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

- **Federal Agency and Organization Element to Which Report is Submitted:**
U.S. Department of Transportation Research and Innovative Technology Administration

- **Federal Grant or Other Identifying Number Assigned by Agency:** DTRT13-G-UTC43

- **Project Title:** Tier 1 Marine Engine Testing and Emissions Laboratory

- **Program Director: Dr.** Richard Kimball, richard.kimball@mma.edu, 207-326-2375

- **Submission Date:** October 30, 2014

- **DUNS and EIN Numbers:** 071746630 and 01-60000724

- **Recipient Organization:** Maine Maritime Academy, Pleasant Street, Castine Maine 04420

- **Recipient Identifying Number or Account Number:** Not Applicable

- **Project/Grant Period:** October 1, 2013 – September 30, 2017

- **Reporting Period End Date:** September 30, 2014

- **Report Term or Frequency:** This report covers the period from April 1, 2014 to September 30, 2014, 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:

- Three research engineers hired
- Website online: www.mainemaritime/metel

A primary activity for METEL over its second six months of operation focused on the development of the test infrastructure to support the various research project. Significant capital equipment purchases and supplies were acquired over this period and steady progress has been made on the development of the testing assets in both the lab and floating assets.

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 Sonolator has been delivered and blending skid system construction is underway.
- Improved testing is being developed for the Eco-Hybrid Fuel on 4 Cyl. Generator; this is accomplished with the addition of a Variable Frequency Drive (VFD) controlled load bank and fuel consumption measurements to establish efficiency.

Quickwater has been outfitted with a secondary fuel system to accommodate testing of fuels in addition to traditional diesel fuel. This system includes all hosing, automated three-way valves and 55 gallon drum barrels on deck [Figure1.1]. The first 100 gallons of glycerin-diesel emulsion has been delivered by SeaChange and run-ability testing on board *Quickwater* has begun.

To establish efficiency, METEL has received delivery of several key instrumentation orders. These instruments include fuel flow meters, torque sensors and RPM sensors [Figure1.2, 1.3]. These systems are currently in the process of being installed and calibrated.

Figure 1.1: Fuel barrels for secondary fuel system on board *Quickwater*.

Figure 1.2:Starboard switching valves, fuel filters and flow meters on board *Quickwater*.

Fiure 1.3: Fuel flow meter displays on board *Quickwater*

Project 2: Hydrogen Injection Fuel Project

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 [Figure 2.1, Figure 2.2]. Run-ability, emissions and efficiency testing with this system is expected to begin during with next quarter.

Figure 2.1: Hydrogen injection on board *Quickwater*.

Figure 2.2: Hydrogen generation system on board *Quickwater*.

Project 3: Forest Biomass Diesel fuel project

The summarized accomplishments for the reporting period are:

- UMaine contract for phase 1 is in place and work commenced on July 1.
- Trained staff to operate 50L semibatch TDO reactor in FBRI's Technology Research Center
- Produced 2L of TDO oil for diesel engine testing.
- Began to develop engine testing plan for TDO/Diesel blends.
- New graduate student started in September.
  Students made two presentations at the UMaine Chemical and Biological Engineering seminar series
- 4 Cylinder Caterpillar Genset test stand constructed and preliminary performance testing run.

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

Summarized accomplishments:

- Thermoelectric test apparatus installation into diesel generator set test platform completed
- Diesel generator set dynamometer system completed
- Initial materials development modeling completed

Description of accomplishments for the TEG project:

The thermoelectric test apparatus has been successfully implemented into the exhaust stream of a diesel generator set (Caterpillar C2.2). The test plan includes varying the loading of the generator set in order to produce differing flow temperatures and velocities of the diesel exhaust. The loading will be controlled by an electronic dynamometer system that features a variable frequency drive (Allen Bradley Powerflex 700) and a resistive load bank (Avtron

Freedom). The dynamometer system has been successfully programmed and tested for use with the diesel generator set, as seen in Figure 4.1.

