particle concentrations

Mole fractions of NOx, CO, CO2, and Total Hydrocarbons (THC) are shown in Figure 12 for the duty cycle described above. Overall concentration uncertainties defined by ASTM D6348 MDC#3 are approximately 2.5% for NOx, 5% for CO, and 3% for CO2. THC is a multicomponent estimated quantity shown primarily for order of magnitude studies and trend analysis. Again, note the time required for near equilibrium of gaseous emissions concentrations due to larger engine mass as compared to data from the significantly smaller CAT genset. Sharp transients are also captured in the gaseous emissions data during load changes.

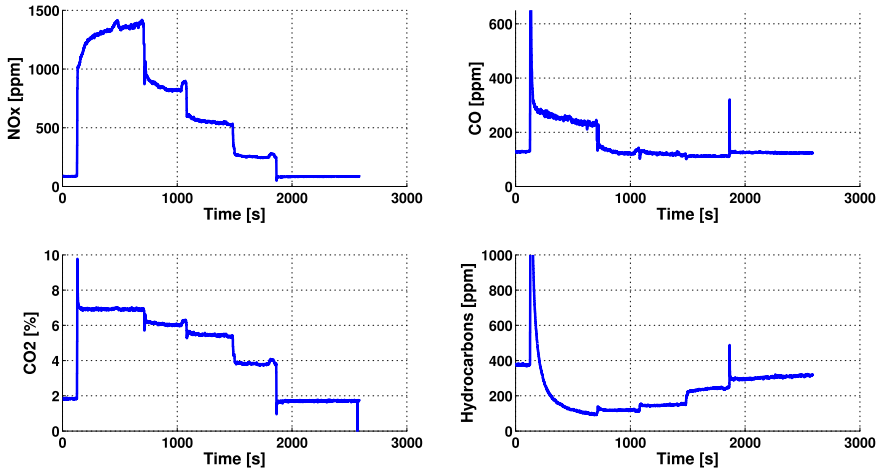

Figure 12 FTIR calculated gaseous emissions of NOx, CO, CO2, and Total Hydrocarbons (THC).

Project 6: Algae based glycerin fuel project

Summarized accomplishments:

- Improved method for small molecule identification
- Medium-scale
- Initiated collaboration with Bigelow Lab for Ocean Science's National Center for Marine Algae (NCMA) in East Boothbay Harbor, ME

Description of accomplishments for the algae biofuels project:

The objective of this project is determining whether glycerol, produced by microalgae, can be an energy positive (*i.e.* produce more energy than they consume) and economically competitive transportation fuel. Both points rely heavily on minimizing the energy required to grow the algae and extract and purify fuel molecules.[i]

What differentiates our approach from other groups working on algae biofuels is our focus on small molecules, like glycerol, that are expelled from the algae into the extracellular media. The leakage of these molecules across the cell membrane allows for the extraction without killing the culture. This is demonstrated on the small scale in figure 13 for *Dunaliella tertiolecta*. Once separated, the glycerol-containing medium can be decanted off and replenished with fresh media.

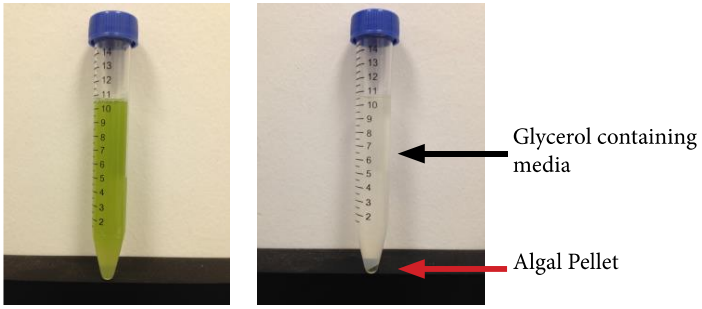

Figure 13 Test tube of mature culture of *Dunaliella Tertiolecta* in UTEX media before and after centrifugation

Initial experiments focused on quantifying the amount of glycerol that could be produced and correlating those concentrations with easily measured physical properties of the algae culture like cell density, refractive index and viscosity. Unfortunately the spectrophotometric assay we used for glycerol quantification was not reliable. We have developed a new Nuclear Magnetic Resonance (NMR)-based procedure for glycerol quantification that is both more sensitive (~10 micromolar/0.01 mg/ml), more reliable and requires less sample (500µL).

