

# **Emulsified Biodiesel Fuel**

## **Operations**

### **At The Port Of Los Angeles**

**August 2010 – To – January 2011**

**Technology Advancement Program**

**Agreement Number – E6535**

**Final Report**

**August 2011**

# Contents

<b>I.</b>	<b>Executive Summary</b>	<b>4</b>
<b>II.</b>	<b>Introduction</b>	<b>8</b>
<b>III.</b>	<b>Phase 1: Engine Laboratory Study – Relationship Between NOx Emissions, Biodiesel Concentration and Water Content</b>	<b>10</b>
	<b>(i) Results without DOC After-Treatment Unit</b>	<b>11</b>
	<b>(ii) Results with DOC After-Treatment Unit</b>	<b>12</b>
	<b>(iii) Discussion of Results</b>	<b>15</b>
	<b>(iv) Conclusions - Phase 1</b>	<b>17</b>
<b>IV.</b>	<b>Phase 2: Evaluation of the Optimized Emulsified B20 Fuel With/Without a DOC After-Treatment Unit</b>	<b>17</b>
	<b>(i) Engine Emissions Results</b>	<b>19</b>
	<b>(ii) Speed, Torque and Fuel Consumption</b>	<b>21</b>
	<b>(iii) Conclusions - Phase 2</b>	<b>23</b>
<b>V.</b>	<b>Phase 3: Planning and Execution of Real Time Demonstration</b>	<b>24</b>
	<b>(i) Test Plan for Field Demonstration</b>	<b>24</b>
	<b>(ii) The Field Demonstration</b>	<b>25</b>
	<b>(iii) Emulsified Fuel Quality Standards</b>	<b>26</b>
	<b>(iv) Conclusions - Phase 3</b>	<b>28</b>
<b>VI.</b>	<b>Overall Conclusions</b>	<b>30</b>
<b>VII.</b>	<b>Next Steps</b>	<b>31</b>
	<b>References</b>	<b>32</b>

## Appendices

<b>Appendix A: TAP Scope of Work: Emulsified Biodiesel Fuel Demonstration</b>	<b>33</b>
<b>Appendix B: Reconciliation of Scope of Work from Appendix A to Conclusions in the Three Work Phases</b>	<b>34</b>
<b>Appendix C: Fuel Characteristics Used in Phase 2 Study</b>	<b>35</b>
<b>Appendix D: Stability of Emulsions; Sedimentation vs. Phase Instability</b>	<b>36</b>
<b>Appendix E: CEN CW 15145: 2004 Fuel Standards Summary</b>	<b>38</b>
<b>Appendix F: Select Analytical Techniques Used by APT for Assuring Consistent Quality of Emulsified Fuel</b>	<b>39</b>
<b>Appendix G: Phase 1 Study - NO<sub>x</sub> and PM Emissions</b>	<b>40</b>
<b>Appendix H: Phase 2 Study – Olson EcoLogic Data</b>	<b>41</b>
<b>Appendix I: Letter from Ports America on Emulsified Biodiesel Fuel Demonstration Using Three Taylor Top Handlers Units</b>	<b>42</b>
<b>Appendix J: Carbon Dioxide Emission Benefits from Use of Emulsified Biodiesel Fuel in Waterfront Trials</b>	<b>43</b>
<b>Appendix K: Operational Photos of APT Distribution Chain for Emulsified Biodiesel Fuel Supplied to Port of Los Angeles</b>	<b>44</b>

## List of Figures

<b>Figure 1: Increase in NO<sub>x</sub> Emissions for Biodiesel Fuels</b>	<b>8</b>
<b>Figure 2: Range of Emulsified Biodiesel Fuels in Screen Test (No DOC)</b>	<b>11</b>
<b>Figure 3: Changes in NO<sub>x</sub> Emissions with Changes in Fuel Composition</b>	<b>12</b>
<b>Figure 4: Changes in PM Emissions with Changes in Fuel Composition</b>	<b>12</b>
<b>Figure 5: Range of Emulsified Biodiesel Fuels in Screen Test (+ DOC)</b>	<b>13</b>
<b>Figure 6: CO Emissions - Effect of Fuel Composition and DOC</b>	<b>13</b>
<b>Figure 7: Hydrocarbon Emissions – Effect of Fuel Composition and DOC</b>	<b>14</b>
<b>Figure 8: PM emissions – Effect of Fuel Composition and DOC</b>	<b>14</b>
<b>Figure 9: Percent NO<sub>x</sub> Reductions for B20, Diesel and DOC</b>	<b>15</b>
<b>Figure 10: Percent PM Reductions for B20, Diesel and DOC</b>	<b>15</b>
<b>Figure 11: Effect of Emulsions, Biodiesel (B20) and DOC on PM Reductions</b>	<b>16</b>
<b>Figure 12: % Changes in NO<sub>x</sub>, PM Emissions vs. Biodiesel Content-Phase 1</b>	<b>18</b>
<b>Figure 13: Emissions with B0 (diesel), B20, EmB20 and EmB20+DOC Unit</b>	<b>19</b>
<b>Figure 14: Emissions with B0 (diesel), B20, EmB20 and EmB20+DOC Unit</b>	<b>19</b>
<b>Figure 15: Relative Changes in PM and NO<sub>x</sub> Emissions (B20 = 100%)</b>	<b>20</b>
<b>Figure 16: Reductions in PM by B20, EmB20, EmB20+DOC Unit</b>	<b>20</b>

## List of Tables

<b>Table 1: Actual and % Changes in Fuel Consumption, Speed (Sp) and Torque (Tq) with Changes in Fuel and After Treatment</b>	<b>21</b>
<b>Table 2: Composition of Emulsified B20 Biodiesel Fuel</b>	<b>22</b>
<b>Table 3: H<sub>2</sub>O &amp; Biofuel in Diesel With/Without DOC: Effects on Emissions</b>	<b>22</b>

# I. Executive Summary

## Overview

In January 2011, Alternative Petroleum Technologies, Inc. (APT) completed a series of evaluations to demonstrate the successful utilization of emulsified biodiesel fuel in operating equipment at the Port of Los Angeles (POLA). The effort was sponsored by the Ports of Los Angeles and Long Beach through the Technology Advancement Program (TAP) and involved four operational tasks set out in the project Scope of Work document (Appendix A). These tasks have been structured into three work phases for the purposes of this report. This report constitutes the last task in the Scope of Work. The three functional work phases were:

Phase 1: Engine Laboratory Study – Establishing a relationship between Oxides of Nitrogen (NO<sub>x</sub>) Emissions, Biodiesel Concentration and Water Content involved laboratory testing to determine the optimal water content of an emulsified biodiesel fuel that would neutralize the NO<sub>x</sub> emissions increase associated with the combustion of regular biodiesel fuel that has been reported by the United States Environmental Protection (EPA) agency over a range of biodiesel fuel concentrations. The laboratory testing conducted in Phase 1 was performed in accordance with a federal testing procedure (FTP) using a full range of biodiesel fuel concentrations including a 100% biofuel (B100), a 50% biofuel (B50) and a 20% biofuel (B20) as well as different water contents below 20%. The testing was conducted in a target engine family considered indicative of the overall heavy-duty diesel engine market with and without a diesel oxidation catalyst (DOC) unit attached to the test engine;

Phase 2: Evaluation of Emulsified B20 Fuel – This work phase involved dynamometer testing of an optimal emulsified biodiesel fuel composition to quantify reduction levels for “criteria” gaseous emissions (NO<sub>x</sub>, hydrocarbon (HC), carbon monoxide (CO) and particulate matter (PM)) in a target engine for top handler units considered prevalent in waterfront operations at POLA. The dynamometer testing conducted in Phase 2 was performed in accordance with an FTP using a 20% volume biodiesel fuel (or B20) with a 6% mass water content - with and without a DOC unit installed on the test engine. The selection of a 6% water content and a B20 fuel was based on analysis of the data generated in Work Phase 1;

Phase 3: Planning and Execution of Real-time Field Demonstration – This work phase involved real-time, in-field demonstration of the “optimal” emulsified biodiesel fuel in port equipment (top handlers) involved in commercial waterfront operations. The records of the real-time, in-field demonstrations conducted in Work Phase 3 were based upon actual feedback from the operators of the top-handler equipment units as well as daily records of fuel consumption and unit operational activities.

