Final Scientific/Technical Report

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1. **Identify the DOE award number; name of recipient; project title; name of project director/principal investigator; and consortium/teaming members.**

Award Number: DE-FG36-05GO85005
Recipient: NextEnergy
Project Title: National Biofuel Energy Laboratory
Subcontractors: Delphi Automotive Systems, LLC and Wayne State University
Cost-Sharing Partners: Art Van Furniture; Biodiesel Industries Inc.; Bosch; Clean Emission Fluids; Delphi; Oakland University; U.S. TARDEC (Army); Wayne State University

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3. **Provide an executive summary, which includes a discussion of 1) how the research adds to the understanding of the area investigated; 2) the technical effectiveness and economic feasibility of the methods or techniques investigated or demonstrated; or 3) how the project is otherwise of benefit to the public. The discussion should be a minimum of one paragraph and written in terms understandable by an educated layman.**

The National Biofuel Energy Laboratory or NBEL was a consortia consisting of non-profits, universities, industry, and OEM's. NextEnergy Center (NEC) in Detroit, Michigan was the prime with Wayne State University as the primary subcontractor. Other partners included: Art Van Furniture; Biodiesel Industries Inc. (BDI); Bosch; Clean Emission Fluids (CEF); Delphi; Oakland University; U.S. TARDEC (The Army); and later Cummins Bridgeway.

NBEL's objectives included:

- Establishing a sound technical basis for biofuels that will assist in setting ASTM specifications for 20% biodiesel fuel blend.
- Gaining a comprehensive understanding of composition-property-performance relationships for biofuels.
- Helping develop the next-generation of biodiesel with acceptable performance, cold flow and stability properties.

The program was awarded to NextEnergy by U.S. DOE-NREL on July 1, 2005, and work commenced approximately one year later, after all of the subcontracts were set and signed. The period of performance was about five (5) years, ending June 30, 2010. This program was executed in two phases:

1. Phase I focused on bench-scale R&D and performance-property-relationships.
2. Phase II expanded those efforts into further engine testing, emissions testing, and on-road fleet testing of biodiesel using additional types of feedstock (i.e., corn, and choice white grease based).

NextEnergy – a non-profit 501(c)(3) organization based in Detroit and dedicated to advancing alternative and renewable energy technologies in the nation – was originally awarded a $1.9 million grant from the U.S. Dept. of Energy for Phase I of the NBEL program. A few years later, NextEnergy and its partners received an additional $1.9MM in DOE funding to complete Phase II. The partners on this program collectively provided $0.5M in cost share per phase. The NBEL funding was completely exhausted by the program end date of June 30, 2010 and the cost share commitment of 20% minimum has been exceeded nearly two times over.

As a result of the work performed by the NBEL consortia, the following successes were realized:

1. Over one hundred publications and presentations have been delivered by the NBEL consortia, including but not limited to: R&D efforts on algae-based biodiesel, novel heterogeneous catalysis, biodiesel properties from a vast array of feedstock blends, cold flow properties, engine testing results (several Society of Automotive Engineers [SAE] papers have been published on this research), emissions testing results, and market quality survey results.
2. One new spinoff company (NextCAT) was formed by two WSU Chemical Engineering professors and another co-founder, based on a novel heterogeneous catalyst that may be retrofitted into idled biodiesel manufacturing facilities to restart production at a greatly reduced cost.
3. Three patents have been filed by WSU and granted based on the NextCAT focus.
4. The next-generation advanced biodiesel dispensing unit (CEF F.A.S.T. unit version 2) was developed by Clean Emission Fluids (CEF).

5. NBEL aided in the preparing a sound technical basis for setting an ASTM B20 standard: ASTM Standard D7467-08 was passed in June of 2008 and officially published on October of 2008.
6. NBEL has helped to understand composition-property-performance relationships, from not only a laboratory and field testing scale, for biodiesel blends from a spectrum of feedstocks.
7. NBEL helped propel the development of biodiesel with improved performance, cetane numbers, cold flow properties, and oxidative stability.
8. Data for over 30,000 miles has been logged for the fleet testing that select members of the consortia participated in. There were five vehicles that participated in the fleet testing. Art Van provided two vehicles, one that remained idle for most of the time and one that was used often for commercial furniture deliveries, Oakland University provided one vehicle, NEC provided one vehicle, and The Night Move provided one vehicle. These vehicles were light to medium duty (2.0 to 6.6 L displacement), used B5 or B20 blends from multiple sources of feedstock (corn-, choice white grease-, and soybean-based blends) and sources (NextDiesel, BDI, or Wacker Oil), experienced a broad range in ambient temperatures (from -9 °F in Michigan winters to 93 °F in the summertime), and both city and highway driving conditions.

The program was not without its challenges, however. More specifically, the following major challenges beset the program:

1. The Biodiesel Industries (BDI) facility that had an initial groundbreaking in 2006 in Detroit (a few blocks away from NextEnergy) and was planned to open in 2007 did not materialize. BDI and other biodiesel manufacturing facilities were continually plagued with financial hardships faced by increasing prices in feedstock, stigmas with cold flow properties in the metro Detroit region, and the hardships also faced by the local economy and especially automotive industry.
2. On a similar note, another biodiesel manufacturing company, NextDiesel, dissolved in 2009.
3. As a result of the fleet testing, there were no issues recorded, except for one major issue. One of the Art Van vehicles that used biodiesel experienced complete engine failure after the fleet testing was complete. Art Van claims that it was the use of the biodiesel that caused this incident, while the NBEL consortia has requested proof which Art Van has not been able to deliver and believes that it was likely that the engine was on its last leg and would have failed, regardless of the fuel used. None of the other vehicles experienced any major issues like this one. All three other vehicles operated perfectly fine during and after the biodiesel fleet testing.
4. Partly because there were so many members of the consortia, and so many layers to the program, several no-cost extensions were requested by NEC and granted by the DOE to ensure that the program was on-track and ample time allowed for comprehensive completion.

The NBEL consortia would also like to pursue opportunities to expand this foundation for the U.S. DOE with a new focus on algae, jatropha-based feedstock and other types of biofuels R&D efforts on both a laboratory and field testing scale. The laboratory equipment at both the NBEL lab on-site at NextEnergy, the CAR lab at WSU, the CEF F.A.S.T. biodiesel dispensing unit on NEC's Alternative Fuels Platform, and the emissions analyzer are all available for continued R&D on biofuels. These may include not only biodiesel, but also ethanol, biobutanol, or any type of liquid biofuel in which there is a vested interest by DOE and the consortia.

4. **Provide a comparison of the actual accomplishments with the goals and objectives of the project. Where applicable, address any comparisons of actual results to programmatic technical barriers and milestones.**

There were 5 major objectives/projects (with sub-tasks embedded within each) to accomplish the NextEnergy NBELs Program. The following is a narrative of the original objectives:

Project 1 – Production of Custom Biodiesel Blends: Tasks –

- To develop methods for the manufacture of biodiesel fuels (initially fatty acid alkyl esters) of varied but precisely controlled composition, including single-component fatty acid esters, and to blend these with a standardized low-sulfur, low-aromatics diesel fuel to be used for test purposes. The "Core Team" of NextEnergy Center (NEC), Wayne State University (WSU), Delphi, Biodiesel Industries (BDI), US DoD, Robert Bosch Corporation (Bosch) and DaimlerChrysler Corporation (DCC) are working partners from both industry and academia to execute the program.
- The team will meet and decide what biofuel blends will be required and what lab equipment will be needed to test the various blends. A new lab will be constructed at NEC to study the various fuel properties. Various biodiesel stocks will be procured by WSU, NEC and BDI.
- As soon as practical, the new Ultra Low Sulfur Diesel (ULSD) fuel with also be obtained to test its properties as a B-20 biodiesel fuel.
- The fuels made or obtained will be tested by WSU in both their on campus and NEC labs.

Project 2 – Biofuel Blends: Lubricity and Degeneration: Tasks-

- WSU and NEC will obtain specialized lab equipment (such as high frequency reciprocal rig and a cylinder scuffing analyzer required.
- The biodiesel fuels needed for the lubricity and scuffing tests will be selected by the Core Team.
- Using the fuels selected, WSU will begin to analyze various blends for their lubricity degeneration characteristics.
- Several additives will be added to improve the lubricity and degeneration and additional tests will be performed by WSU.
- Based on the results, recommendations for fuel additives to improve lubricity will be made.