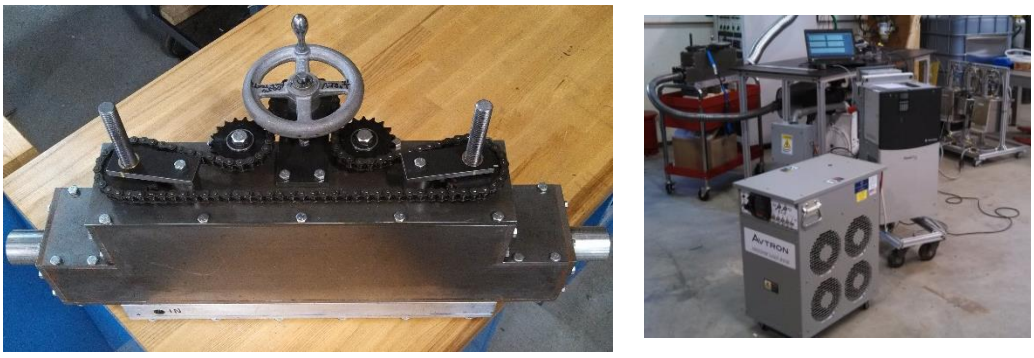

Figure 4.1: TEG Apparatus Installation and Dynamometer system

A Fortran model to compare predicted outputs of functionally graded thermoelectric materials has been completed and some initial modeling has been completed based on blends of the following thermoelectric materials: Bismuth Telluride, Lead Telluride, and Silicon Germanium. The code uses a sigmoidal function for each of the material characteristics that control thermoelectric output to predict the electrical output and efficiency of the material if the thermoelectric element is functionally graded. Combinations of the three materials were used to study which combinations and of which concentrations may be the most beneficial. The sigmoidal function basically shows, as seen in Figure 4.2, the volume fraction the blending material until it finally becomes the blending material itself. Figures 4.2 and 4.3 show the volume fraction and the influence of blending on thermoelectric efficiency, respectively, of Silicon Germanium as it is blended into Lead Telluride. As can be seen in Figure 4.3, the thermoelectric efficiency of Silicon Germanium can be increased making it a functionally graded material using Lead Telluride.

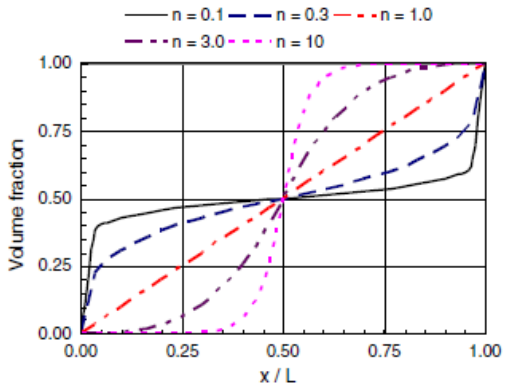

Figure 4.2: Volume fraction of Silicon Germanium in a Lead Telluride/Silicon Germanium Blend

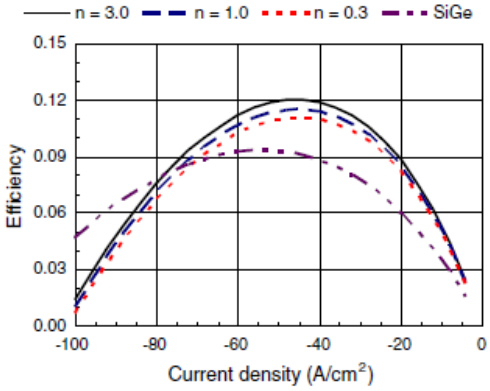

Figure 4.3: Efficiency of Functionally graded material compared to pure Silicon Germanium

Project 5: Marine Engine Continuous Emissions Monitoring System

The summarized accomplishments for the reporting period are:

- All primary emissions equipment ordered and delivered
- Preliminary diesel engine gaseous emissions test completed with Fourier Transform Infrared Spectrometer (FTIR)
- Condensation Particle Counter (CPC) and integrated systems installed with LabVIEW control and monitoring program finalized

All primary emissions measurement equipment has been ordered and delivered. As such, the fully automated continuous emissions monitoring system is well into the development and build stage. Progress on the two components of the continuous emissions monitoring system is outlined below.