METEL also starting working with Bigelow Laboratory for Ocean Science's National Center for Marine Algae (NCMA). NCMA has the largest and most diverse collection of marine algae in the world and is an immense resource for algae culturing techniques on the small and large scale. NCMA is providing the culture and media for METELs experiments and consulting on METEL's algae maintenance, handling and culturing procedures.

The potential of this collaboration is substantial. Many of the cultures that NCMA maintains export other small hydrocarbon molecules to the extracellular medium and METEL and NCMA are initiating a project to identify and quantify these molecules and profile their potential as diesel fuel additives.

[1] L. Brennan, P. Owende, "Biofuels from microalgae—A review of technologies for production, processing, and extractions of biofuels and co-products." *Renew. Sust. Ener. Rev*. vol. 14. pp. 557–577. *2010*.

Education, Workforce development and STEM accomplishments

Initiated Maritime Transportation Environmental curriculum developed co-funded by a Woods Foundation grant of $40k. This effort will develop a five course environmental engineering sequence for MMA and begins in earnest over the summer of 2015.

STEM Events:

Participated in Maine Engineers Week at University of Southern Maine.

Significant Results:

TDO Significant Result

Experimental results indicate that processing hydrolyzate streams containing sulfuric acid can be achieved without impacting TDO bio-oil yields or composition thereby reducing the need for sulfur recovery operations prior to TDO processing. Furfural has been identified as a carbon-rich process stream component with opportunity for co-processing. However, these materials require alternative processing methods to improve material handling. This work has stimulated research into improved TDO processing methods.

Key Outcomes:

None to report at this time

How have the results been disseminated?

Presented FAsP fundamental research entitle "Calcium-Catalyzed Pyrolysis of Lignocellulosic Biomass Components" at the 2014 American Institute of Chemical Engineers (AIChE) Annual Meeting, Atlanta, GA.

A manuscript entitled "Calcium-catalyzed pyrolysis of lignocellulosic biomass components" was accepted for publication in *Bioresource Technology* (Elsevier)

Presented FAsP fundamental research entitled "Effects of Calcium Compounds on Pyrolysis of Biomass Components" at the Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products (TCS2014) Meeting in Denver, CO.

A manuscript entitled "Hydroprocessing of Bio-Renewable Thermal Deoxygenation Oils" was accepted for publication in *Energy & Fuels* (American Chemical Society)

Presented TDO fundamentals research at the Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products (TCS2014) Meeting in Denver, CO.

What do you plan to do during the next reporting period to accomplish the goals?

Over the next reporting period we plan the following goals and accomplishments for the projects:

Project 1: Diesel/Glycerin Emulsion fuel project

- Production of pilot quantities of fuel using the fuel production skid
- Completion of preliminary results on Vessel R/V Quickwater for Fuel and emissions tests and sea trials using the fuel

Project 2: Hydrogen Injection Fuel Project

- Results of the of GMC system on Lab 4 cyl. Diesel test stand
- Sea Trials and preliminary results of GMC system on R/V Quickwater

Project 3: Forest Biomass Diesel fuel project

FAsP Continuing Work

- Testing and commissioning the high pressure pyrolysis system
- Examine the effects of pressure on formate-assisted fast pyrolysis derived bio-oils and yields

TDO Continuing Work

- Production of 20 L of TDO derived bio-oil for engine testing and hydroprocessing experiments.
- Blend crude TDO-derived bio-oil with ULSD and develop engine response baseline
- Determine fuel chemistry effects on engine efficiency and emissions
- Hydroprocess remaining TDO-derived bio-oils to improve cetane
- Blend hydroprocessed oils with ULSD to quantify engine performance and emission responses to materials processing.
- Fractionate distillate components from hydroprocessed TDO oil and quantify engine performance and emission response to pure TDO oil product.
- Complete installation of a bench-scale continuous TDO reactor and demonstrate process yields and bio-oil physic-chemical properties.

Project 4: Thermoelectric Exhaust heat recovery generator project

- Testing of the Experimental TEG test system on single cylinder diesel using Hi-Z thermoelectric modules

Project 5: Continuous Emissions Monitoring System

- Final installation of CEMS onboard R/V Quickwater
- Shakedown tests and measurements of emissions in at-sea trials

Project 6: Algae Based Glycerin fuel project

- Final development of inexpensive culture media
- Results from continuous monitoring system for glycerin production.