Project 3 – Biofuel Oxidative Study: Tasks –

- A Rancimatt instrument to measure oxidative characteristics will be required for this project. It will be obtained by WSU and put into the WSU/NEC lab.
- The fuels to be tested will be chosen by the Core Team.
- WSU will evaluate and document these fuels in bench tests for such parameters as cetane number, oxidative and hydrolytic stability in storage and

lubricity prior to selecting the best candidates for use in engine tests. For the most part, existing standardized test procedures will be used.

- Stabilizing additives will be evaluated for various biofuel blends.
- Recommendations will be made by the Core Team for degradation-resistant fuel formulations based upon the test results.

Project 4 – Engine Emissions, Impact on Aftertreatment Systems: Tasks –

- A: To evaluate the impact of such fuels on the effectiveness and long-term performance of exhaust aftertreatment systems such as diesel exhaust particulate traps and NO_x reduction systems. Engine emissions (regulated emission constituents) testing will be performed. Various biofuels/blends will be selected. The effect of these fuels on emissions performance will be evaluated.
- B: Engine emission testing for non-regulated constituents will be performed to evaluate the engine design and operating variables and the respective engine-out emissions profile.
- C: At the same time, various different aftertreatment systems will be supplied for evaluation of their performance.

Project 5 – Develop Database for Final Biofuel Blends: Tasks –

- To develop a database of information on biofuels for use by NEC, its research partners and perhaps others. The database will also provide the foundation for NextEnergy's participation in the process of setting industry standards for biodiesel fuels through, for example, ASTM. Computer systems and type of database desired will be determined by the Core Team.
- The fuels and their respective data will be selected for inclusion into the Teams database.
- Other information required by the Team will be identified and entered into the database.
- WSU will build the database to be shared by all partners.

More details on the status of each task and subtask is provided in Table 1 below, including accomplishments and barriers.

Table 1. **NBEL Tasks/Subtasks, Accomplishments, and Technical Barriers Matrix.**

Task / Subtask Number	Task/Subtask Milestone or Go / No Go Decision Point	Actual Accomplishment(s)	Technical Barrier(s)
A.0	Production of custom biodiesel/blends: Select, Acquire & Install Equipment.	Equipment was selected and installed in Detroit on-site at NextEnergy Center (NEC), Laboratory #2 of 8 labs, and at the Wayne State University (WSU) College of Engineering. WSU Chemical Engineering professors, graduate students, and industry partners (Delphi, Bosch, etc.) provided their technical expertise with respect to the operation of single and multiple cylinder engine testing. Testing included: cold flow testing, gas chromatography / mass spectroscopy, cetane number, oxidative stability, and other analytical tests.	None.
A.1.ML.1	Develop Fuel Blending Stocks.	By Jan. 1, 2007, the lab at NEC was fully operational and fuel blending stocks were developed on lab scale.	None.
A.2	Produce B-20 Blends with ULSD Fuel.	B20 blends were produced on both a laboratory and field-testing scale (using a biodiesel dispensing unit provided by Clean Emission Fluids, which is heated and blends on the spot). The ULSD fuel used was provided by RKA Petroleum; and three types of B100 were provided: NextDiesel provided corn-oil-based and choice white grease-based B100. BioDiesel Industries provided soybean-based B100. Later on, after NextDiesel and BDI succumbed to high feedstock prices that were inconsistent with demand, soybean-based B99 from Wacker Oil was used and blended to B20 in the CEF unit for fleet testing. On a lab-scale, WSU was able to produce algae-based biodiesel in limited yield (not enough for field testing).	Several biodiesel manufacturers (including Biodiesel Industries and NextDiesel) were unable to provide biodiesel toward the end of the program due to challenging economic and market conditions.
A.3.DL.1	Use Custom Fuels & Blends in Engine, Other Tests (e.g., Projects 5A-5B).	Numerous test results have been produced and published (too many to go into detail here) and a monthly working committee was established to review the results. These results were then discussed with the Core Team at regular bimonthly meetings. See the Publications/Presentations listing.	None.
B.0	Biofuels: blends - lubricity and degeneration: Select, acquire and install equipment.	Results were presented on lab scale and single cylinder engine testing. In ongoing research, the cetane improver components of oxidized biodiesel were separated, and their structures were elucidated. Initial laboratory testing confirmed that these newly discovered chemical compounds show superior cetane improver and lubricity properties than conventional nitrate based cetane improvers. Further experiments are underway to prove that these biocetane improves has potential market in current diesel additive industry.	None.
B.1.GN.1	Select matrix of biofuels and biofuel blends.	This was completed as planned.	None.

B.2	HFRR or other tests -Low sulfur fuels and blends.	Several accomplishments were made in this area: • HFRR and other tests on low sulfur fuels and blends were conducted. • The comparison of different methods of cetane measurement for fuels such as biodiesel blends, ultra low sulfur diesel (ULSD), synthetic jet fuel (S-8) and military jet fuel (JP-8) were continued to be investigated.	None.
B.3	Effectiveness of biodiesel components/Blends as additives.	• Evaluated fuel additives for cold flow, oxidative stability, and other impacts. • The formation of insolubles in biodiesel blends was shown to potentially have serious implications for diesel engine fuel delivery systems, such as filter plugging, and deposits on injectors and other critical fuel system components. The amount of insolubles is usually measured according to ASTM D2274 or D4625, subjecting the sample to high temperature and/or oxidation treatment. NBEL reported findings on insoluble formation after low temperature storage of biodiesel blends. A series of samples: B0, B2, B5, B10, B20, B50, B70, and B100 were subjected to low temperature storage at either 4 or -15°C for 20 hours. The time to filter and precipitate mass were then measured after the samples returned to ambient temperature. At 4°C, which is substantially higher than the cloud point of biodiesel blends, longer filtration times and more insolubles were measured when B20 compared to B100. This observation was attributed to the non-polar nature of ULSD fuel. For B20 and B100, the filtration time and amount of insolubles formed at 4°C were investigated as a function of storage time. There was a gradual increase in precipitate mass from 1 to 8 hours for the B20; while for B100, significant increase was only observed after 3 days. • The correlations of insoluble formation to the cloud point, pour point, and cold flow plugging point were discussed. • The findings were consistent with reports that oxidative stability degradation is more pronounced in B20 than in neat soy-based biodiesel.	Fuel additive suppliers such as Infineum and Monsanto were unable to provide samples, due to proprietary limitations. Also, some equipment was unavailable (such as x-ray diffraction equipment) that would have helped analyze cold flow additive experimental results on a microscopic scale.
B.4.DL.1	Effects of biodiesel blends on lubricant functionality & performance.	Reported on the results of report on the results of lubricity/degeneration testing.	None.

C.0.ML.1	Biofuels: Oxidative Stability - Select, acquire and install equipment.	A by Rancimat® apparatus was procured and installed in NEC's lab #2 (the NBEL lab). The induction period of biodiesel was determined by Rancimat® according to EN 14214.	None.
C.1.GN.1	Select matrix of biofuels and biofuel blends.	A matrix was developed and used, including soy oil, cottonseed oil and poultry fat based biodiesel blended with ultra-low sulfur diesel (ULSD) to B20, with eight group IV transition metals: Zn, Cu, Ni, Co, Fe, Cr, Mn, and V, investigated at various concentrations (from 0.02 – 100 ppm).	None.
C.2	Resistance of selected fuels/blends to oxidation, hydrolysis, etc.	• NBEL reported the effects of Group IV transition metals on the oxidative stability of various biodiesel blends, including soy oil, cottonseed oil and poultry fat. Biodiesel is often blended with ultra-low sulfur diesel (ULSD), which may contain the transition metals (see C.1.GN.1). Although there were considerable differences in catalytic activity, these metals all reduced the induction period of B100 and B20. The effect of antioxidants and chelating agents to counteract the metal effects were discussed in the literature and presentations. • Engine tests were conducted in the CAR lab with B-20 at swirl ratios of 1.44, 3.77 and 7.12 at IMEP higher than previously run IMEP of 3 bar. Evaluated the effect of Swirl on autoigintion, combustion and engine out emissions for JP-8 fuel.Introduced ECU controlled common rail fuel injection system in existing bulk modulus test rig. • NBEL also evaluated effect of bulk modulus of a fuel on injection timing in an electronically operated high pressure fuel injection systems.	None.
C.3	Evaluate the effect of stabilizing additives.	• Conducted dynamometer testing to review the resistance of selected fuels to oxidation. Several papers written by Dr. Henein's Center for Automotive Research (CAR) engine group at Wayne State University in collaboration with industry partners were accepted by SAE for publication (see previous quarterly report under "Publications").	None.
C.4.DL.1	Develop recommendations for degradation-resistant fuel formulations.	It was found that, the oxidative stability of untreated soybean-based biodiesel significantly decreases as a function of time, while the addition of the antioxidant TBHQ can improve and maintain oxidative stability up to 36 months. Moreover, metallic contaminants in the ppm level were proven to be detrimental factors of the oxidative stability of biodiesel. The greatest level of instability was brought by Cu contamination, as low as 1 ppm can decrease the oxidative stability by around 60%. To address metallic contamination, Citric acid metal chelator was found to counteract	None.