Soot Measurement System

A Condensation Particle Counter (CPC) was sourced to measure total soot particle concentrations from diesel engine exhaust. Mounting of the CPC, switching valves, and soot sampling subsystem in a storage container is complete. The soot measurement system is shown in Fig. 5.1. Inlet and outlet sample lines are easily connected to the exterior of the container. The fully automated LabVIEW control and monitoring system for the CPC and subsystems is complete and shown in Fig. 5.2. Samples from two engines can be selected and soot concentrations calculated in real time. Several projects are underway to complete the system including installation of a CPC gimbal for stabilization at sea, software integration with all other emissions measurement systems, and finalized control wiring.

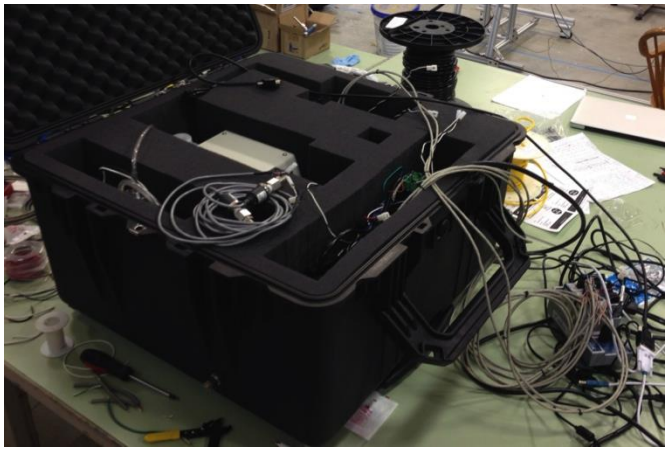

Figure 5.1: Mounted and plumbed soot sampling system.

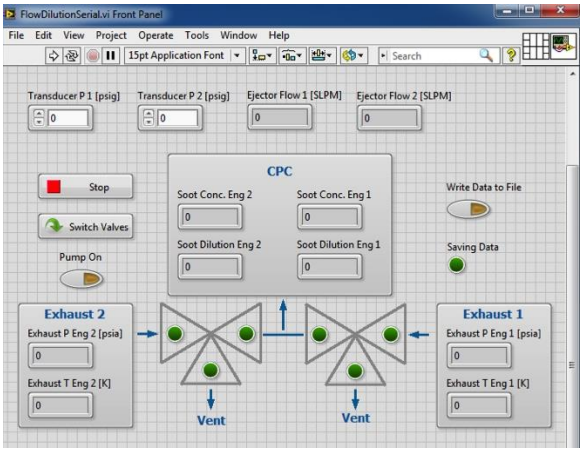

Figure 5.2: Soot sampling control system.

Gaseous Emissions Measurement System

A Fourier Transform Infrared Spectrometer (FTIR) was obtained to measure gaseous diesel engine emissions concentrations. All gas handling equipment and control systems were sourced and final installation is in process. A preliminary diesel exhaust emission test of the FTIR was completed as shown

in Fig. 5.3. Full exhaust emission absorption spectrums and resulting chemical species concentrations were recorded at one-second intervals during engine warm up. Fig. 5.4 shows a full absorption spectrum snapshot to the left and a time resolved plot of CO, NO, and NO2 during engine warm up. Distinct temporal changes in species concentrations are noticeable during the trial due to the non-equilibrium operating condition. Future work will serve to finalize the system and integrate the resulting FTIR data into the planned LabVIEW based continuous emissions monitoring and data logging control software.

Figure 5.3: FTIR system and gaseous emissions test during engine warm up.

