# Fuel Testing for Sylvatex

## Cooperative Research and Development Final Report

## CRADA Number: CRD-16-636

NREL Technical Contact: Jonathan Burton

**NREL is a national laboratory of the U.S. Department of Energy**
**Office of Energy Efficiency & Renewable Energy**
**Operated by the Alliance for Sustainable Energy, LLC**

**CRADA Report**
NREL/TP-5400-70914
January 2018

Contract No. DE-AC36-08GO28308

## NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at SciTech Connect http:/www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
OSTI http://www.osti.gov
Phone: 865.576.8401
Fax: 865.576.5728
Email: reports@osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
NTIS http://www.ntis.gov
Phone: 800.553.6847 or 703.605.6000
Fax: 703.605.6900
Email: orders@ntis.gov

*Cover Photos by Dennis Schroeder: (left to right) NREL 26173, NREL 18302, NREL 19758, NREL 29642, NREL 19795.*

NREL prints on paper that contains recycled content.

# Cooperative Research and Development Final Report

In accordance with Requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the DOE Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

**Parties to the Agreement:** Sylvatex, Inc.

**CRADA number:** CRD- 16-636

**CRADA Title:** Fuel Testing for Sylvatex

**Joint Work Statement Funding Table showing DOE commitment:**

| Estimated Costs | NREL Shared Resources a/k/a Government In-Kind |
|---|---|
| Year 1 | $110,129.00 |
| TOTALS | $110,129.00 |

## Abstract of CRADA Work:

Sylvatex is a green nano-chemistry company that has developed a platform technology utilizing renewable, non-toxic inputs to create a stable nanoparticle that can be used in multiple applications. Their mission is to increase the use of renewables globally, to empower a cleaner and healthier future. The main application is a fuel technology product – MicroX - that utilizes proprietary knowledge to scale low-cost, cleaner-burning renewable diesel fuel and additives by using a co-location commercial model. The aspects of this project will include testing of two Sylvatex MicroX fuels on an engine dynamometer platform. Industry standard ultra-low sulfur diesel (ULSD) B3 fuel and a ULSD B20 will both be used for comparison of the Sylvatex fuels (U.S. standard diesel fuel at the pump contains an average of approximately 3% biodiesel; this is why B3 would be used as a baseline comparison). Sylvatex is currently using a prototype formulation (MicroX 1) that applies a high cost surfactant. An experimental formulation (MicroX 2) that uses lower cost materials is under development. The MicroX 1 will be blended at a 10% level into the B3 ULSD fuel and the MicroX 2 will be blended at a 10% level into both the B3 and the B20 ULSD fuels for study on the engine dynamometer test platform. All fuel blends will be tested over the FTP transient engine test cycle and a steady state ramped modal engine test cycle. Each test cycle will be performed a minimum of 3 times for each fuel. Tailpipe and/or engine out gaseous exhaust emissions ($CO_2$, CO, $NO_x$, THC, $O_2$,), engine out PM emissions, and brake-specific fuel consumption rates will be evaluated for all test cycles.

**Summary of Research Results**:

The purpose of this project was to evaluate the Sylvatex fuel blend formulations with a primary objective to compare fuel consumption and emissions of blended fuel to those of a regular diesel fuel for two different low carbon input formulations of MicroX.

Two Sylvatex fuel formulations were examined using a heavy duty diesel engine on a dynamometer. Testing occurred in two phases as the formulations were not available both at the same time. Both fuel additive formulations were blended with California Air Resources Board (CARB) certification reference diesel fuel which was also used as baseline fuel for comparisons. Phase I consisted of testing the MicroX formulation based on sustainable palm oil derivative. This formulation was blended into the CARB reference diesel at 10% by volume. This blend was tested both with and without addition of 500ppm of 2-ethylhexyl nitrate cetane boosting additive.

Phase II consisted of testing a different MicroX formulation based on non-edible corn oil derivative. For the purpose of differentiating the formulation used in Phase II it is denoted as MicroX II. Again, this blend stock was tested at 10% blend in CARB reference diesel fuel. After considering the NOx results from phase I with the cetane booster, phase II only consisted of testing a cetane boosted blend. Both phases included testing a baseline CARB reference fuel.