		the effect of the contaminants at a comparable loading.	
D.1.0.ML.1	Biofuels: Regulated emissions - Augment existing equipment at WSU.	The WSU Center for Automotive Research (CAR) lab purchased and installed a new Bosch smoke meter last quarter and began operating it in the 2nd fiscal quarter of 2008.	None.
D.1.1.GN.1	Select matrix of biofuels and biofuel blends.	This was completed as planned.	None.
D.1.2	Database of regulated emissions performance for selected biofuels.	• Developed the database of regulated emissions performance for selected biofuels.	None.
D.1.3	Effect of engine design and operating variables on emissions.	• Evaluated engine design and operating parameters. • Completed the base-line tests on ULSD (B0) to determine the effect of injection pressure, EGR, and swirl ratio on auto ignition, combustion, fuel economy, and engine-out regulated emissions. • Completed tests on B20 and compared between the auto ignition, combustion, fuel economy and engine-out emissions with B0. • Reviewed literature to find out the reason(s) behind the discrepancy on the effect of biodiesel on NOx emissions. Delphi (Art Quader & Mike Wu) completed a joint paper entitled “Effect of Biodiesel (B-20) on Performance and Emissions in a Single Cylinder HSDI Diesel Engine” with Dr. Henein and Vinay Nagaraju of WSU, approved for presentation and publication in SAE 2008 World Congress. Delphi contributions to the SAE paper are (1) carried out a statistical design of engine test matrix, (2) actively participated in engine tests and advised students of WSU, (3) performed a statistical analysis of the data, (4) reported the results in the SAE paper. • See also D.2.3 below for sample results.	None.
D.2.0.ML.1	Biofuels: Non-regulated emissions - Augment existing equipment at WSU.	By Spring/Summer of 2008, all necessary equipment was installed and working properly in the CAR lab.	None.
D.2.1.GN.4	Select matrix of biofuels and biofuel blends.	This was completed as planned.	None.
D.2.2	Database of non-regulated emissions performance for selected biofuels.	The engine emissions database parameters were previously set. This is complete.	None.
D.2.3	Effect of engine design and operating variables on emissions.	• Conducted a review of potential impact on various engine design parameters based on biofuel blend used. • The main conclusions based on the statistical analysis are summarized in the following points (see SAE 08-PFL225, under Publications/Presentations). • B20 decreased NO_x (4%) relative to B0 contrary to previous studies. Though the effect was small it was significant near the	None.

		95% confidence level. We speculate this to be due to the significant impact of B20 on decreasing the ignition delay. However, an increase in the maximum rate of heat release with B20, as discussed below, could have opposing effects on NO_x emissions. • B20 had no statistically significant effect on smoke and HC emissions. Directionally decreases in smoke and HC (10% lower smoke and 9% lower HC) relative to B0 were noted, which are similar in trend to earlier studies. Higher exhaust temperature observed with B20 than with B0 explains well lower smoke number and HC emissions with B20, as discussed in section IV through section VI. • B20 decreased CO emissions slightly (3%) but this effect was significant at the 95% confidence level. • Fuel consumption increased significantly (7%) with B20 and is higher than expected based on slightly lower heating value (about 2%) relative to B0. • There was no significant difference in start of injection between B20 and B0. • B20 fuel has a 29% lower ignition delay than B0. The shorter ignition delay with B20 will result in less time for vaporization and therefore less premixed burning that could result in lower NO_x emissions in the initial combustion phase with B20 relative to B0. This could be a factor contributing to lower NO_x emissions with B20 noted above. The two-factor interaction between fuel and EGR shows that at 60% EGR the B0 fuel increases the ignition delay much more than the B20 fuel. This could be due to rapid degradation of combustion with B0 at 60% EGR. The implication is that B20 has better EGR tolerance. • The maximum rate of heat release (RHR Max) for B20 was 8% higher than that for B0. This implies faster burning of the charge with B20. In general faster burning is associated with higher combustion temperature and should contribute to higher NO_x emissions with B20. The opposing effect of shorter ignition delay and less premixed combustion and lower NO_x suggests that in these tests the factors that contribute to lower NO_x dominate the factors that increase NO_x. The net effect of these opposing effects seems to lead to lower NO_x with B20 in these tests. • The above observations apply to the engine operating conditions for these tests that may be characterized as relatively low speed (1500 rpm), light load	

		(3 bar IMEP), and moderate level of swirl (3.77 swirl number).	
D.3.0.ML.1	Biofuels: Impact on exhaust aftertreatment systems - Augment existing equipment at WSU.	Bosch supplied a Urea Dosing unit.	A manufacturer delay in building a Urea Dosing unit caused a delay in this activity.
D.3.1	Select aftertreatment devices/systems to be evaluated.	After-treatment devices and systems were evaluated accordingly.	None.
D.3.2.GN.1	Select matrix of biofuels and biofuel blends.	This was completed as planned.	None.
D.3.3.GN.2	Effect of fuel selection and engine design on aftertreatment systems.	• Conducted testing on multi-cylinder VM Motori engine, SCR aftertreatment system. • Two focus areas were quantification of impact of B20 on the SCR system and on the DPF system. • In addition, fuel engine oil dilution was initiated during the last quarter of 2007. • Delphi initiated and launched engine oil dilution project during the 4th quarter in 2007. However, continued problems with the engine dyno cell which is maintained and run by WSU prevents any meaningful data taking and progress of the project. • With help from Prof. Ng's team (NBEL), the viscosity of fresh engine oil (0W40) diluted with B1, B2, B5, and B10 were determined at 40 °C, 50 °C, and 60 °C, respectively. The data was used as the base for the engine oil dilution project. • The SCR and Exhaust Speciation Project update (Craig DiMaggio and Mike Wu from Delphi are the project leads): • B20 data was obtained at test point 7 for 0% EGR and 40% EGR . This higher load condition was used to produce an emissions product distribution large enough to analyze and also be representative of a condition where urea aftertreatment could be used to mitigate NOx concentrations. For this study, absolute concentrations of many species cannot be established due to lack of calibration gases, Therefore, the main intent was to compare the emission distribution of the multicylinder engine using B20 and B0. As mentioned, B20 data was obtained. However, several attempts to obtain B0 data were postponed because of engine or dyno failures. The most recent failure resulted in replacement of the engine. When this engine is characterized and operating in a stable fashion, the B0 data will be collected and compared to B20. • Interpretation of the B20 data at test point 7 for 0% and 40%EGR showed that:	• Delphi advised and worked with WSU on selecting various engine operating conditions for the DPF project. However, continued engine dyno problems during the end of 2007 hindered progress of this project. • Delphi proposed a project that piggybacked on the vehicle fleet test initiative of NBEL to understand impact of B20 on oil dilution of engine equipped with modern aftertreatment devices. However, the project was delayed due to unavailability of the selected vehicle (VW Jetta). • For the B20 data at test point 7 for 0% and 40% EGR, other species that were present, but could not be identified because of their high excitation energy include CO and mass signals clustered around m/e's of 95 and 150 were also present, but as yet unidentified.