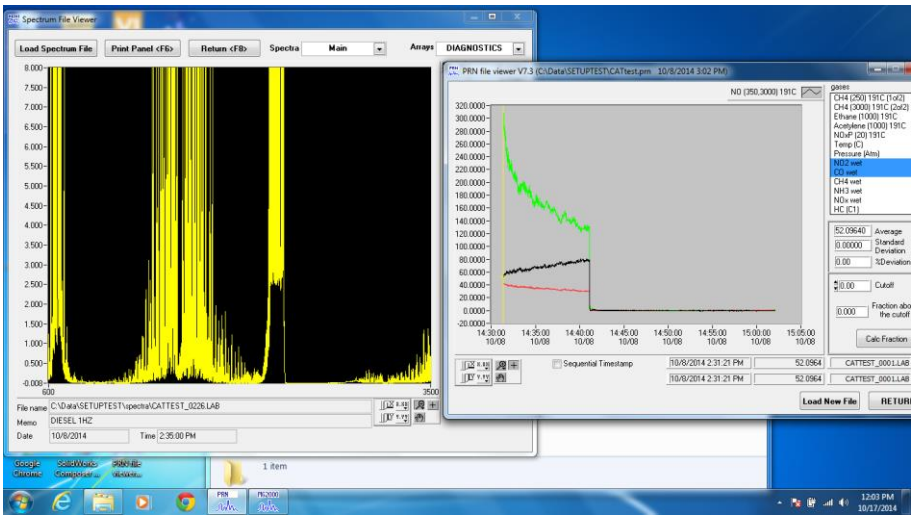

Figure 5.4: Diesel engine gaseous emission infrared spectrum snapshot and time resolved CO, NO, and NO2 concentration plot during engine warm up.

Project 6: Algae based glycerin fuel project

Summarized accomplishments:

- Initial culturing experiments involving *Dunaliella tertiolecta* completed
- Analytical tools for monitoring glycerol production identified
- Grant proposal submitted with industrial partner

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]

Chlamydomonas reinhardtii, a freshwater microalgae species, and *Dunaliella tertiolecta*, a saltwater microalgae species, have been shown to produce glycerol extracellularly from fixed atmospheric CO_2.[ii] The leakage of glycerol across the cell membrane allows for the extraction of glycerol from the culture medium, without killing the algae. This is demonstrated on the small scale in Figure 6.1 for *Dunaliella tertiolecta*. Once separated, the glycerol-containing medium can be decanted off and replenished with fresh media.

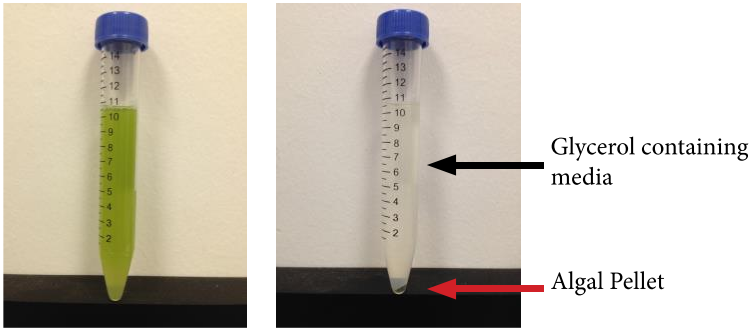

Figure 6.1. Test tube of mature culture of *Dunaliella Tertiolecta* in UTEX media before and after centrifugation.

Once refreshed with new media the remaining algae continue to grow in the new media and produce glycerol.[iii] How the separation affects the rate of glycerol production is still under investigation, but assuming glycerol production is proportional to cell concentration this is a very positive result. It means that the targeted molecules can be separated from the algae by simple physical processes like centrifugation or membrane microfiltration and without a large expenditure of energy.[iv]

Initial experiments have focused on manipulating the algal chemical environment to realize maximum glycerol production at minimum cost. Two hundred milliliters of 4 different solutions (UTEX, Provasoli's Modified Seawater, Duna Base and sterilized Penobscot Bay seawater) were inoculated with algae from 20ml of stock algae solution that had been chilled and centrifuged to remove the stock culture medium. Cultures were put in a sterile 500ml Erlenmeyer flask, covered with a gas permeable lid and placed under a grow lamp. Initially we have focused on media that did not contain significant fertilizing additives. A 17hr/7hr light/dark cycle at $160\ \frac{W}{m^2}$ illumination was maintained throughout the experiment. From the outset it was clear from qualitative observation that certain media (Provasoli's and PB Seawater) did not promote healthy culture growth. This was supported by measurements of algal cell concentrations, shown in Figure 6.2.