Testing was performed at NREL's ReFUEL laboratory using a 2012 Cummins ISL 8.9 L engine running the Federal Transient Procedure (FTP) and the Suplemental Emissions Test (SET) test cycles on an engine dynamometer. Gaseous and particulate exhaust emissions were measured during testing, as well as the fuel consumption.

FTP cycle average hot start test results are shown in Table 1, cold start test results are shown in Table 2. The baseline CARB reference diesel fuel was tested in both phases of the project, the results for that fuel were combined into one result which is used as a comparison for all Sylvatex fuels. Composite fuel consumption and tailpipe emissions are shown in Table 3. Emissions for the FTP engine cycle are calculated and listed as composite emissions as prescribed per the Code of Federal Regulations – Title 40 – Part 86.007-11. They are calculated as 1/7 of the cold start test cycle emissions plus 6/7 the average of the hot start cycles emissions.

The fuel consumption of the MicroX blended fuels, with or without cetane improver, is shown to increase between 3.4% to 4.2% in the FTP composite data. This is likely due to the lower energy density of the MicroX blended fuels. CO2 emissions increased between 0.6 and 2.0% for the MicroX blends compared to the CARB reference fuel.

Tailpipe NOx emissions for the MicroX blend without the cetane additive indicate an increase in tailpipe NOx emissions by roughly 20%. Additionally, emissions for the MicroX blend were above the engine's emission certification level; however, an engine is only required to meet the emissions certification level when tested on certification diesel fuel. Adding the cetane additive to the MicroX blends showed an improvement in NOx back to the baseline CARB fuel levels for phase I and an increase of only 5% for phase II. Engine tailpipe emissions results for total hydrocarbons are near zero for all fuels tested and are at levels below the detection limits of the analyzers. Carbon monoxide emission were also very low, nearly zero and differences were determined to be inconsequential. There were no significant differences in these emissions for any of the fuels for all FTP engine test cycles.

Tailpipe PM emissions on a modern engine with after treatment system are very low and are very insensitive to fuel properties as nearly all PM gets trapped in the diesel particulate filter (DPF). Thus, PM emissions were measured on the engine out level. Modern engine PM formation is variable due to the engine control system putting emphasis on curbing NOx formation through EGR, which affects the well documented NOx-PM trade off phenomenon. To minimize variability in observed PM measurement it was performed using a steady state SET test and results are shown in Figure 1. The engine-out PM emissions are significantly lower with the MicroX fuel blend than the with CARB reference fuel.