		• High concentrations of H_2O, CO_2, and O_2 at both 0% and 40% EGR were present. • NO, NO_2, and N_2O was identified, but no NH_3 was observed. • Nitric acid is also observed in small quantities at 0% and 40% EGR (3:1). Suggests a mildly corrosive environment downstream of the combustion process. • Small concentrations of amines such as $CH_3CH_2NH_2$ appeared to be present. Four time more at 0% EGR than 40%EGR. • HCHO (Formaldehyde) and CH_3CHO (Acetaldehyde) were present at 0%EGR and 40%EGR at the same level. • Other oxygenates such as ethanol, 1-propynol, propenal, propanal, and butenal were observed at both EGR settings. • Additional observable HCs include propane, butane, butene, and pentene.	
E.0.ML.1	Develop biofuels and biofuels blends: Acquire computer system and select preferred database	This activity has been completed.	None.
E.1	Select matrix of biofuels and biofuel blends for inclusion into database	This activity has been completed.	None.
E.2	Identify information needs	The database design has been completed at WSU.	None.
E.3.DL.1	Build database	Continued to modify database with the latest R&D results so multiple partners can view and use.	None.
F.1.GN.1	Select matrix of biofuels and biofuel blends for NBEL phase II	This activity has been completed.	None.
G.1	Biofuels: Non-regulated emissions - Order and install all additional equipment required for phase II to augment existing equipment at WSU NBEL lab.	Center for Automotive Research (CAR lab on-site at WSU Engineering) equipment included: • CO, CO_2 analyzer • Cold room update • Combustion analyzer NBEL lab (Lab#2 at NextEnergy) equipment included: • Centrifuge (Sediment, Rotor + Adaptor) • Pensky-Martens Tester for Flash Point (closed cup) • MCRT-160 Micro Carbon Residue Tester • Distillation System & Copper corrosion • Total Sulfur and Furnace (Sulfated Ash) • Karl Fisher titrator for total water (Hydranal Coulimat & Coulometer) • Reactor systems • ICP OES (Cyclonic, Chiller & Auto sampler) • FT IR Microscope (SPECTRUM400)	None.

		• Cold Flow Refrigerator (Freezer General Purpose 74CuFt 20 DIR) • IKA C 2000 calorimeter • Online Composition Analyzer • Mass Flow Controller • ELSD for Composition Analyzer	
H.1.GN.1	Select aftertreatment devices/systems to be used in phase II (non-regulated emissions testing) to be evaluated.	• Diesel Oxidation Catalysts (DOC's), Diesel Particulate Filters (DPF's), and urea-based Selective Cataytic Reduction (SCR) apparatus were placed in series for the testing. • Two emissions test benches were also used: Horiba OBS-2200 and a MKS MultiGas 2030HS, which had a Fourier-transform infrared (FTIR) unit. Both emissions test benches used emissions from ampling lines at 191°C.	None.
I.1.0	Biofuels: Evaluation of quality, performance, and properties	• Installed the FAST (Fluids Affordably Stored) biodiesel storage, heating, blending, and dispensing unit for NBEL II fleet testing on NextEnergy's Alternative Fuels Platform (AFP), and worked with CEF to ensure that the unit was explosion proof, UL-listed, and at the right temperature. NEC and CEF trained all four fleet drivers, and kicked off the NBEL II fleet testing program in Winter of 2008. • The drivers for this project and a breakdown of the fuel used included: two (2) Art Van Furniture Drivers using B20 blended from RKA Petroleum ULSD #2 dyed fuel (B0) and NextDiesel corn-oil-based B100 (provided as a cost-share by NextDiesel) by a solenoid valve in the F.A.S.T. unit. • Jim Leidel, Energy Manager at Oakland University, used his Volkswagen vehicle,m which ran on on B20 blended from NextDiesel choice-white grease (CWG) based B100 blended with the RKA ULSD #2 fuel. • Roland Kibler of NextEnergy, used B5 derived from the RKA ULSD plus soy-based B100 from BioDiesel Industries.	• NextDiesel, one of the biodiesel suppliers to the CEF unit and the NBEL lab at NEC dissolved in 2009, due to financial hardships plaguing the biodiesel industry. • One of the Art Van vehicles that used biodiesel experienced complete engine failure after the fleet testing was complete. Art Van claims that it was the prolonged biodiesel use that caused this incident, while the NBEL consortia requested proof, which Art Van was unable to provide. The consortia believed that it was likely that, the engine was on its last leg and would have failed, regardless of the fuel used. • None of the other vehicles experienced any major issues like this one.
I.1.1	Evaluate effectiveness of biodiesel components/blends as additives to determine the cold flow parameter, O2 and other variables, lubricant functionality & performance	R&D on new algal feedstocks, cold flow parameters, and on novel catalysts for biodiesel synthesis was completed: • The studies of environmental parameters, such as light source, light intensity, CO_2 concentration, and photoperiod on the growth of *Dunaliella tertiolecta* and *Chlorella Minutissima* and fatty acid	None.

		compositions were performed. Red LEDs, white LEDs, and fluorescent lights all were equally effective for algal growth. • Increasing light intensity significantly resulted in more rapid algal growth, while increasing the period of light also significantly increased algal growth. Similar growth rates were observed for 2%, 4%, and 6% CO_2 concentrations. • Moreover, the biodiesel from *Dunaliella tertiolecta* and *Chlorella Minutissima* contains mainly saturated and mono-unsaturated fatty acids ester. Thus, *Dunaliella tertiolecta* and *Chlorella Minutissima* could be considered as a potential organism for biodiesel production. • The development of a novel catalyst for the conversion of brown grease (containing high free fatty acids content) in to biodiesel is under extensive investigation. The high Sulfur levels (700 ppm) in brown grease requires desulfurization methods and Sulfur tolerance transesterification and esterification catalysts. (Initial data obtained using heterogeneous ZrO_2 decreases sulfur level to 50% and has potential application to convert waste brown grease into biodiesel with 78% FAME yield.) • In addition, synthesis method for the CaO supported La_2O_3 catalyst is studied in order to be used in a continuous flow reactor for a long term usage. • The long term durability of the heterogeneous Zn_3La_1 catalysts was continued to be investigated during this report period. The development of S-based catalysts, including the activity and durability test, and catalyst structure characterization and preparation of series of ZnO-containing catalysts, and evaluation of their activity in a batch reactor were also investigated. Research was also done on the effectiveness of biodiesel components/blends as additives to determine the cold flow parameter, O2 and other variables, lubricant functionality & performance; reports will be from WSU.	
I.1.2	Evaluate effectiveness of fuel selection and engine design on aftertreatment systems and engine design and operating variables on emissions	For the tests conducted on the aftertreatment systems, (DOC's, DPF's, and SCR's in series), it was shown that: • Temperature affected NO_X reduction. • B20 had lower de-NO_X efficiency than ULSD at low exhaust temperature. • Longer SCR entrance section improved the SCR performance at low temperature. • N_2O emitted from the SCR is more than NH_3 slip.	None.

		• DOC and catalyzed DPF affected the NO/NO_2 ratio significantly. • NO_2 was more difficult to react with NH_3 than NO, regardless the temperature effect. • DEF was slightly overdosed, while SCR stores more NH_3 at low temperature. • A more powerful battery was recommended with the utilization of the urea-SCR system. • EGR influenced NO_X reduction • Biodiesel affected NO_X emissions levels, but not significantly.	
I.1.3	Evaluate review completed by OEMs for potential engine and equipment design based on required operating parameters	Lab, engine and vehicle results were evaluated and reported to the Core Team on a regular (at least monthly) basis.	None.
I.1.4	Impact on various engine design parameters based on biofuel blends / stabilizing additives used.	The Core Team and WSU evaluated the potential impact on engine design based on data presented.	None.
J.1.DL.1	Develop recommendations for degradation-resistant fuel formulations - fuel blends material make-up is recommended based upon prior results of additives.	Recommendations for degradation-resistant formulations include the following: • A cost-effective processing technique to reduce steryl glucoside (SG) and acylglycerols (impurities) in biodiesel, as well as more effective analytical techniques for their determination and distillation processes on SG removal was developed. Results show that vacuum distillation is the most effective method to remove the SG and acylglycerols content in biodiesel. • The long-term stability for soybean based biodiesel with or without 1000 ppm synthetic/natural antioxidants stored at room temperature for 36 months was performed. Results indicate that the oxidative stability of untreated SBO-based biodiesel significantly decreases as a function of time, while the addition of the antioxidant TBHQ can improve and maintain oxidative stability up to 36 months. • Initial data obtained using heterogeneous ZrO_2 as a catalyst in the biodiesel esterification process decreases sulfur level to 50% and has potential application to convert waste brown grease into biodiesel with 78% FAME yield. • Metallic contaminants were proven to be detrimental factors of the oxidative stability of biodiesel. The greatest level of instability was brought by Cu contamination, as low as 1 ppm can decrease the oxidative stability by around 60%. To address this, citric acid metal	None.

		chelator was found to effectively counteract the contaminants at a comparable loading.	
K.1	Build & complete database.	The database has been built and was populated with new data as available.	None.