Education, Workforce development and STEM:

- Development of Algae STEM project for use by middle school science teachers
- Development of Lab for the Environmental Compliance course sequence at MMA

2. PRODUCTS: What has the program produced?

Publications, conference papers, and presentations

Journal publications:

1. Case, P.A., Truong, C., Wheeler, M.C. and DeSisto, W.J. "Calcium-Catalyzed Pyrolysis of Lignocellulosic Biomass Components" Bioresources Technology 2015, In Press.

2. Eaton, S.J., Beis, S.H., Karunarathne, S.A., Pendse, H.P. and Wheeler, M.C. "Hydroprocessing of Bio-Renewable Thermal Deoxygenation Oils" Energy & Fuels 2015, In Press.
3. Eaton, S.J., Harakas, G.N., Kimball, R.W., Smith, J.A., Pilot, K.A., Kuflik, M.T. and Bullard, J.M. "Formulation and Combustion of Glycerol-Diesel Fuel Emulsions" Energy & Fuels 2014, 28, 3940-3947.
4. S.J. Eaton, G.N. Harakas and R.W. Kimball "Characterization of Glycerol-Diesel Emulsion Fuels". American Institute of Chemical Engineers (AIChE) annual meeting, Atlanta, GA **2014**. (Oral Presentation)
5. S.J. Eaton, G.N. Harakas and R.W. Kimball "Combustion of Glceyrol-Diesel Emulsion Fuels" American Society of Mechanical Engineers (ASME) 8th International Conference on Energy Sustainability (ESFuelCell2014), Boston, MA. **2014**. (Oral presentation).

Books or other non-periodical, one-time publications: Nothing to Report

Other publications, conference papers and presentations:

1. P.A. Case "Calcium-Catalyzed Pyrolysis of Lignocellulosic Biomass Components". American Institute of Chemical Engineers (AIChE) annual meeting, Atlanta, GA **2014**. (Oral Presentation)
2. P.A. Case, W.J. DeSisto, and M.C. Wheeler. "Effects of Calcium Compounds on Pyrolysis of Biomass Components". Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products (TCS2014), Denver, CO **2014**. (Technical Poster)
3. S.J. Eaton, M.C. Wheeler and H.P. Pendse. "Levulinate and Formate Salt Reactions During Thermal Deoxygenation (TDO)". American Institute of Chemical Engineers (AIChE) annual meeting, Atlanta, GA **2014**. (Oral Presentation)
4. S.J. Eaton, M.C. Wheeler and H.P. Pendse. "Decomposition Pathways During Pyrolysis of Hydrolyzate Salts". Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products (TCS2014), Denver, CO **2014**. (Technical Poster)

Website(s) or other Internet site(s)
The METEL website can be found at: www.mainemaritime/metel
This is the main website for the DOT UTC Center, describing the center's mission as well as the projects, key personnel and serves as a repository for the research reports generated by the project.

Technologies or techniques Nothing to Report

Inventions, patent applications, and/or licenses Nothing to Report

Other products
Instrumentation:

Developed a high pressure pyrolysis reactor to investigate the fundamental aspects of biomass thermal processing. This system, as detailed in Figure 14 and Figure 15, is capable of pressures up to 150 psi, can process a wide variety of feedstocks and is capable of producing research quantities of bio-oils for chemical characterization. This system will be utilized to investigate effects of pressure and reactive gas species on bio-oil composition and yields. Experimental results will yield valuable insights into the mechanisms of biomass thermal conversion and may lead to improved reactor designs in pursuit of biomass to biofuel commercialization.

Figure 14 Photograph of the high pressure pyrolosis system developed at UMaine

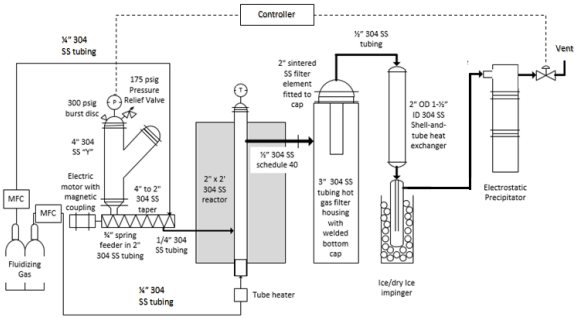

Figure 15 Schematic of the high pressure pyrolysis system developed at UMaine.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS:

Who has been involved?

What individuals have worked on the program?