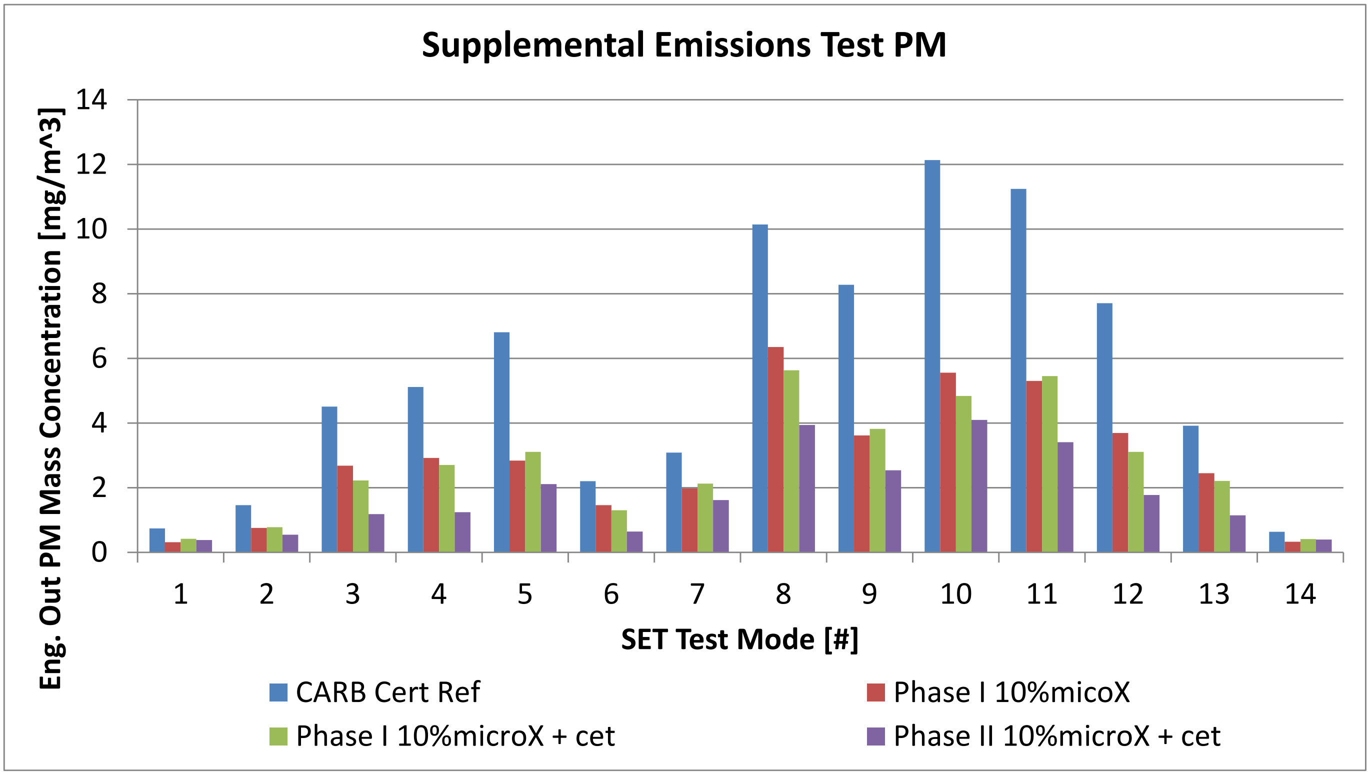

**Figure 5. SET engine-out PM emissions.**

While the decreased engine out PM will have negligible effect on tailpipe PM emissions in a modern engine due to the high effectiveness of the DPF, there is a distinct potential for other benefits. The DPF has to be periodically regenerated to prevent clogging the filter. This process involves addition of heat (fuel) into the exhaust stream to increase the temperature of the DPF and the deposited soot to the point where it will oxidize. During this process the fuel consumption is increased and the high temperatures prevent the SCR system from performing its function. It is possible that late model engines with more sophisticated algorithms controlling the regeneration events based on actual needs rather than a schedule would benefit from lower engine out PM in reduced fuel consumption and NOx emissions. These benefits will not be apparent from certification type of testing which does not include regeneration events. The quantification of these benefits is beyond the scope of this project. It would require conducting a fleet study to determine and compare the frequency of regenerative events in vehicles using regular fuel and the MicroX blend. Or possibly could also be performed by heavy-duty vehicle testing on a chassis dynamometer.

The measurement of acetaldehyde, formaldehyde, and alcohol toxic emissions using an Fourier Transform Infrared Spectroscopy (FTIR) analyzer proved to be below sensitivity levels to detect any significant differences between the different fuels.

In conclusion, the findings resulting from the study are summarized as follows:

- Engine out PM is significantly lower with MicroX than with CARB reference fuel.
- Cetane enhancer is needed for the blends to maintain NOx emissions levels of the CARB reference diesel.
- No differences in toxic emissions were able to be detected via FTIR analyzer.
- Slight increases in fuel consumption were observed for the MicroX fuel blends.