5. **Summarize project activities for the entire period of funding, including original hypotheses, approaches used, problems encountered and departure from planned methodology, and an assessment of their impact on the project results. Include, if applicable, facts, figures, analyses, and assumptions used during the life of the project to support the conclusions.**

At the time this project commenced, little was known about the impact of the unavoidable compositional variability of biodiesel (and even conventional diesel) on diesel emissions. The alkyl ester makeup of biodiesel varies very widely world-wide, as does the hydrocarbon makeup of petroleum diesel. Not enough is known about the impact of these variations on fuel characteristics (e.g., cetane number, stability and cold weather performance) and engine performance (e.g., emissions, power output, and cold-weather driveability, wear of fuel system and engine parts). In particular, very little is known of the impact of biodiesel on the production of certain emissions, such as formaldehyde, that are currently not regulated but are expected to be regulated in the future. It is the purpose of this program to help resolve these issues and establish a recommended ASTM revised standard for B-20 diesel fuel that allows OEMs to warrant their products with the use of B-5 to B-20 levels of biodiesel fuels.

The Core Team consisted of: NextEnergy Center (NEC), Wayne State University (WSU), Delphi, Biodiesel Industries (BDI), US DoD, Robert Bosch Corporation (Bosch), and others as described below. These members each brought a unique value to the program, from industrial, academic, and non-profit perspectives. Other partners were added as the Core Team broadened the sphere of interest and as testing was taken from a lab-scale to field testing.

NEC – Acted as prime project manager. This included: lab construction, scheduling meetings for the Core Team, assisting in maintaining a program schedule, producing meeting minutes, communicated items to the Core Team, providing Team direction, assisting in the preparation and reviewing of all report material (both task completion and financial information) prior to submission to the Government. Performed cost-tracking and control. Costs were gathered and reviewed on a monthly basis to support quarterly submissions.

An aerial view of NEC is shown in Figure 1 below, with the NBEL lab (Lab #2 of 8 labs) on-site circled in yellow. Also noteworthy is that, the CEF biodiesel fueling station was (and currently is) located on the Alternative Fuels Platform, across from the lab.

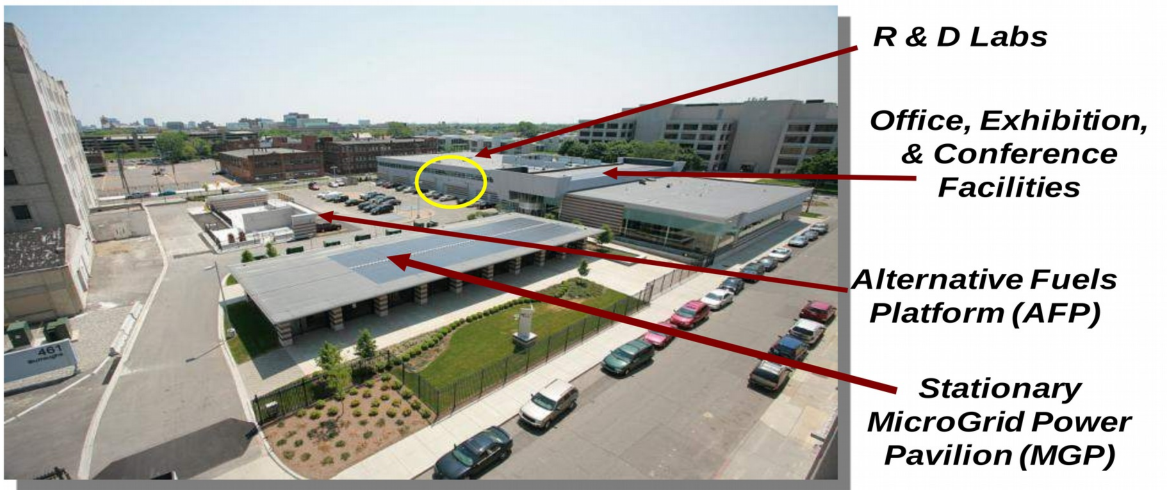

Figure 1. **Aerial view of the NextEnergy Center in Detroit, NBEL Lab highlighted.**

Wayne State University (WSU) – Performed laboratory testing at both NEC and WSU labs and provided their technical expertise in the chemical engineering of biodiesel blends and engineering with respect to the operation of single and multiple cylinder engine testing. Testing included: cold flow testing, gas chromatography / mass spectroscopy, cetane number, oxidative stability, emissions and engine testing, and other analytical tests.

See Figures 2 through 7 below for images taken at both NEC and WSU, as well as Table 2 (below the images) for a listing of NBEL equipment (except in the CAR lab at WSU, which has far less equipment and which equipment was aforementioned).

Figure 2. **NextEnergy Center NBEL Lab (Lab #2), where biodiesel characterization testing and lab-scale blending was performed.**

Figure 3. **Former WSU Dean of Engineering (Dr. Ralph Kummler, right) and Dr. Simon Ng (middle) of NBEL speaking with former President Bill Clinton during his Spring 2007 visit to NEC in Detroit.**

Figure 4. **Images from the Center for Automotive Research (CAR) Lab at WSU Danto Engineering Building, where engine and emissions testing was performed.**

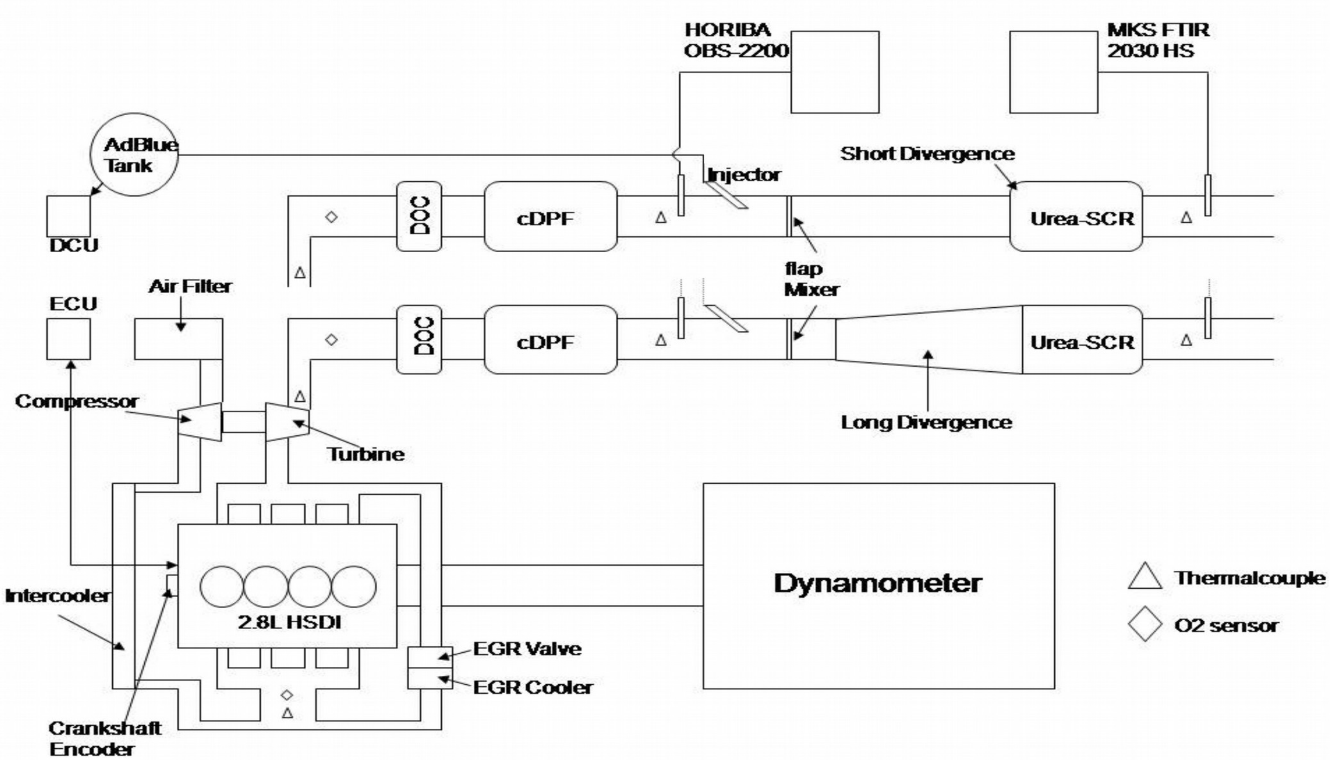

Figure 5. **Experimental setup at CAR lab (WSU College of Engineering) for emissions testing described above (Table 1) for subtask H.1.GN.1.**