## Background on Emulsified Fuels and Emulsified Biodiesel Fuels

Emulsified diesel fuels have previously been recognized by the California Air Resources Board (CARB) under both the verification and interim verification programs back in the early 2000s. The emulsified diesel fuels recognized by CARB were primarily focused on 15% or more reductions of NO<sub>x</sub> to qualify under certain verification programs in place at that time. These emulsified fuels contained nearly 17% water, approximately 3% additive and the balance was a #2 CARB diesel fuel. These verified emulsified diesel fuels achieved limited commercial success due in part to the peak power loss that was experienced in using a high water content emulsified diesel fuel.

Emulsified diesel fuels have been of considerable interest for a long time and many technical papers have been published [1, 2] that explain the advantages and limitations of emulsified diesel fuels. General observations made about emulsified diesel fuels include the fact that the higher the water content of the emulsified diesel fuel, the greater are the emissions reductions. Moreover, many of the documented tests demonstrated that each unit of water introduced to the emulsified fuel will result in a corresponding unit reduction in NO<sub>x</sub> emissions. For example, a 10% water content in a diesel emulsion fuel is generally expected to reduce NO<sub>x</sub> emissions by 10% when compared to the diesel fuel baseline. However, the higher the water content of the emulsified diesel fuel, the greater is the dilution to the peak power performance of an engine. The peak power loss can be caused when the fuel delivery system does not possess sufficient capacity to deliver an adequate amount of emulsified fuel to the engine to achieve an equal amount of energy content as resident in the base fuel. For example, a diesel emulsion with 20% water content may require as much as a 25% increase in the fuel delivery system capacity in order to deliver a comparable amount of energy content at peak power conditions as that delivered by a base diesel fuel.

Emulsified fuels have been recognized in Europe since the late 1990's [3]. Unlike CARB, Europe does not have minimum level NO<sub>x</sub> emission requirements for their recognition so the emulsified fuel industry settled on a water content of 9 to 15% which was considered an appropriate balance of potential power loss and emission reduction. Emulsified diesel fuels have been provided to thousands of buses and trucks commercially in Italy and France over the last decade [3].

In fact, because emulsions of water and conventional diesel fuels have been recognized as commercial fuels for some time, national standards were developed in France in 2000 and in Italy in 2001. The Coordinating European Council for the Development of Performance Test for Fuels, Lubricants and Other Fluids (CEC) has issued a workshop standard; CEN CW 15145:2004 for emulsified diesel fuels (Appendix E). The 6% (by mass) emulsified B20 fuel complies with the CEN CW 15145 specification listed in Appendix E for Grade B fuel (5% to 8% - by mass - water content emulsion fuel).

Surprisingly, neither CARB nor the EPA has created any general or specific fuel specifications for emulsified fuels despite both agencies recognizing the emission benefits of such fuels under formal test programs. The CARB and EPA agencies elected to focus primarily on the emission reduction aspects of emulsified fuels. The marketing implication is therefore that the emulsified fuel providers must work intimately with the end users to jointly establish fuel stability requirements on a case-by-case basis.

In Phase 3 of the present project, APT utilized an emulsified biodiesel fuel that provided a minimum of four weeks of stability. The distribution chain was intentionally designed to evaluate the stability of the emulsified fuel in a commercial setting with production of the emulsified fuel being accomplished in Sacramento, truck transportation to a separate storage tank at POLA and then daily transfer to the top handler test units by a dedicated daily fuel delivery (Appendix K). In this way, the daily fueling was consistent with normal port operations; however, the emulsified biodiesel fuel was stored in a temporary and separate tanker so that accurate fueling records could be maintained.

Although biodiesel fuels can be important elements in California's low carbon fuel efforts, biodiesel fuels can conflict with California's efforts to reduce NO<sub>x</sub> emissions as part of its State Implementation Plan (SIP) efforts to comply with federal air quality mandates. It has been well documented that conventional biodiesel fuels increase NO<sub>x</sub> emission levels as compared to traditional diesel fuels by as much as 3 to 16% depending on the biodiesel concentration [4]. In other words, a biodiesel fuel containing 20% biofuel (a B20 biodiesel fuel) would emit less NO<sub>x</sub> emissions than a biodiesel fuel containing 50% biofuel (a B50 biodiesel fuel). A further contribution to the variability in NO<sub>x</sub> emissions is the source of the biofuel (e.g. plant or animal derivative) as well as the age, model and duty-cycle of the engine in which the biodiesel fuel is operating.

A limited number of technical studies were previously conducted using water to mitigate or reduce the NO<sub>x</sub> emissions associated with use of biodiesel fuels [2, 5]. However, none of these was developed into a commercial proposition. The technology used to produce the emulsified biodiesel used in the TAP demonstration includes a proprietary, patented and patent pending technology developed by APT.

## **Intent of Demonstration and Achievement**

It was the intent of APT to demonstrate the ability of an emulsified biodiesel fuel with an optimum water content to mitigate the increase of NO<sub>x</sub> emissions associated with regular biodiesel fuels, and to reduce PM emissions while maintaining the operational capability of port equipment and not compromising the other "criteria" (or regulated) emissions.

Relative to baseline diesel fuel emissions, this report demonstrates the following determinations:

- The NOx emissions increase measured when the base diesel fuel is changed to a regular B20 biodiesel fuel is mitigated when the fuel is changed to an emulsified B20 biodiesel fuel as illustrated in Figures 3, 9, 14, and 15 in this report;
- The PM emissions reduction measured when the base diesel fuel is changed to a regular B20 biodiesel is further enhanced when the fuel is changed to an emulsified B20 biodiesel fuel. Further, the cumulative reduction in PM emissions associated with an emulsified B20 fuel - when the emulsified B20 fuel is combined with a DOC after-treatment unit - reaches more than 50% – as illustrated in Figures 4, 8, 10, 11 and 16 in this report;
- The HC and CO emission reductions measured when the base diesel fuel is changed to a regular B20 biodiesel fuel are either neutral or slightly reduced. When the regular B20 biodiesel fuel is changed to an emulsified B20 biodiesel fuel - and that emulsified B20 fuel is combined with a DOC unit – these emissions are significantly reduced as illustrated in Figures 6, 7 and 13 in this report.

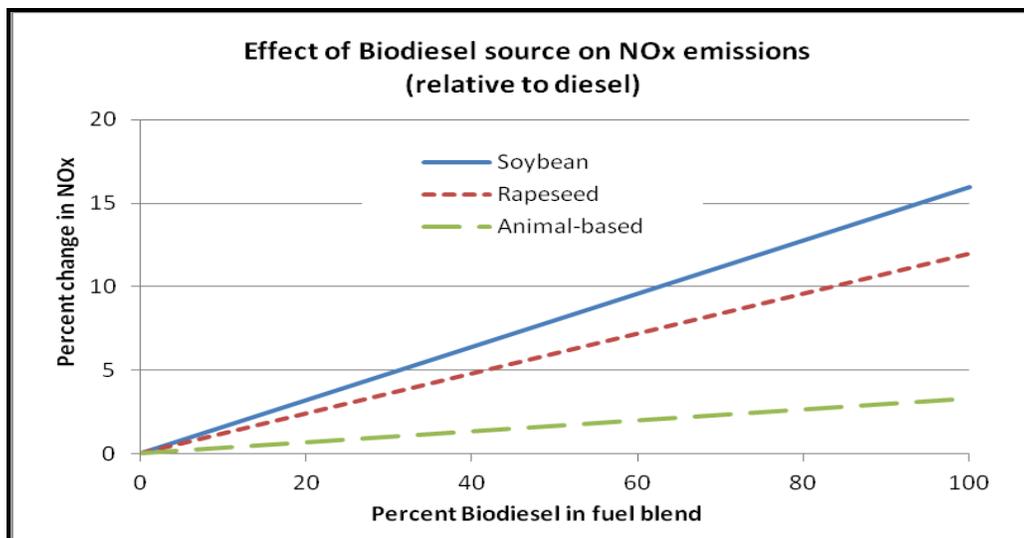
Furthermore, the operability of the test top handler units - when running with the optimal emulsified B20 fuel composition - with and without a DOC unit - was evaluated by the commercial terminal management as follows:

- “During the trial period (4 months) the operators did not report any operational issues with fuel or its use in the top Handlers” (Appendix I)

APT completed the three operational phases of the TAP project and in so doing addressed all of the individual tasks in the original statement of work which is included as Appendix A to this report. AS stated previously, this report constitutes the fourth work phase of the project. A summary of the specific accomplishments of the project – delineated by task - is provided in Appendix B to this report.