The tables below summarize the information for the individuals who have worked on the program:

Name	Dr. Richard Kimball
Program/Project Role	P.I. /Technical Director
Work Effort during reporting period	3 months
Contribution to Program/Project	METEL Technical Director
Funding support	DOT UTC
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	NA
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	NA

Name	Thomas Lokocz
Program/Project Role	Research Engineer
# Hours worked during reporting period	120 hrs (Full time since March 7)
Contribution to Program/Project	METEL Research Engineer (full time) for all projects

Funding support	DOT UTC
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

Name	Brendyn Sarnacki
Program/Project Role	Research Engineer (Full time)
# Hours worked during reporting period	400 hours
Contribution to Program/Project	METEL Research Engineer for all projects
Funding support	DOT UTC
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

Name	Mathew Cameron
Program/Project Role	Research Engineer (Part time)
# Hours worked during reporting period	420 hours
Contribution to Program/Project	METEL Research Engineer for all projects
Funding support	DOT UTC
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

Name	Richard Smith
Program/Project Role	Research Engineer (Part time)
# Hours worked during reporting period	480 hours
Contribution to Program/Project	METEL Research Engineer for all projects
Funding support	DOT UTC
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No

If travelled to foreign country(ies) duration of stay	N/A

Name	Dr. Joshua Henry
Program/Project Role	Research Engineer (Part Time)
# Hours worked during reporting period	450 hours
Contribution to Program/Project	METEL Research Engineer; TEG project and STEM Algae project
Funding support	DOT UTC
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies)duration of stay	N/A

Name	Dr. Clay Wheeler
Program/Project Role	UMaine Co-P.I.
# Hours worked during reporting period	1 month
Contribution to Program/Project	Lead P.I. for UMaine effort; Leading the TDO/FAsP project at UMaine
Funding support	1 month (UMaine)
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

Name	Dr. William DeSisto
Program/Project Role	UMaine Senior Personnel
# Hours worked during reporting period	1 month
Contribution to Program/Project	Co- P.I. for UMaine effort; Co-supervising graduate student research.
Funding support	1month (UMaine)
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

Name	Nathan Hill

Program/Project Role	Technical Staff
# Hours worked during reporting period	3 month DOT, 3 month UMaine
Contribution to Program/Project	Equipment fabrication and testing
Funding support	DOT
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A
Name	Paige Case
Program/Project Role	Graduate Student
# Hours worked during reporting period	6 month
Contribution to Program/Project	Formate-assisted fast pyrolysis fundamentals
Funding support	DOT materials and supplies, UMaine stipend and tuition
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

Name	Scott Eaton
Program/Project Role	Graduate Student
# Hours worked during reporting period	6 month
Contribution to Program/Project	TDO fundamentals
Funding support	DOT
Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

Name	Chi Truong
Program/Project Role	Graduate Student
# Hours worked during reporting period	6 month
Contribution to Program/Project	Formate-assisted pyrolysis fundamentals
Funding support	DOT stipend, UMaine tuition

Collaborated with individual in foreign country	No
Country of Foreign Collaborator	N/A
Travelled to Foreign Country	No
If travelled to foreign country(ies) duration of stay	N/A

What other organizations have been involved as partners?
Organization: SeaChange Group LLC (SCG) , Brunswick Maine
Contribution to Project: SCG is providing the Diesel/Glycerin Emulsion fuels for testing in MMA's test engines and marine vessels. They are constructing and operating the fuel blending skid and collaborating with MMA on the engine and vessel testing.

Organization: Global Marine Consulting (GMC)
Contribution to Project: GMC is providing the Hydrogen Injection test equipment and have delivered most of the system. Preliminary test have been run on a lab diesel engine.

What other collaborators or contacts been involved?
Nothing to Report

4:IMPACT:
What is the impact on the development of the principal discipline(s) of the program?
Nothing to Report
What is the impact on other disciplines?
Nothing to Report
What is the impact on the development of transportation workforce development?
Nothing to Report
What is the impact on physical, institutional, and information resources at the university or other partner institutions?
Physical Resources such as facilities, laboratories, or instruments
Development of an Emulsion fuel blending skid for processing pilot plant quantities of emulsion fuels has been completed and initial blends have been produced.
What is the impact on technology transfer?
Nothing to Report

What is the impact on society beyond science and technology?
Nothing to Report

5:CHANGES/PROBLEMS
Nothing to Report

6: SPECIAL REPORTING REQUIREMENTS
Nothing to Report