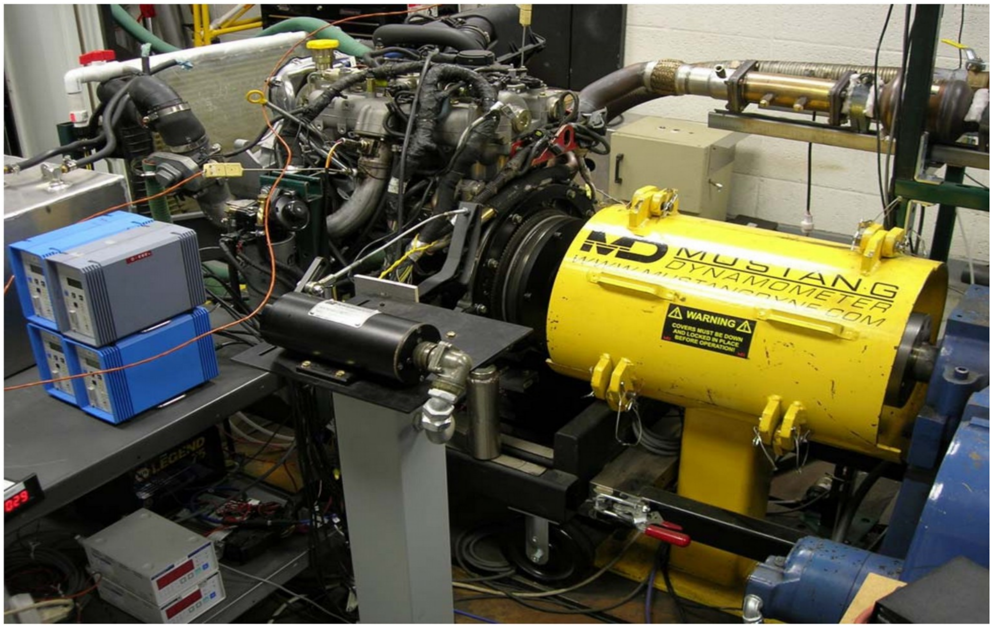

Figure 6. **4.0 Cylinder, 2.8 L, 120 kW Engine at CAR lab used in the experimental setup described (Table 1) in H.1.GN.1.**

Figure 7. **Horiba OBS-2200 (left) and MKS MultiGas 2030HS with FTIR (middle and right) at CAR lab used in the setup described in H.1.GN.1.**

Table 2. **Listing of NBEL Instruments at NEC and WSU (not including CAR equipment). (See http://www.eng.wayne.edu/page.php?id=5177 for pictures and detailed descriptions.)**

Instrument	**Lead Researcher / Subject Matter Expert**
GC - MS	Dr. Dr. HaiyngTang
GC - FID	Dr. Dr. HaiyngTang
IQT	Dr. Kapila Wadumesthrige
Kinematic Viscometer (Automated)	Dr. Haiying Tang
Cold properties analyzer (automated)	Dr. Haiying Tang
809 Titrando	Dr. Haiying Tang
Rancimat® Machine	Dr. Haiying Tang
HFRR	Dr. Kapila Wadumesthrige, Mahbuba Ara
SLBOCLE	Dr. Kapila Wadumesthrige, Dr. Haiying Tang
DI water System	Dr. Manhoe Kim
Cenrifuge (Sediment)	Dr. Manhoe Kim, Gaurav nahar
KF titrator for total water	Dr. Haiyng Tang, Dr. Manhoe Kim
MCRT-160 Micro Carbon Residue Tester	Dr. Kapila Wadumesthrige, Mark Galant
Pensky-Martens Tester for Flash Point	Dr. Kapila Wadumesthrige, Mark Galant
Distillation System	Dr. Manhoe Kim
Copper corrosion	Dr. Haiying Tang
Total Sulfur (UV spectrometer)	Dr. Nadia Abunasser
Furnace (Sulfated Ash)	Dr. Manhoe Kim
Reactor system	Dr. Manhoe Kim
ICP OES	Dr. Kapila Wadumesthrige, Dr. Haiying Tang
FT IR Microscope	Dr. Haiying Tang, Dr. Nadia Abunasser
Cold Flow Refregirator	Mark Galant
Biodiesel Reactor	Dr. Manhoe Kim
IKA C 2000 Calorimeter	Dr. Kapila Wadumesthrige, Mark Galant
Online Composition Analyzer	Dr. Manhoe Kim
Mass Flow Controller	Dr. Manhoe Kim
HPLC and ELSD for Composition Analyzer	Dr. Haiying Tang

Other valued members of the NBEL consortia included:

Delphi – Provided program management and catalysis expertise on the impacts of diesel fuel on these systems.

BDI and NextDiesel – Provided their fuel blending experience in the diesel fuel arena and provide various biodiesel fuels to the Team (Regular diesel fuel, B-5, B-10, B-20, etc).

US TARDEC/Army – Provided another user interface as part of the Team membership (high user of diesel fuel). This group presents different usage requirements as compared to the typical automotive manufacturer.

Bosch – Provided fuel systems expertise and some of the equipment necessary for testing purposes.

Art Van, The Night Move, Oakland University, and Roland Kibler of NEC – Provided vehicles for use in fleet testing, man hours, and data on vehicle performance, especially during cold-weather start-up and operability. See Figure 2 below.

Clean Emission Fluids (CEF) – Provided a user-friendly, modular, heated, above-ground biodiesel fueling station that measures 10’x8’x8’ (half the size of a standard ISO container). This station allowed users to select biodiesel blends from different feedstocks, mixed the blend on-the-spot, and dispensed the blend into the vehicle, similar to a typical gas station pump. This modular fueling station is shown on the left-hand side of Figure 8 below.

Figure 8. **CEF modular biodiesel fueling station on NEC’s Alternative Fuels Platform (see Fig. 1) in Detroit (left) and Art Van fleet (right), both part of the NBEL field testing effort.**

Please refer to the listing of publications for facts, figures, and data that was analyzed and printed as part of the program. (Since there were over one hundred publications as a result of the program, there are too many facts and figures and too much data to clearly communicate here.)

6. **Identify products developed under the award and technology transfer activities, such as:**

a. **Publications (list journal name, volume, issue), conference papers, or other public releases of results. If not provided previously, attach or send copies of any public releases to the DOE Project Officer identified in Block 11 of the Notice of Financial Assistance Award;**

The following is a comprehensive listing of NBEL related publications and references:

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13. K. Wadumesthrige, Nicholas Johnson, Mark Winston-Galant, Noel Bezaire, Sidong Zeng, Eric Sattler, Steven Salley and K.Y. Simon Ng, "Performance, Durability, and Stability of a Power Generator Fueled with ULSD, S-8, JP-8, and Biodiesel", in press, 2010 SAE World Congress.
14. Mark Winston-Galant, Philip Dingle, Steven Salley, and K. Y. Simon Ng, " Temperature Effect on Performance of a Commercial Fuel Filter for Biodiesel Blends with ULSD". in press, 2010 SAE World Congress.
15. Haiying Tang, Rhet C. De Guzman, Steven O. Salley, K. Y. Simon Ng. "The Effect of Antioxidants on the Storage Stability of Soybean Oil Based Biodiesel," *Energy and Fuels*, v 24, n 3, p 2028-2033, March 18, 2010.
16. S.Yan, M.Kim, S. Mohan, S.O. Salley, and K.Y.S.Ng, "Effects of preparative parameters on the structure and performance of Ca-La metal oxide catalysts for oil transesterification",