## II. Introduction

Biodiesel fuel production has steadily increased during the past decade. In 2009, the US [6] produced over 1700K tons of biodiesel fuel. In Europe [7] the production of biodiesel fuel exceeded 9000K tons. In both Europe and USA, production grew by over 100% in just 3 years. The chief attraction of biodiesel fuel is that it is “renewable”. Part of the hydrocarbon content of the fuel is derived from either crops or animal products and thus from water and atmospheric CO<sub>2</sub>. Additionally, biodiesel fuels reduce national dependence on imported fossil fuels and further reduce vehicle emissions such as CO, PM and HC. This exciting technology has had two notable hurdles with which to contend. The first hurdle regards the calculated reduction of greenhouse gases using a lifecycle analysis - which inevitably contains many factors – that may difficult to quantify. The concept of “Advanced Biofuels” (also referred to as “second generation biofuels”) addresses these factors as it emphasizes the “renewability” aspect by tightly defining what this means. “Renewability” demands that the natural materials must be obtained from existing fallow land and not displace food production – or from algae and/or waste organic matter. The second hurdle to be overcome relates to the fact that one significant diesel engine emission, namely NO<sub>x</sub>, actually increases when burning biodiesel fuels. Although biofuels can be important elements in California’s low carbon fuel efforts, biodiesel fuels can conflict with California’s efforts to reduce NO<sub>x</sub> emissions as part of its State Implementation Plan (SIP) to comply with federal air quality mandates. The EPA has measured the biodiesel NO<sub>x</sub> increase to be between 3% and 16%, depending on the amount of biodiesel in the fuel and on the source of the biofuel content – either vegetable or animal oil [4] as shown in Figure 1.



(US EPA document 420-P-01\_001 [4])

Note: On the x-axis the zero value represents the emissions from diesel alone;  
The 100% value represents % increase in emission with neat biodiesel.

**Figure 1 – Increase in NO<sub>x</sub> Emissions for Biodiesel Fuels**

Various commercial developments featuring water-in-diesel emulsion fuels used up to 20% mass water content in order to maximize the reduction in PM and NOx emissions associated with diesel fuels. Various emulsified fuels have been verified by CARB. For example, "PuriNOx" emulsion fuel commercialized by the Lubrizol Corporation, opted for a water content of up to 20% [8]. This high water content fuel was also registered by the EPA under its fuel registration program [9]. In 1997, a predecessor company to Alternative Petroleum Technologies (APT) showed that the emulsified fuel technology developed by the company could significantly decrease the NOx emissions generated by regular diesel fuels [10]. In 2003, CARB completed formal verification of an emulsified diesel fuel that reduced NOx emissions by 15% and PM emissions by 58% [11]. Likewise, in 2003, the US Environmental Protection Agency (USEPA) registered the emulsified diesel fuel for commercial sale under the auspices of 40 CFR 79.13 [12].

Encouraged by this experience with diesel fuels, APT entered into an agreement with the City of Los Angeles to test the proposition that emulsified fuel technology could likewise decrease the NOx emissions of biodiesel fuels. The resultant project was conducted under the Technology Advancement Program (TAP) of the Ports of Los Angeles/Long Beach. The TAP project consisted of three operational tasks and one reporting task as shown in Appendix A.

Emulsified fuels feature microscopic droplets of water uniformly distributed throughout the base fuel. Normally, the reduction in NOx levels produced by emulsified fuels is directly related to the water content of the fuel. Thus, the CARB verified fuel produced by APT featured water content of 20% that led to a reduction of 15% in diesel oil emulsion (DOE) fuels.

As is usual in engineering, one often has to balance system parameters to produce an optimal solution. Although high water content values can generate large NOx reductions in emulsified diesel fuels, water cannot burn; thus the combustion energy produced by emulsified diesel fuels – with high water contents – normally cannot produce the highest engine power output needed in some operations. Fortunately, emulsified fuel technology allows the composition of emulsified fuels to be varied to accommodate the dual requirements of emission reduction and power production.

### **III. Phase 1: Engine Laboratory Study: Relationship Between NO<sub>x</sub> Emissions, Biodiesel Concentration and Water Content**

The functional objectives of this work phase were as follows:

Objective 1—Evaluate the use of emulsified fuels made from a range of water contents and biodiesel concentrations in an engine family that has been previously verified by CARB for verification;

Objective 2—Determine if any relationship between the water content of an emulsified biodiesel fuel and the NO<sub>x</sub> mitigation it produced for various biofuel test blends could be identified;

Objective 3—Determine what, if any, of the other ‘criteria’ emissions that would be evaluated during the CARB verification process are affected by emulsion technology. Of particular interest would be the net change in HC emissions that resulted from the use of an emulsified biodiesel fuel;

Objective 4—Determine if a DOC unit is effective in reducing the expected increase in HC from an emulsified fuel and what impact the DOC has on the other ‘criteria’ emissions.

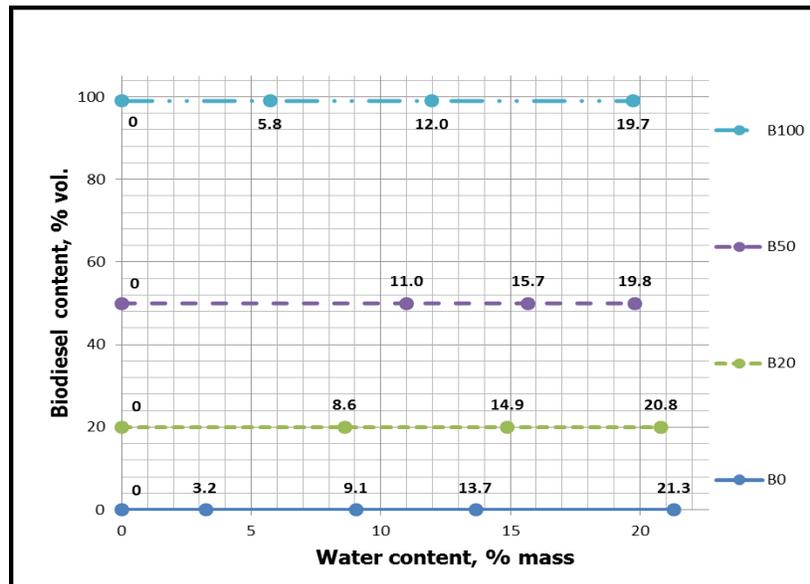
#### **Engine Laboratory Study – w/without Diesel Oxidation Catalyst (DOC)**

APT embarked upon a Screen Testing Program [13] at the internationally recognized Southwest Research Institute (SWRI) in San Antonio, TX, to determine the composition of an emulsified biodiesel fuel that would both neutralize the NO<sub>x</sub> emission increases associated with regular biodiesel fuels as well as minimize the power losses normally associated with water content emulsified fuels.

A detailed engine dynamometer test program comprising 25 experiments (each performed in triplicate), with varying amounts of water and biodiesel in the fuel blend as well as with and without an exhaust gas after-treatment were conducted. The test engine was a 1991 12.7 liter Detroit Diesel Series 60, six cylinder configuration rated at 365 hp at 1800 rpm. The federal FTP was used for performance evaluation and each fuel was tested in triplicate with repetitive hot starts. The diesel fuel was commercial ultra-low sulfur diesel (<15ppm S) and the “neat” biodiesel (B100) fuel complied with ASTM D6751 specification. All the fuels were able to complete the test transient cycles which is required for valid measurements to be conducted. Seventeen of these experiments were performed on the engine without an after-treatment device; eight experiments were carried out on the same engine fitted with a diesel oxidation catalyst (DOC) supplied by Engine Control Systems, Inc. The results obtained without the DOC after-treatment device will be discussed first.

## (i) Results without DOC After-treatment Unit

The range of fuel compositions tested is shown graphically in Figure 2. Although emulsion fuels affect the maximum power output that can be achieved relative to diesel fuel, the engine was able to perform the required accelerations with all of the fuels shown in Figure 2. In practice, experience teaches us that the loss of maximum power output only becomes an issue with a high water content emulsion fuel operating under severe conditions.

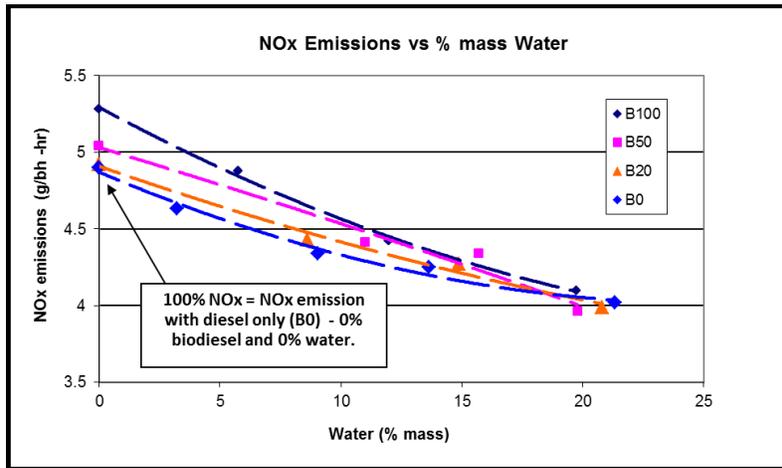


**Note:** The four horizontal lines are the four levels of biodiesel in the blend (0, 20, 50 and 100%v)  
The values along the x-axis are the water content (% mass).