**Table 1. FTP Cyce Hot Start Fuel Consumption and Tailpipe Emissions Results**

| Hot Start Test Cycle Results | | Fuel Consumed | Cycle Energy | BSFC | NOx | THC | CO2 | CO | Raw NO | Raw Nox | Raw NO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (kg) | (HP-hr) | (g/bHP-hr) | (g/bHP-hr) | (g/bHP-hr) | (g/bHP-hr) | (g/bHP-hr) | (ppm) Eng Out | (ppm) Eng Out | (ppm) Eng Out |
| **CARB Ref (Pre & Post Test)** | avg | 4.676 | 22.902 | 204.158 | 0.230 | -0.005 | 665.586 | 0.121 | 144.049 | 173.720 | 29.671 |
| | stdev | 0.033 | 0.076 | 1.486 | 0.009 | 0.002 | 4.875 | 0.054 | 8.835 | 6.709 | 2.210 |
| **Phase I 10% MicroX /CARB** | avg | 4.848 | 22.769 | 212.940 | 0.276 | -0.003 | 674.583 | 0.104 | 127.235 | 197.643 | 70.408 |
| | stdev | 0.018 | 0.044 | 0.885 | 0.028 | 0.001 | 3.858 | 0.044 | 1.483 | 1.755 | 0.705 |
| **Phase I 10%MicroX + cet /CARB** | avg | 4.857 | 22.806 | 212.956 | 0.219 | -0.003 | 670.532 | 0.110 | 123.757 | 191.214 | 67.457 |
| | stdev | 0.016 | 0.048 | 1.053 | 0.005 | 0.004 | 1.629 | 0.008 | 0.548 | 0.968 | 0.494 |
| **Phase II 10% microX + cet /CARB** | avg | 4.880 | 22.783 | 214.197 | 0.226 | -0.009 | 679.193 | 0.183 | 155.156 | 177.819 | 22.663 |
| | stdev | 0.005 | 0.042 | 0.484 | 0.004 | 0.010 | 0.646 | 0.010 | 2.036 | 2.064 | 0.029 |

**Table 2. FTP Cycle Cold Start Fuel Consumption and Tailpipe Emissions Results**

| **Cold Start Test Cycle Results** | | **Fuel consumed** | **Cycle energy** | **BSFC** | **Nox** | **THC** | **CO2** | **CO** | **Raw NO** | **Raw Nox** | **Raw NO2** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **(kg)** | **(HP-hr)** | **(g/bHP-hr)** | **(g/bHP-hr)** | **(g/bHP-hr)** | **(g/bHP-hr)** | **(g/bHP-hr)** | **(ppm)Eng Out** | **(ppm)Eng Out** | **(ppm)Eng Out** |
| **CARB Ref (Pre & Post Test)** | ave (3 data points) | 4.852 | 22.632 | 214.377 | 0.620 | 0.008 | 699.303 | 0.196 | 134.136 | 160.701 | 26.565 |
| **Phase I 10% MicroX/CARB** | ave (2 data points) | 4.925 | 22.435 | 219.528 | 0.756 | 0.027 | 699.529 | 0.147 | 123.123 | 187.088 | 63.965 |
| **Phase I 10%MicroX+cet/CARB** | ave (2 data points) | 4.918 | 22.407 | 219.477 | 0.673 | 0.023 | 696.029 | 0.146 | 94.409 | 180.735 | 86.326 |
| **Phase II 10% microX+cet/CARB** | 1 data point | 5.005 | 22.246 | 224.989 | 0.751 | -0.081 | 712.041 | 0.137 | 148.335 | 168.363 | 20.028 |

Table 3. FTP Composite Calculation Results and % Comparison to Baseline CARB Cert Ref Fuel

| | Fuel Consumption Composite | | NOx FTP Composite | | CO2 FTP Composite | |
|---|---|---|---|---|---|---|
| | (g/bhp-h) | % Increase | (g/bhp-h) | % Increase | (g/bhp-h) | % Increase |
| **CARB Ref (Pre & Post Test)** | 4.700 | | 0.285 | | 670.354 | |
| **Phase I 10% MicroX /CARB** | 4.859 | 3.4 | 0.344 | 20.6 | 678.102 | 1.1 |
| **Phase I 10%MicroX + cet /CARB** | 4.865 | 3.5 | 0.283 | -1.0 | 674.120 | 0.6 |
| **Phase II 10% microX + cet /CARB** | 4.897 | 4.2 | 0.300 | 5.0 | 683.790 | 2.0 |

**Subject Inventions Listing:**

N/A

**ROI #:**

N/A

**Report Date:**

1/8/2018

**Responsible Technical Contact at Alliance/NREL:**

Jonathan Burton

**Name and Email Address of POC at Company:**

Kristen Aramthanapon, karamthanapon@sylvatex.com

**DOE Program Office:**

Fuel Cells Technologies

**This document contains NO confidential, protectable, or proprietary information.**