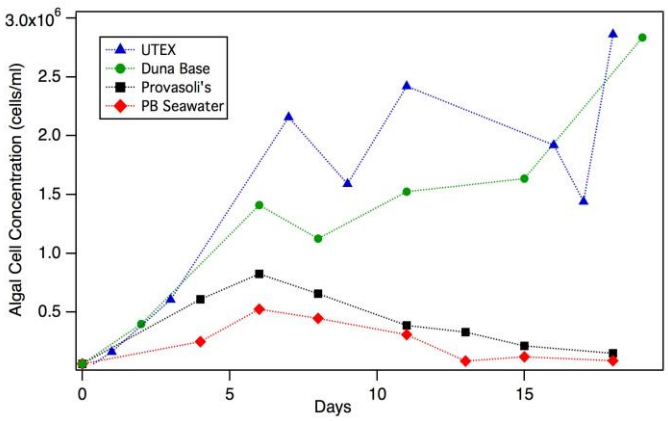

Figure 6.2. Hemocytometry measurements of algal cell concentrations in three standard microalgae cultures and sterilized Penobscot Bay Seawater.

Duna Base and UTEX medium proved to be significantly better than any of our other formulations. Interestingly Duna Base also proved to be chemically very simple. The lack of an active CO_2 source (besides atmospheric diffusion) and the presence of sodium bicarbonate ($NaHCO_3$, baking soda) in Duna Base targeted Duna for a second round of experiments. Figure 6.3 compares Duna Base with and without $NaHCO_3$. The results speak for themselves. Algae populations in the media without $NaHCO_3$ never took off. Experiments tweaking media formulations continue.

Unfortunately, little information was gleaned from these experiments in terms of the relationship between algal cell population and glycerol concentration. Based on our reading of the literature and due to instrumental constraints glycerol was quantified using a published chemical spectroscopic assay.[v] A calibration curve was reproduced from the paper and the assay initially seemed to produce reasonable results, however about a month into experiments it was clear that glycerol measurements were not correct. An assay of the media, including UTEX and Duna Base, indicated significant glycerol concentrations confirming the suspected lack of assay specificity. Future measurements of glycerol concentration will be carried out using Gas Chromatography Mass Spectrometry (GCMS).

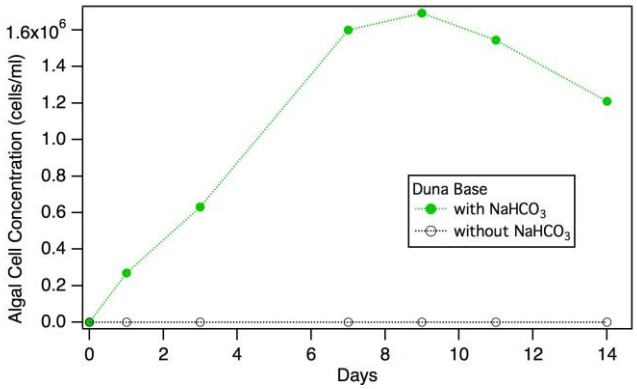

Figure 6.3. Graph plotting algal cell concentration versus time for Duna Base media with and without sodium bicarbonate (Baking Soda)

Since GCMS is not a practical for method for in situ glycerol measurements, some of our initial efforts have been directed towards identifying whether simple measurements of physical properties like viscosity and index of refraction could be correlated with glycerol concentration in spite of other changes that may be occurring in solution.