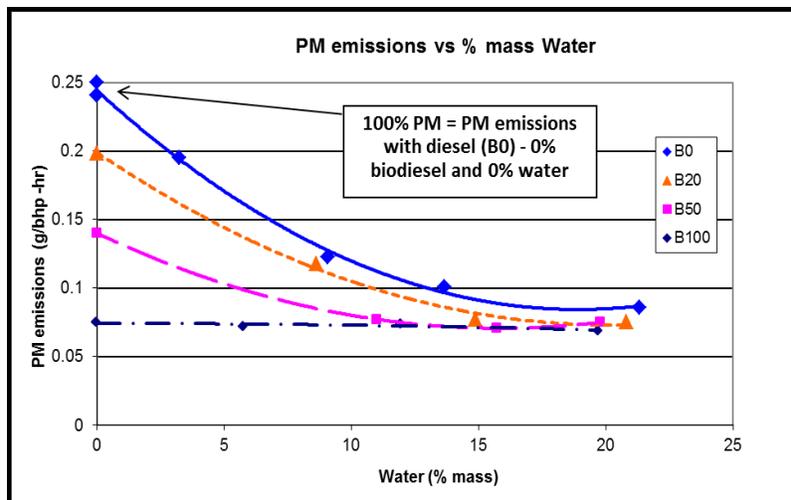
**Figure 2 - Range of Emulsified Biodiesel Fuels in Screen Test (No DOC)**

The effects of changes in the biodiesel content of the fuel on the NO<sub>x</sub> and PM emissions are illustrated in Figures 3 and 4 (tabulated values are shown in Appendix G) In both of these graphs, the intercept on the y-axis is the effect of changing from diesel (B0) to B20 to B50 and to B100 (with no water present). In the case of NO<sub>x</sub>, the intercept is at higher values indicative of an increase in NO<sub>x</sub> as the biodiesel content increases, whereas in the PM graph the y-axis intercepts decrease as biodiesel content increases. PM emissions steadily decrease and NO<sub>x</sub> emissions increase with increasing biodiesel content. This is consistent with published data [4].

Figure 3 shows that the NO<sub>x</sub> emissions for all fuel blends diminish as the water content increases and converge to nearly 4 g/bhp-hr at high water content (around 20% mass water).



**Figure 3: Changes in NOx Emissions with Changes in Fuel Composition**



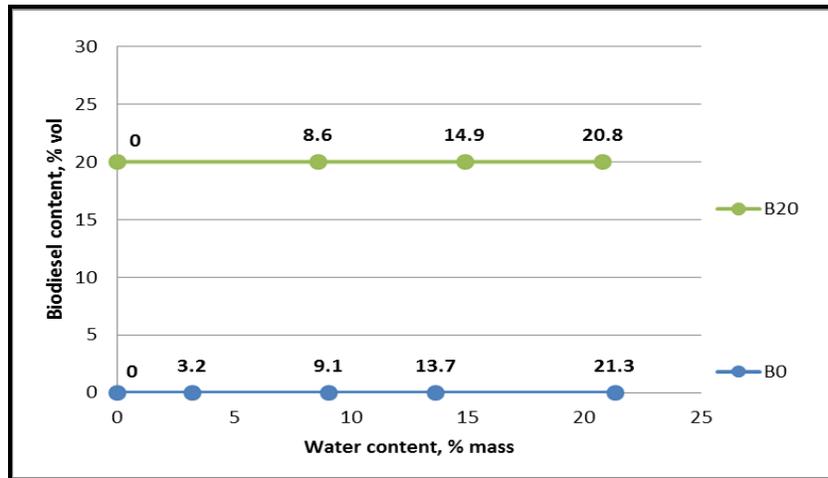
**Figure 4: Changes in PM Emissions with Changes in Fuel Composition**

Figure 4 shows the PM emissions with increasing water content converge asymptotically to around 0.07 g/bhp-hr PM for all the fuels. Exceptionally, for the neat biodiesel, B100, the PM emissions are so low that addition of water has virtually no incremental effect.

### (ii) Results with DOC After-Treatment Unit

A DOC was fitted to the engine and various fuels with varying level of biodiesel and water were tested (Figure 5 shows the experimental matrix of fuels tested). DOCs are fitted as exhaust after-treatment systems in order to fully oxidize the products and by-products of combustion. As such, CO is converted to CO<sub>2</sub>, hydrocarbons, HC or THC (Total Hydrocarbons), are

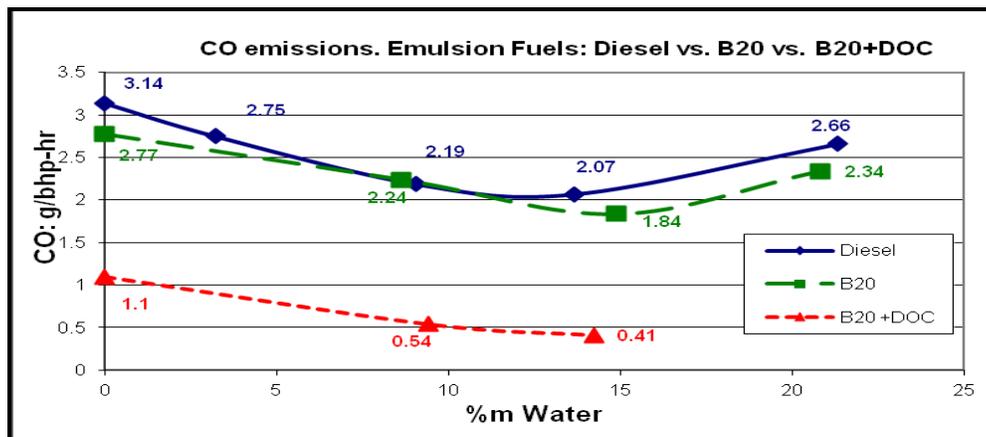
converted to water and CO<sub>2</sub> and particulate matter, PM, which is primarily unburned carbon, is in part converted to CO<sub>2</sub>. The effect of a DOC unit on NO<sub>x</sub> emissions is negligible.



**Note:** Four fuels were tested without water (B0, B20, B50 and B100). The B0 and B20 fuels were also emulsified – the above diagram shows the water content of the emulsified fuels with B0 and B20. The values along the x-axis are the water content (% m)

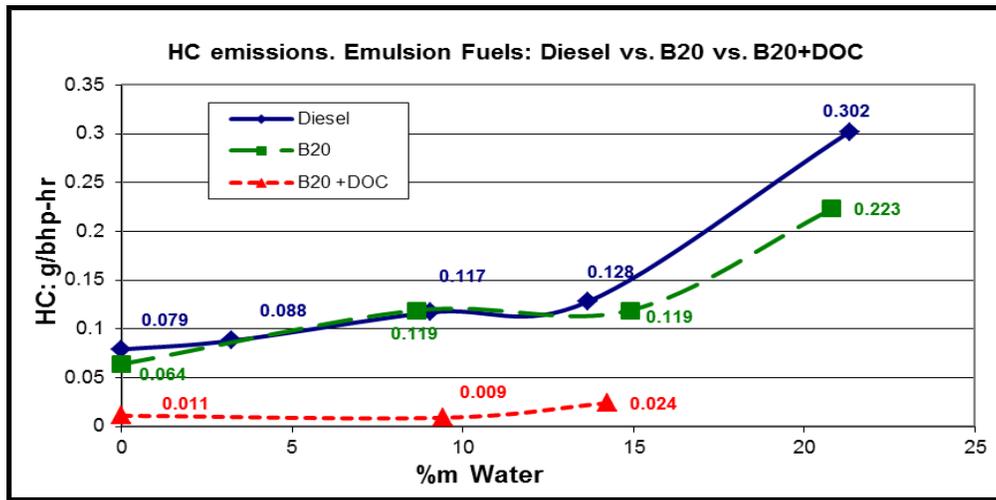
**Figure 5 - Range of Emulsified Biodiesel Fuels in Screen Test (+ DOC)**