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58. SAE 2002-01-0218: Characteristics of a Common-Rail Diesel Injection System Under Pilot and Post-Injection Modes. Author(s): Naeim A. Henein, Ming-Chia Lai, Joong Sub Han, Lurun Zhong, Inderpal Singh.
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60. Kapila Wadumesthrige, Mark Winston-Galant, Haiying Tang, "Deterioration of B20 Under Compression Ignition Engine Operation Conditions" presented at the AIChE Annual Meeting 2009.
61. Haiying Tang, Nadia J. Abunasser, Mario Enrique Danton Garica Perez, Steven O. Salley, John Wilson, and K. Y. Simon Ng. “Extraction and Analysis of Algal Oil from Dunaliella tertiolecta for biodiesel” presented at the 100th AOCS 2009 Annual Meeting in Orlando, FL, May 2009.
62. Haiying Tang, Rhet Joseph Caballes De Guzman, Steven O. Salley, K. Y. Simon Ng. “Effect of Minor Components Content on Precipitate Formation in Biodiesel” presented at the 100th AOCS 2009 Annual Meeting in Orlando, FL, May 2009.
63. Rhet Joseph Caballes De Guzman, Haiying Tang, Steven O. Salley, K. Y. Simon Ng. “Factors Affecting Biodiesel Oxidative Stability” presented at the 100th AOCS 2009 Annual Meeting in Orlando, FL, May 2009.

64. Nadia J. Abunasser, Haiying Tang, Mario Enrique Danton Garica Perez, Steven O. Salley, John Wilson, and K. Y. Simon Ng. “Photobioreactor Design and Operation: Effect of Light Intensity and CO2 Concentration” presented at the 100th AOCS 2009 Annual Meeting in Orlando, FL, May 2009.
65. Haiying Tang, Rhet Joseph Caballes De Guzman, Steven O. Salley, John Wilison, K. Y. Simon Ng. “Process Development to Reduce Minor Component Content In Biodiesel” presented at the AIChE’s 2008 Annual Meeting in Philadelphia Pennsylvania, November 2008.
66. Haiying Tang, Rhet Joseph Caballes De Guzman, Steven O. Salley, John Wilison, K. Y. Simon Ng. "Study of Antioxidants on the Oxidative Stability of Biodiesel” presented at the AIChE’s 2008 Annual Meeting in Philadelphia Pennsylvania, November 2008.
67. N. Abunasser, M. E. D. Garcia Perez, H. Tang, S. O. Salley, J. Wilson, and K. Y. S. Ng, “Novel Algal Photobioreactor Design and Operation for the Biofuels Industry” presented at the 2008 AICHE Annual Meeting, Philadelphia, PA, November 2008.
68. N. Abunasser, M. E. D. Garcia Perez, H. Tang, S. O. Salley, J. Wilson, and K. Y. S. Ng, “Properties of Algal-Based Biodiesel” presented at the 2008 AICHE Annual Meeting, Philadelphia, PA, November 2008.
69. N. Abunasser, S. O. Salley, J. Wilson, and K. Y. S. Ng, “Simulation of Algal Growth In a Photobioreactor” presented at the 2008 AICHE Annual Meeting, Philadelphia, PA, November 2008.
70. K. Y. S. Ng, S. O. Salley, J. Wilson, H. Tang, S. Yan, N. Abunasser, M. Kim, “The Future of Biodiesel as a Viable Alternative Fuel: Challenges and Opportunities” presented at the 2008 AICHE Annual Meeting, Philadelphia, PA November 2008.
71. N. Abunasser, M. E. D. Garcia Perez, H. Tang, S. Yan, M. Kim, H. Wang, S. O. Salley, J. Wilson, and K.Y.S. Ng, “Properties of Algal Oil to be Used as Feedstock for Biofuels” presented at the 99th AOCS Annual Meeting, Seattle, WA, May 2008.
72. Shuli Yan, Manhoe Kim, Steve O. Salley, John Wilson, and K. Y. Simon Ng, “Reaction Kinetics of Soybean Oil Transesterification at High Temperature”, presented at the AIChE 2008 Annual Meeting in Philadelphia Pennsylvania, November 2008.
73. Shuli Yan, Manhoe Kim, Steve O. Salley, and K. Y. Simon Ng, “Biodiesel from Waste or Unrefined Oils Using Calcium Oxide-based Catalysts”, presented at the AIChE 2008 Annual Meeting in Philadelphia Pennsylvania, November 2008.
74. Shuli Yan, Manhoe Kim, Steve O. Salley, John Wilson, and K. Y. Simon Ng, “Simultaneous transesterification and esterification to biodiesel using zinc-based catalyst”, presented at the AIChE 2008 Annual Meeting in Philadelphia Pennsylvania, November 2008.
75. Manhoe Kim, Shuli Yan, Huali Wang, John Wilson, Steven O. Salley, K. Y. Simon Ng "Mixed metal oxide supported CeO2 catalysts for the transesterification of soybean oil with methanol (session 692g)", presented at the 2008 AIChE Annual Meeting & Centennial Celebration, Philadelphia, PA, November 2008.
76. Manhoe Kim, Shuli Yan, Huali Wang, John Wilson, Steven O. Salley, K. Y. Simon Ng "Development of a vanadium oxides loading method on solid supports (session 335e)", presented at the 2008 AIChE Annual Meeting & Centennial Celebration, Philadelphia, PA November 2008.
77. Nadia Abunasser, Steven O. Salley, K. Y. Simon Ng, John Wilson "Modeling and Simulation of a Photobioreactor for the Cultivation of Algae to be used as a Feedstock for Renewable Fuels", presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008.

78. Mark Winston-Galant, Philip Dingle, Haiying Tang, Steven O. Salley[1], K. Y. Simon Ng "Effect of Temperature on Filter Performance of Biodiesel Fuel", presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008.
79. Kapila Wadumesthrige, Sidong Zeng, Mark Winston-Galant, John Wilson, Steven O. Salley, K. Y. Simon Ng "Properties of Functionalized Fatty Acid Methyl Esters", presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008.
80. Kapila Wadumesthrige, J.C Smith, John Wilson, Steven O. Salley, K. Y. Simon Ng" Structure Function Relationship of Oxidized Biodiesel", presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008.
81. Shuli Yan, Manhoe Kim, John Wilson, Steven O. Salley , Simon K. Y. Ng "Biodiesel Production by Simultaneous Esterification and Transesterification", presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008.
82. Manhoe Kim, Shuli Yan, Huali Wang, John Wilson, Steven O. Salley, K.Y. Simon Ng "Catalytic Activities of Vanadia Loaded Heterogeneous Catalysts on Transesterification of Soybean Oil with Methanol" presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008.
83. Haiying Tang, Huali Wang, Steven O. Salley, K. Y. Simon Ng "Process Development to Reduce Sterol Glucosides Content in Biodiesel" , presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008.
84. Haiying Tang, Rhet Joseph Caballes De Guzman, Steven O. Salley, K. Y. Simon Ng "Precipitate Formation above the Cloud Point in Soy-, Cottonseed-, Poultry Fat-, Yellow Grease-, and Palm-based Biodiesel Blends", presented at the 99th AOCS Annual Meeting in Seattle, Washington 2008
85. K. Y. Simon Ng, "The Current Status Of Biodiesel Application Technology", "Alternative Fuels and Enabling Technologies I" presented at the AIChE's 2007 Annual Meeting in Salt Lake City Utah, November 2007.
86. Haiying Tang, Anfeng Wang, Steven O. Salley, K.Y. Simon Ng. "Insolubles Formation in Biodiesel Blends observed after Low Temperature Treatments" presented at the 98 th AOCS Annual Meeting, Quebec City, QC, Canada, May 2007.
87. Bradley R. Clark, Anfeng Wang, Steven O. Salley and K. Y. Simon Ng. "Effects of Group IV Transition Metals Catalytic Effects of Group IV Transition Metals on the Oxidative Stability of Biodiesel" presented at the 98th AOCS Annual Meeting, Quebec City, QC, Canada, May 2007.
88. Haiying Tang, Steven O. Salley, and K. Y. Simon Ng, "Precipitate Formation Above Cloud Point In Soy-, Cottonseed-, And Poultry Fat-Based Biodiesel Blends", presented at the AIChE Annual Meeting, Salt Lake City, Utah, November 2007.
89. Manhoe Kim, Steven O. Salley and K. Y. Simon Ng, "Mixed Metal Oxide Loaded Nano Zsm-5 Catalyst For The Transesterification Of Soybean Oil With Methanol", "Catalysis With Microporous And Mesoporous Materials II" presented at the AIChE's 2007 Annual Meeting in Salt Lake City, Utah, November 2007.
90. Manhoe Kim, Steven O. Salley and K. Y. Simon Ng, "Heterogeneous Catalytic Activities Of Anion Exchange Resins On The Transesterification Of Soybean Oil With Methanol" , "16002 Catalytic Biodiesel Production" presented at the AIChE's 2007 Annual Meeting in Salt Lake City, Utah, November 2007.
91. Bradley R. Clark, Steven O. Salley, K. Y. Simon Ng, "Catalytic Effects Of Transition Metals On The Oxidative Stability Of Various Biodiesels", "Alternative Fuels and Enabling

Technologies II" presented at the AIChE's 2007 Annual Meeting in Salt Lake City, Utah, November 2007.