The experiment was carried out with the intent of generating experimental plots of viscosity and refractive index of extracellular solution versus glycerol concentration. Cells were first separated from the growth media by centrifugation. Viscosity of the resulting solution was then recorded manually using a Zahn cup (#1) and measuring the solution's efflux time. Refractive index was measured using a digital refractometer (Sper Scientific). Because of the difficulties in measuring glycerol concentration an experimental plots of refractive index and viscosity as a function of extracellular glycerol were not generated. Calibration plots of viscosity and refractive index over the range of extracellular glycerol concentrations reported in the literature, however, suggest that it is possible (Figure 6.4).

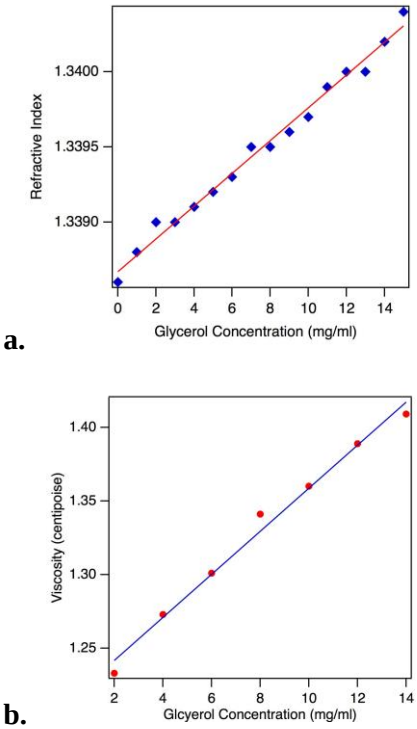

Figure 6.4. Plot of **a.** refractive index and **b.** of seawater media as a function of glycerol concentration.

METEL also collaborated on a grant proposal with Fluid Imaging Technologies (FIT), a company based Scarborough, ME. Fluid Imaging Technologies digital imaging instruments (FlowCam) and software are capable of measuring algal cell concentration and quantifying individual cell properties like cell morphology (size and shape). The grant proposes to determine whether cell size and morphology data can be correlated with concentration of extracellular glycerol concentration. A correlation would result in the writing of a larger collaborative grant between METEL and FIT for the development of FIT's planned in-situ instrument, FlowCam ES.

Education, Workforce development and STEM accomplishments

The accomplishments in this area are summarized as:

- (2) STEM events funded/attended
- Glycerine from Algae STEM effort initiated

STEM Events: METEL is committed to exposing students of all ages and particularly high school students to our research through participation in numerous events and outreach activities. Under the leadership of Professor Paul Wlodkowski, the STEM coordinator at MMA, METEL has participated in two major events in cooperation with MMA's engineering department. METEL has provided displays and hands-on activities at these events, along with lab personnel to explain our research and answer general questions about the science and engineering behind our projects.

The first such activity was the Engineering Expo held in Bangor on March 22, 2014 as part of Maine Engineer's Week. The event attracted between 2000 and 2500 members of the general public with a large number of middle school and high school students attending. METEL contributed a strong presence to the MMA booths, with a number of lab personnel engaged with the public at the booth and both hands-on and active displays of METEL projects to augment the MMA display. Hundreds of students stopped by the booth to interact with both the displays and METEL engineers.

The second activity was The Maine State Math Meet held in Bangor, Maine on April 8, 2014. Over 900 of the state's top mathletes get together to compete for state titles, with the winning teams going on to the regional competition. METEL set up a booth with information and static displays and had engineers on hand to talk to students during breaks and at lunch, as well provide information and outreach to parents and teacher in attendance.

Algae Based Glycerine Fuel STEM Project

Work continues on the development of an Algae based Glycerin fuel STEM project with planning to implement middle school teacher training program as part of MMA's summer STEM teacher workshops which will occur every summer in Castine Maine.