The results obtained with emulsified B20 fuel are used to illustrate the trends observed and these are shown in Figures 6, 7 and 8. As a general point, the changes taking place at the lower water content (below 10% mass water) are more significant and of particular interest. Emulsification has a positive benefit on CO emissions. The incorporation of a DOC catalyst has an additional benefit, virtually eliminating CO emissions. (Figure 6)



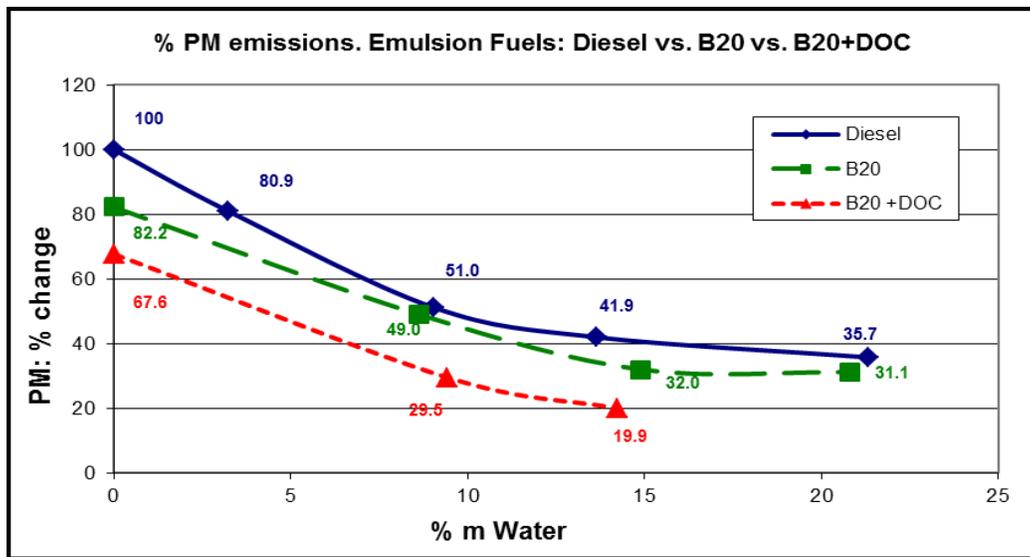
**Figure 6 – CO Emissions – Effect of Fuel Composition and DOC**

In Figure 7 the effect of water is to increase the hydrocarbon emission – hydrocarbon emissions are low in any case and the effect is slight below a 10% water content. The inclusion of a DOC catalyst virtually eliminates HC emissions.



**Figure 7 – Hydrocarbon Emissions – Effect of Fuel Composition and DOC**

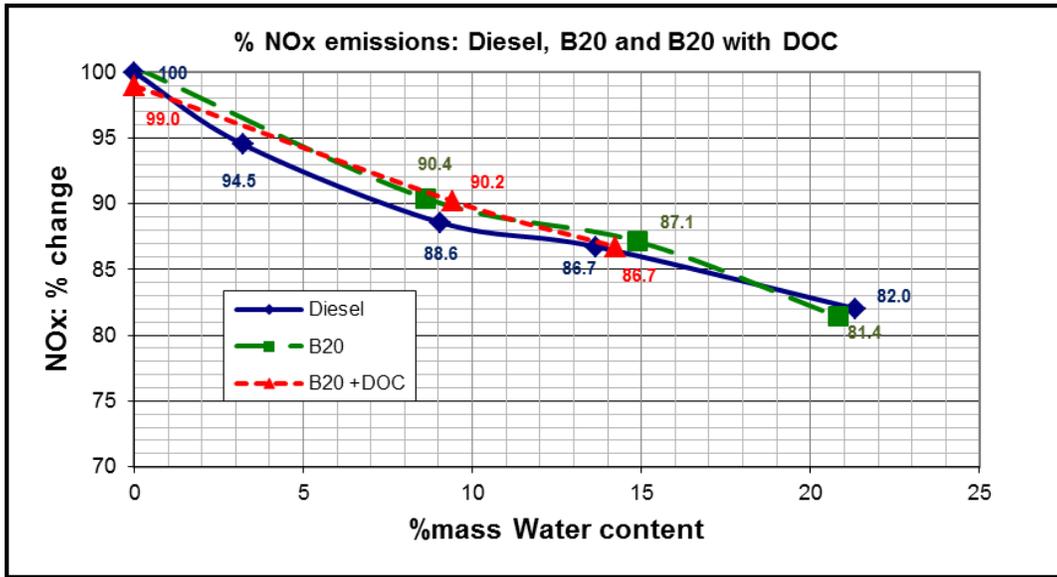
Relative to the low sulfur diesel base fuel, PM emission reductions are achieved when each of the three technologies are introduced, water emulsion, B20, and DOC. The overall reductions achievable with a combination of technologies are impressive (Figure 8).



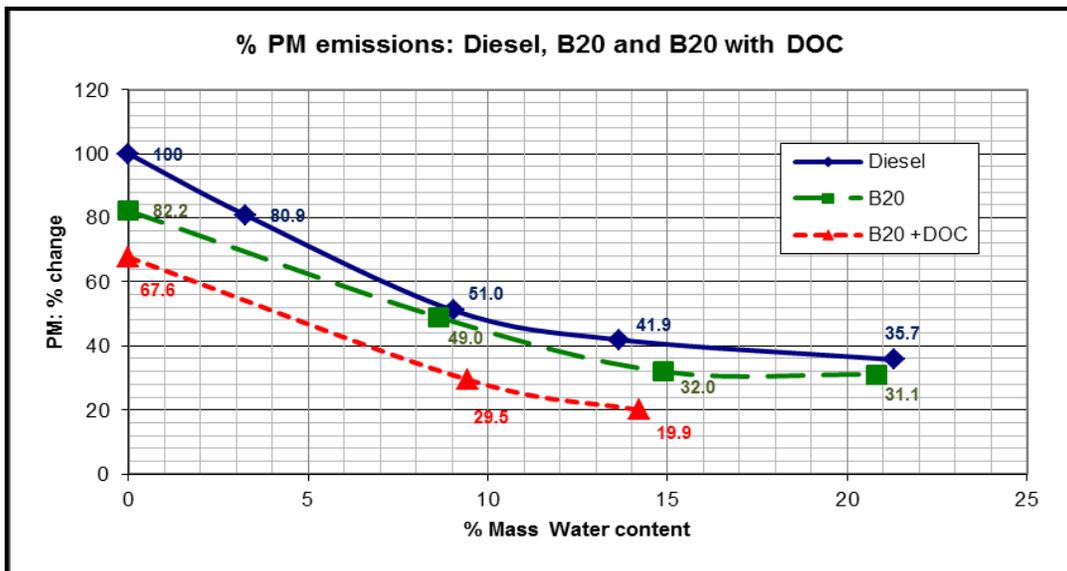
**Figure 8 – PM Emissions – Effect of Fuel Composition and DOC**

### (iii) Discussion of Results

In view of the specific interest in B20 emulsion fuels, Figures 9 and 10 are presented which illustrate the percentage changes in NO<sub>x</sub> and PM emissions respectively with increasing water content. From these graphs it is evident that an approximate 6% mass water in a B20 emulsion fuel would give at least a 6% reduction in NO<sub>x</sub> emissions.



**Figure 9: Percent NO<sub>x</sub> Reductions for B20, Diesel and DOC**

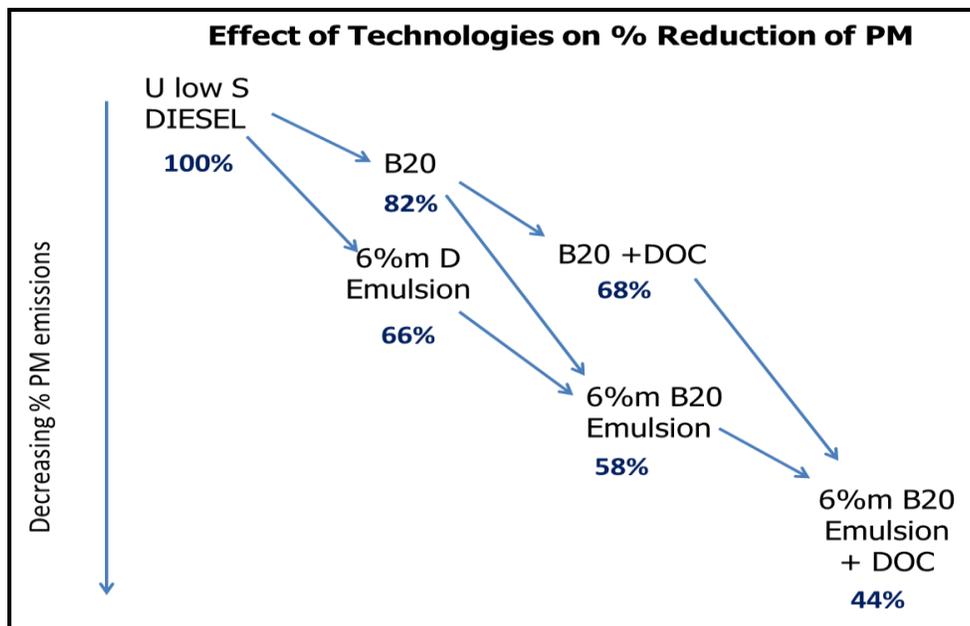


**Figure 10: Percent PM Reductions for B20, Diesel and DOC**

Figure 11 summarizes the effect of the various emissions abatement technologies on PM emission reductions. The emulsification of an ultra-low sulfur diesel fuel – with a 6% (by mass) water content - reduces PM emissions levels by 34%. The PM emission levels of an emulsified ultra-low sulfur diesel fuel are only 66% of the PM levels of a regular ultra-low sulfur diesel fuel.