92. Kapila Wadumesthrige, Steven O. Salley and K. Y. Simon Ng, "Effect Of Major And Minor Components Of Biodiesel On The Lubricity Of Petroleum And Synthetic Fuel" has been accepted into "Alternative Fuels and Enabling TechnologiesI", "Sustainable Fuels" presented at the AIChE's 2007 Annual Meeting in Salt Lake City, Utah, November 2007.
93. Kapila Wadumesthrige, Steven O. Salley and K. Y. Simon Ng, "Investigation of the Parameters Affecting Cetane Number of Biodiesel", presented at the AIChE's 2007 Annual Meeting in Salt Lake City, Utah, November 2007.
94. Anfeng Wang, Bradley Clark, Steven O. Salley, and K. Y. Simon Ng, "Oxidative Stability of 20% Soy-based Biodiesel (B20) in Ultra-low Sulfur Diesel," presented at the 98th AOCS Annual Meeting, Quebec City, Canada, May 2007.
95. Haiying Tang, Anfeng Wang, John Wilson, Steven O. Salley, and K. Y. Simon Ng, "Insolubles Formation in Soy, Cottonseed , and Poultry Fat-Biodiesel Blends observed after Low Temperature Storage," presented at the International Congress on Biodiesel: The Science and The Technologies, Vienna, Austria, November 2007.
96. Anfeng Wang, Haiying Tang, Bradley Clark, John Wilson, Steven O. Salley, and K. Y. Simon Ng, "Oxidative Stability of Fatty Acid Methyl Esters (FAMEs) in Ultra-low Sulfur Diesel", presented at the International Congress on Biodiesel: The Science and The Technologies, Vienna, Austria, November 2007.
97. Anfeng Wang, Haiying Tang, Bradley Clark, John Wilson, Steven O. Salley, and K. Y. Simon Ng, "Quality Survey of Retail Biodiesel Blends on Michigan Market," presented at the International Congress on Biodiesel: The Science and The Technologies, Vienna, Austria, November 2007.
98. Bradley Clark, Anfeng Wang, John Wilson, Steven O. Salley, and K. Y. Simon Ng, "Catalytic Effects of Transition Metals on the Oxidative Stability of Various Biodiesels," presented at the International Congress on Biodiesel: The Science and The Technologies, Vienna, Austria, November 2007.
99. M. Kim. Cited in: Industrial & Engineering Chemistry Research, Volume: 48 Issue: 13 Pages: 6162-6172 Published: July 1, 2009.
100. M. Kim. Cited in: Catalysis Communications, Volume: 10, Issue: 14 Pages: 1913-1919 Published: Aug. 25, 2009.

b. Web site or other Internet sites that reflect the results of this project;

The WSU link that cites NBEL work, equipment, research staff and objectives is located at: http://www.eng.wayne.edu/page.php?id=4765.

NextEnergy discussed NBEL on its website, including at: http://www.nextenergy.org/services/collaborativeprograms/nbel.aspx.

Some articles were printed describing a Wayne State University spin-off company called NextCat, as described in the link appended below: http://media.wayne.edu/2010/04/01/detroitbased-nextcat-inc-signs-an-option-agreement.

Other links, including one to the National Biodiesel Board (NBB) and NextDiesel, may be accessed at:

http://www.eng.wayne.edu/page.php?id=4776.

c. **Networks or collaborations fostered;**

With the exception of Art Van Furniture, all of the consortia is interested in continuing to work on future projects related to the next generation of biodiesel research and development, particularly on advancing the algae-based biodiesel research spearheaded by Dr. Nadia Abunassar along with Drs. Steven Salley and Simon Ng, as well as developing the “next-generation” non-platinum group metal (non-PGM) catalyst for “green diesel” production. This catalyst would convert the non-FAME (fatty acid methyl ester) component of crude algal lipid strains to the green diesel fuel, and would not necessarily be related to the catalyst used in the FAME esterification process. If successful, this approach will fully utilize the lipid portions of crude algae biomass and greatly advance the production of domestic algae biofuels, leading to competitive petroleum alternatives and multiple value streams for algae biomass processors.

A strong relationship has formed between the new spinoff company called NextCAT and the Wayne State University NBEL team. This group has recently submitted a SBIR through the National Science Foundation on the novel “green diesel” catalyst work. However, since there is very limited funding available from this NSF award and this work is limited in scope to what this funding would support, the consortia is very interested in continuing to work on more research and development for the next generation of biofuels through the DOE/USDA/DoD, including, but not limited to: algae, stinkweed, and jatropha based biodiesel, green diesel, and biobutanol characterization, engine testing, field testing, and development. The laboratory on-site at NEC, the sister lab run by Dr. Simon Ng at Wayne State University’s College of Engineering (down the street from NEC), the engine testing lab run by Dr. Henein also at WSU Engineering, the proximity of NEC and WSU to major OEMs’ research centers and TARDEC/NAC, the relationship fostered through the NBEL consortia, the existence of the CEF modular biodiesel dispensing unit on-site at NextEnergy for fleet testing, and the proven track record by the NBEL team for results (as shown by the vast number and quality of publications and presentations) all make the consortia a formidable force for continuing such work on advancing the next-generation of biofuels.

d. **Technologies/Techniques;**

The technologies and techniques are outlined separately in each publication (see list above). Where applicable, ASTM prescribed test methods were utilized for characterization and SAE methods for engine testing.

e**. Inventions/Patent Applications, licensing agreements;**

The following patents were filed as a result of the NBEL research:

- Shuli Yan, Steven O. Salley, K. Y. Simon Ng, “Method and catalysts for making biodiesel from the transesterification and esterification of unrefined oil ” 12/468,309.
- Shuli Yan, Steven O. Salley, K. Y. Simon Ng, "Lanthanum-based heterogeneous catalyst for simultaneous transesterification and esterification" 61/054,205.
- Shuli Yan, Steven O. Salley, K. Y. Simon Ng, "Calcium and lanthanum solid base catalysts for transesterification " 61/111,508.

f. **Other products, such as data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments or equipment.**

See Table 2 for a listing of equipment.

7. **For projects involving computer modeling, provide the following information with the final report:**

No computer modeling was used as part of this project.

a. Model description, key assumptions, version, source and intended use;

b. Performance criteria for the model related to the intended use;

c. Test results to demonstrate the model performance criteria were met (e.g., code verification/validation, sensitivity analyses, history matching with lab or field data, as appropriate);

d. Theory behind the model, expressed in non-mathematical terms;

e. Mathematics to be used, including formulas and calculation methods;

f. Whether or not the theory and mathematical algorithms were peer reviewed, and, if so, include a summary of theoretical strengths and weaknesses;

g. Hardware requirements; and

h. Documentation (e.g., users guide, model code).

8. **Ensure the report does not contain any Protected PII. Protected PII is defined as an individual's first name or first initial and last name in combination with any one or more of types of information, including, but not limited to, social security number, passport number, credit card numbers, clearances, bank numbers, biometrics, date and place of birth, mother's maiden name, criminal, medical and financial records, educational transcripts, etc.**

This report does not contain any protected PII.