Figure 10: Algae Biofuel reactor and Algae culture

The project, though simple, touches on many important STEM areas and contemporary issues. The system promotes careful laboratory study techniques, requires the use of dimensional analysis to scale up the number to a real farm size, connects biological science with engineering, acts as a conduit to studying global warming using data and analysis as well as

studying global energy security. The projects intent is to motivate students that by being good scientists and engineers they can solve major real world issues and make a difference to the planet.

Significant Results: None to report at this time

Key Outcomes: None to report at this time

How have the results been disseminated?

Results for this reporting period have resulted in two journal papers in the UMaine effort on TDO/ FasPyrolosis oils. Other projects are still developing test hardware, and conference papers are committed for the next reporting period.

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
- Blending Sonolator and blending skid system placed, completed and operational
- Production of pilot quantities of fuel using the aforementioned 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
- Production samples of FAsPyrolysis fuel
- Fuel properties characterization of FAsP and TDO/diesel blends.
- Presentation of student research results at the Annual Meeting of the American Institute of Chemical Engineers in Atlanta Georgia.

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 at MMA

2. PRODUCTS: What has the program produced?

Publications, conference papers, and presentations

Journal publications: Nothing to Report

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

Other publications, conference papers and presentations: Nothing to Report

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:

- Four Cylinder Diesel Engine Test Stand
  Used for fuel testing and characterization of marine diesel fuels
- Thermoelectric Exhaust Heat Recovery research test apparatus.
  Specialized apparatus to provide basic data for designing TEG Systems
- MKS FTR Emissions measurement system and Bectel CPC for laboratory grade emissions measurements of various emissions gases and particulate matter.

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	Dr. Darrell Donahue
Program/Project Role	Co-P.I. Administrative Director
# Hours worked during reporting period	1 month
Contribution to Program/Project	METEL Administrative Director Contracts and sponsored programs activities
Funding support	MMA internal
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	Prof. Laurie Flood
Program/Project Role	Researcher/ Faculty
# Hours worked during reporting period	0.2 months
Contribution to Program/Project	STEM and Environmental Curriculum Development
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	1.5 month
Contribution to Program/Project	Lead P.I. for UMaine effort; Leading the TDO/FAsP project at UMaine
Funding support	1 month (DOT), 0.5 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	1.0 month
Contribution to Program/Project	Co- P.I. for UMaine effort; Co-supervising graduate student research.
Funding support	0.5 month (DOT) 0.5 month (UMaine)
Collaborated with individual in foreign country	No

Name	Dr. Paul Wlodkowski
Program/Project Role	STEM Coordinator/Faculty
# Hours worked during reporting period	0.25 Months
Contribution to Program/Project	Leading STEM efforts for program
Funding support	MMA Internal
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	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	Jessica Menges
Program/Project Role	Undergraduate researcher
# Hours worked during reporting period	400 hrs
Contribution to Program/Project	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	Mathew Mercier
Program/Project Role	Undergraduate Researcher
# Hours worked during reporting period	400 hrs
Contribution to Program/Project	Website Development and engineering assistance.
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

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 a Four Cylinder diesel engine stand is a new physical resource which will impact both research capabilities as well as engineering training in the thermodynamics lab sequence as well as the environmental compliance course at MMA. Also the basic instrumentation of the R/V Quickwater vessel has been completed and initial data collected.

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

[i] 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*.

[ii] Y. Chow, S. Goh, Z. Su, D. Ng, C. Lim, N. Lim, H. Lin, L. Fang b, Y. K. Lee, "Continual production of glycerol from carbon dioxide by Dunaliella tertiolecta" Bioresource Technol. vol. 136. pp. 550–555. *2013*.

[iii] Unpublished Results.

[iv] B. Petrusevski, G. Bolier, A.N. Van Breemen, G. J. Alaerts, "Tangential flow filtration: a method to concentrate freshwater algae." *Water Research*. vol. 29(5).pp.1419–24. *1995.*

[v] P. Bondioli and L. Della Bella, "An alternative spectrophotometric method for the determination of free glycerol in biodiesel" *Eur. J Lipid Sci. Tech. vol. 107, p.153-157, 2005.*