The emulsification of a regular biodiesel (B20) fuel – with a 6% (by mass) water content - reduces PM emission levels by 42%. The PM emission levels of an emulsified biodiesel (B20) fuel are only 58% of the PM emission levels of regular ultra-low sulfur diesel fuel.

The inclusion of a DOC unit with the emulsified biodiesel (B20) fuel reduces PM emission levels by 56%. The PM emission levels of an engine running on an emulsified biodiesel fuel – with a DOC unit attached to the engine – are only 44% of the PM emission levels of an engine running on regular ultra-low sulfur diesel fuel.



**Figure 11: Effect of Emulsions, Biodiesel (B20) and DOC on PM Reductions**

In other words, an emulsified B20 with 6% mass water will neutralize the NOx increase produced by changing from diesel to B20 and a significant additional benefit in PM reductions are anticipated. Furthermore, the expectation is that the loss in maximum power output would be imperceptible.

## **(iv) Conclusions – Phase 1**

Objective 1 was met by using an FTP procedure where a wide range of biodiesel and water concentrations were evaluated. It was observed that a 6% water content emulsion of a 20% biodiesel (B20) fuel was the “optimal” blend that provided for a balance of NOx mitigation and engine power level.

Objective 2 was met and a relationship between water content and NOx mitigation was established. In summary, it was determined that higher water content emulsions were required to mitigate the higher NOx associated with greater concentrations of biofuel in biodiesel fuel blends.

Objective 3 was met and it was determined that with respect to the other “criteria” emissions: a) the emission benefits for emulsion fuels and the emission benefits for the biodiesel fuels have complimentary aspects for PM emission reductions; b) CO emissions were decreased or unchanged for emulsified biodiesel fuels; c) HC emission reductions due to biodiesel contents offset the emission increases of HC due to emulsions in part.

Objective 4 was met and a DOC proved effective in eliminating the HC increase associated with the emulsified fuel without compromising the other “criteria” emissions.

## **IV. Phase 2: Evaluation of the Optimized B20 Emulsified Fuel With/Without DOC After-treatment Unit**

The functional objectives of this study were as follows:

Objective 1 — Identify an engine family that is indicative of common engines used in top handler equipment at the Port in high peak performance applications and test it at a California based laboratory recognized by CARB for verification programs using an emulsified B20 biodiesel fuel with a 6% water content for NOx mitigation;

Objective 2 — Determine what, if any, of the other “criteria” emissions are affected by the technology blend of biofuel and emulsification;

Objective 3 — Observe the changes in emissions when using an emulsified B20 fuel with and without a DOC unit;

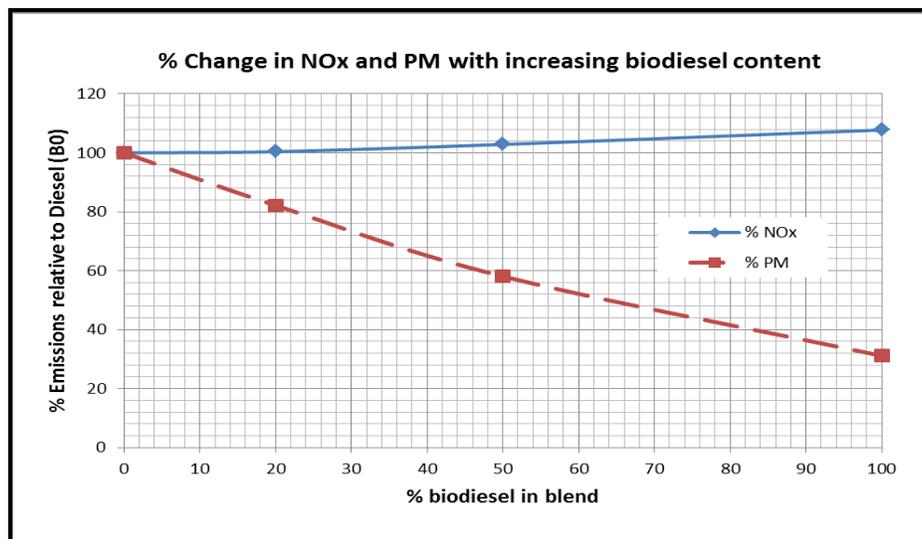
Objective 4 — Determine the impact of a B20 and emulsified B20 with and without a DOC on engine fuel consumption.

Objective 5 — Determine the impact of a B20 and emulsified B20 fuel - with and without a DOC - on engine speed and torque.

In this work phase of the project, the conclusions of Phase 1 were further evaluated in an engine test study (Phase 2) prior to the real-time field evaluation that would be accomplished in the final (Phase 3) project activity. This second engine evaluation – which focused on emulsified B20 biodiesel fuels with 6% (by mass) water content (the “optimal” fuel) - with and without DOC unit installed on the test engine - is now presented in detail.

An important issue to be considered was the type of biodiesel to use in this Phase 2 study. In Figure 12 the changes in NOx and PM emissions observed in Phase 1 with respect to changes in biodiesel content are shown. The NOx increase for a B20 is less than 2% and is approximately 8% for the B100 fuel. From these data it can be surmised that the fatty acid methyl ester is similar to the “animal-based” biodiesel as shown in Figure 1. The soy-based biodiesel fuel clearly represents a worse fuel with a predicted NOx increase for the B20 blend that is approximately twice as high. For this reason it was decided to select the soy-based biodiesel fuel for Phase 2 testing.

This second study [14] was conducted at Olson EcoLogic Engine Testing Laboratories, which is an independent, state-of-the-art emission testing facility that has received compliance recognition from the CARB, EPA and the Texas Commission for Environmental Quality (TCEQ).



**Figure 12: % Changes in NOx and PM Emissions vs. Biodiesel Content ~ Phase 1 Study**

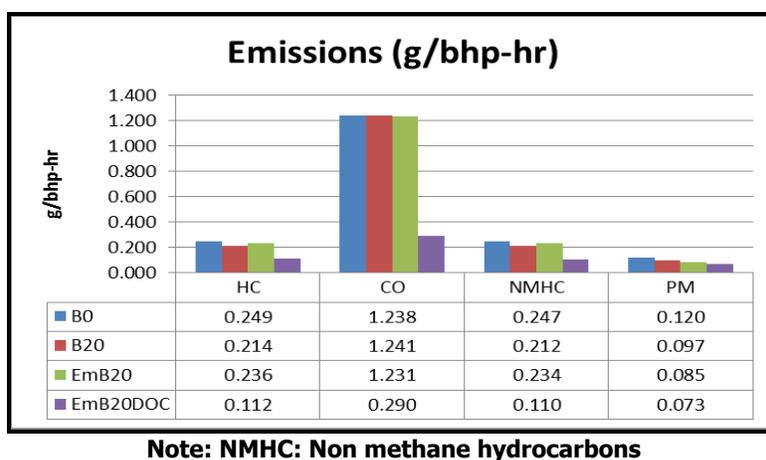
A Tier 2 Model Year 2004 Cummins QSM 11C engine was chosen as the test engine. It was representative of the engines installed in the top handler units that would be featured in the Phase 3 field evaluations. The QSM 11 C is rated at 330hp at 2100 rpm. Its emissions were shown to comply with associated standards. The engine was tested according to the non-road transient cycle (NRTC), an engine dynamometer transient driving schedule of a total duration of 1200 seconds. The data record from this testing at the Olson EcoLogic Laboratories is shown in Appendix H.

## (i) Engine Emissions Results

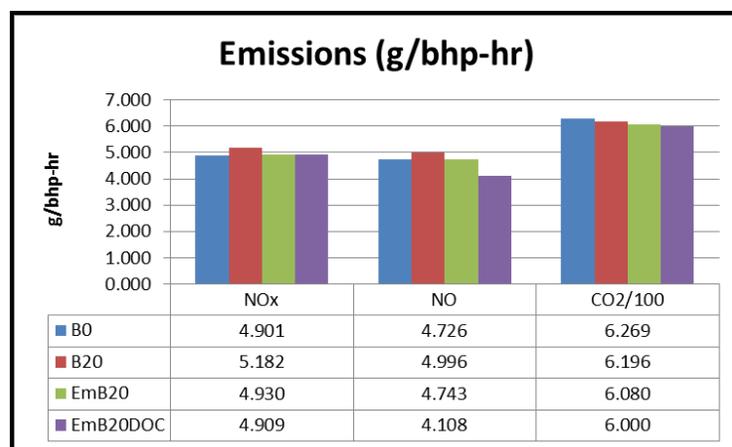
The baseline diesel fuel tested was a commercial California ultra-low sulfur diesel fuel. The B100 "Neat" Biodiesel was prepared by Community Fuels in Stockton, California from 100% soybean biodiesel feed stock (see Appendix C for the Certificate of Analysis for the B100 fuel). The B20 blend was prepared at the Ramos Oil Terminal in West Sacramento, CA.

The fuel properties and characteristics are shown in Table 1 below. The stable emulsion was prepared using an APT commercial blender and additive. The emulsified fuel, EmB20, used in this study was found to contain 6.55% mass water (Karl Fischer method).

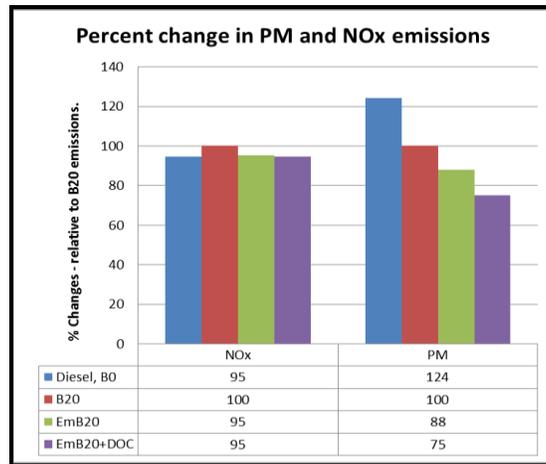
Four NRTC dynamometer tests were conducted (in duplicate) using the following fuels: Diesel (low Sulfur), B20 biodiesel blend, Emulsified B20 (EmB20) with 6.55% mass water, and EmB20 with diesel oxidation catalyst (DOC). The results are summarized in Figures 13, 14 and 15:



**Figure 13: Emissions with B0 (diesel), B20, EmB20 and EmB20+DOC Unit**

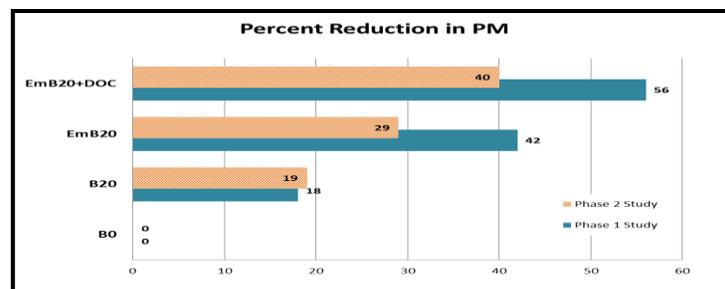


**Figure 14: Emissions with B0 (diesel), B20, EmB20 and EmB20+DOC Unit**



**Figure 15: Relative Changes in PM and NOx Emissions (B20 = 100%)**

- The increase in NO<sub>x</sub> (Figure 14) from B0 (diesel) to B20 (biodiesel) is 5.7% - higher than the reported 3-4% increase for B20 (Soybean) biodiesel fuel [3] shown in Figure 1;
- A 6.55 % water content Emulsified B20 Fuel effectively mitigated the NO<sub>x</sub> increase associated with regular biodiesel fuel;
- The NO<sub>x</sub> mitigation occurred under the most difficult conditions i.e. highest NO<sub>x</sub> increase as a result of the combination of a soy-based biodiesel (5.7% NO<sub>x</sub> increase versus ULSD fuel) and a transient test cycle;
- The HC increase was effectively controlled by the use of a low water emulsion (a point of contrast with high water content emulsions). Indeed the HC and CO emissions for EmB20 fuels are lower than those seen in B0 (diesel) fuels, Figure 13;
- The DOC unit was able to more than halve the emissions of HC, CO and NMHC (non-methane hydrocarbons) seen in Phase 1. Figure 15 illustrates the stepwise reduction in PM emissions when the fuel is changed from diesel (100%) to B20 (81%) to EmB20 (71%) and to EmB20+DOC (60%). This is also illustrated in Figure 16, which shows the reductions measured in both the Phase 1 and 2 studies.



**Figure 16: Reductions in PM by B20, EmB20 and EmB20+DOC Unit**

## (ii) Speed, Torque and Fuel Consumption

Table 1 below lists the fuel use, speed and torque averages measured for each test fuel:

**Fuel/g:** The total amount of fuel used throughout the Test - measured as a gravimetric difference.

**Speed:** Engine speed – average throughout the cycle.

**Torque:** Engine torque - average throughout the cycle.

Fuel Consumption: The water content of the emulsified biodiesel test fuel – measured by the Karl Fischer method- was found to be 6.55% mass. The additive has a calorific value close to the base fuel as shown in Table 2. Therefore, it is included as part of the base fuel in subsequent determinations.

As the engine testing demonstrated, if there is no change in fuel efficiency when changing from B20 to EmB20 then – as shown in Table 1 below - the expectation will be that 107g of EmB20 will be used for every 100g of B20 when performing the same duty cycle. From Table 2 it appears that a fuel consumption penalty (2.1%) results when changing from diesel to regular B20 biodiesel. This is due to the lower calorific value of the fatty acid methyl ester relative to diesel (a hydrocarbon). The increase in fuel consumption for emulsified biodiesel fuel (EmB20) is slightly less than expected – by 0.1%.

<b>Fuel</b>	<b>Average:</b>	<b>Fuel/g</b>	<b>Speed/rpm</b>	<b>Torque/ft-lb</b>
<b>Baseline, B0</b>	A	8322	1655	401
<b>B20</b>	B	8507.5	1655	400
<b>EmB20</b>	C	9087.5	1657	398
<b>EmB20+DOC</b>	D	9070.5	1655	398

	<b>FC %m</b>	<b>% rpm Sp</b>	<b>%ft-lb Tq</b>
<b>Baseline, B0</b>	100	100	100
<b>B20</b>	102.1	100.0	99.7

<b>B20</b>	100	100	100
<b>EmB20</b>	106.9	100.1	99.3
<b>EmB20+DOC</b>	106.7	100.0	99.5

**Table 1: Actual and % Changes in Fuel Consumption (FC), Speed (Sp) and Torque (Tq) with Changes in Fuel and After Treatment**

<b>Fuel</b>	<b>Density (19°C)</b>	<b>% mass</b>
<b>B20</b>	0.842	93.45
<b>Water</b>		6.55
<b>EmB20</b>	0.855	100.00

<b>Fuel Property</b>	<b>Test Method</b>	<b>EMB20</b>		<b>B20</b>		<b>Additive</b>
Heat of Combustion, Gross, BTU/lb ( <i>MJ/kg</i> )	D240	17887 (41.606)	17869 (41.563)	19215 (44.695)	19218 (44.701)	16335 (37.995)
Heat of Combustion, Net, BTU/lb ( <i>MJ/kg</i> )	D240	16701 (38.848)	16683 (38.805)	18009 (41.889)	18013 (41.899)	15325 (35.647)

**Table 2: Composition of Emulsified B20 Biodiesel Fuel**

Speed and Torque: The speed remained remarkably consistent during all of the engine tests. However, the torque was reduced slightly (by 0.3%, 0.7% and 0.5% for B20, EmB20 and EmB20DOC relative to diesel). Excellent repeatability of the test runs helped identify slight differences in torque between fuels. There does appear to be a change in the speed – torque relationship as the calorific value of the fuels change, resulting in a slight loss of torque and a slight gain in fuel economy.

A summary of the observations from this phase are that for B20 emulsion containing 6.55% water, no significant change in power, speed and torque would be expected in operation. It is worth noting that emulsion fuels containing 13% mass water have been in commercial use for many years in Europe without significant operational difficulties. The overall impact, positive and negative, through addition of water, biodiesel, DOC after-treatment and water-biodiesel emulsion with DOC after-treatment are illustrated in Table 3 below.

	<b>Changes relative to Diesel</b>			
	<b>Water</b>	<b>B100</b>	<b>DOC</b>	<b>EmB20+DOC</b>
<b>THC</b>	+	-	-	-
<b>CO</b>	-	-	-	-
<b>NOx</b>	-	+	0	-
<b>PM</b>	-	-	-	-

Key: (-) indicated a reduction in emissions; (+) indicates an increase; (0) indicates no change

**Table 3: H<sub>2</sub>O & Biofuel in Diesel With/Without DOC: Effects on Emissions**

### **(iii) Conclusions – Phase 2**

Objective 1 was met. The Cummins QSM 11C was identified as the appropriate engine and evaluated in a qualified laboratory - with and without a DOC after-treatment unit. The testing demonstrated that a 6% water emulsion effectively mitigated the NOx increase associated with the regular B20 biodiesel fuel. However, it was noted that the NOx emissions generated from the B20 base fuel was higher than the levels reported by the EPA. It is expected that this increase is primarily a function of the soy feedstock in the biofuel component of the emulsified B20 biodiesel fuel.

Objective 2 was met and analysis of the other “criteria” emissions revealed an unexpected finding. The HC for the emulsified biodiesel fuel was lower than the baseline diesel fuel. Thus, a DOC is not required for reducing all “criteria” emissions as originally suspected.

Objective 3 was met and the DOC unit results complemented all of the reported emission reductions of the emulsified biodiesel.

Objective 4 was met and it was observed that for a B20 biodiesel fuel, consumption increased in proportion to the lower calorific value of the biodiesel fuel, in agreement with theoretical estimates. With emulsified B20 biodiesel fuel, the consumption was also as expected after correcting the B20 biodiesel fuel consumption for added water content.

Objective 5 was met and it was observed that for regular B20 biodiesel fuel there was no noticeable impact on speed and torque. For emulsified B20 biodiesel fuel, speed remained unchanged while torque was slightly reduced.

## V. Phase 3: Planning/Execution of a Real-time Field Demonstration

The functional objectives for this phase of the work were as follows:

Objective 1 — Operate the optimum emulsified biodiesel in top handlers used in normal waterfront activities and determine if the operators of the equipment observe any differences in units operations;

Objective 2 — Observe any changes when using a DOC unit in combination with the optimal emulsified biodiesel fuel blend;

Objective 3 — Evaluate the consumption of the emulsified B20 biodiesel fuel compared to both the regular B20 biodiesel fuel as well as the standard diesel fuel;

Objective 4 — Monitor the production, transportation, storage and daily delivery of the test fuels;

Objective 5— Provide an overview of the existing quality control standards for emulsified fuels and the APT approach to quality control of its emulsified biodiesel product.

### (i) Test Plan for Field Demonstration

The test plan for the utilization of emulsified biodiesel fuel at the Port of Los Angeles (POLA) waterfront contained both strategic and tactical determinations.

The first strategic determination concerned the supplier of the biodiesel fuels used in the demonstration. After a thorough review of in-state California suppliers of biodiesel fuel, APT chose Community Fuels of Stockton, CA. The company operates an analytical laboratory with state-of-the-art instrumentation for accomplishing the full suite of fuel analyses. This asset assures that its products continuously meet the American Standard Test Method, ASTM D6751 Standard Specification for Biodiesel Fuel Blend Stock (B100) and ASTM D7467 for B6 to B20 blend fuels and for Middle Distillate Fuels as well as American Oil Chemist Society (AOCS) methods for assessing biodiesel feedstock quality.

The second strategic determination concerned the site location for the blending of emulsified biodiesel fuel. APT had previously blended emulsified diesel fuel at the Dixon, CA terminal of the Ramos Oil Company for customers in northern California. Subsequent negotiations resulted in Ramos providing a dedicated production tank where emulsified biodiesel fuel could be segregated from regular diesel fuel storage prior to the loading of tanker vehicles for transport of the emulsified biodiesel fuel to POLA.

APT provided the emulsified biodiesel fuel blending unit and delivered sufficient quantities of its proprietary additive to periodically blend the tanker volumes necessary to support demonstration activities. APT also sampled and recorded the composition of every batch of emulsified biodiesel fuel produced at the Ramos terminal to insure the continuous quality of the emulsified biodiesel fuel delivered to POLA.

The final strategic determination that was affected concerned the selection of the partner at the POLA waterfront that would utilize emulsified biodiesel fuel in its cargo handling operations. In this regard, Ports America personnel had previous experience in using the "PuriNOx" emulsified diesel fuel product and readily volunteered to test the new emulsified biodiesel fuel product.

The primary tactical determination that was affected concerned the actual disposition of the emulsified biodiesel test fuel at the waterfront. In order to avoid unnecessary construction costs that would accompany a permanent storage tank installation at the port, it was decided that the blended emulsified biodiesel fuel would be off-loaded to a storage tanker truck provided by the General Petroleum Company at the port.

In addition to providing cost-effective segregated storage of the emulsified biodiesel test fuel, this tanker storage also facilitated the final disposition of the emulsified biodiesel test fuel to the individual top-handler units involved in the actual demonstration activities at the waterfront.

Once all of the business submissions necessary to support the test plan were signed off by all of the principals, the performance of the proposed demonstration commenced. The execution of subsequent demonstration activities are now reported in detail.

## **(ii) The Field Demonstration**

Three primary activities constituted the waterfront demonstration performance for emulsified B20 biodiesel fuel:

1. Operation of three top-handler units on regular B20 biodiesel fuel;
2. Operation of three top-handler units on emulsified B20 biodiesel fuel;
3. Operation of one top-handler unit on emulsified B20 biodiesel fuel with a DOC

Demonstration activities began on August 12, 2010 when "red" (i.e., untaxed) B20 biodiesel fuel was loaded into three MY 2008 Taylor top handler units at the Western Basin Container Terminal (WBCT) in the Port of Long Beach. Each top handler unit was powered by a 330 HP Cummins QSM11 diesel engine. Regular fueling practices were maintained during all subsequent operations at the waterfront.

The record of regular B20 biodiesel fuel utilization follows:

- 697 hours over 27 days for 3 top-handler units.
- 2908 gallons of soy based B20 biodiesel consumed.
- 25.8 hours (total) per day average of top handler operation.

- 8.6 hours per day average per top handler unit.
- 108 gallons per day average fuel consumption.
- 4.17 gallons per hour (GPH) average per top handler unit.
- An approximate 4.3% increase in gross fuel consumption compared to the 4.0 gallons per hour (GPH) of diesel fuel consumption provided by Ports America for the WBCT top handler fleet.
- It was noted that B20 biodiesel fuel had demonstrated a 2.45% increase in brake specific fuel consumption (BSFC) versus ultra low sulfur diesel (ULSD) fuel during the QSM11 engine dynamometer testing.
- Regular/established equipment maintenance schedules were maintained.
- No operational issues reported/all processes “transparent” to equipment operators.

On September 3, 2010, operations of the top handler fleet on emulsified B20 fuel commenced. Operations of the three units continued – without interruption – until January 21, 2011. The record of emulsified B20 fuel utilization follows:

- 2,742 hours over 118 days (excluding holidays and Sunday).
- 12,300 gallons of soy based emulsified B20 biodiesel consumed.
- 23.3 hours per day average total top handler operation.
- 7.8 hours per day average per top handler.
- 104 gallons per day average fuel consumption.
- 4.48 gallons per hour average per top handler.
- An approximate 11.0% increase in emulsified fuel consumption (which includes the water content of the emulsified fuel) as compared to the 4.0 GPH of diesel fuel consumption provided by Ports America for the WBCT top handler fleet.
- It was noted that emulsified B20 biodiesel fuel had demonstrated a 10.4% increase in BSFC versus ULSD fuel measured during the QSM11 engine dynamometer testing.
- Regular/established equipment maintenance schedule maintained.
- No operational issues reported/all processes “transparent” to equipment operators.

On November 5, 2010, one of the top handlers units operating on emulsified biodiesel fuel was fitted with a DOC. This top handler unit continued operating on emulsified B20 fuel until the conclusion of the demonstration period on January 21, 2011. The complementary operation of an alternative fuel (emulsified biodiesel fuel) together with a verified after-treatment (DOC) technology proceeded without any reported “operational issues” by equipment operating personnel. A letter (Appendix I) dated January 26, 2011 from Ports America – the company managing the top-handler fleet at the waterfront - indicates that individual operators of the equipment running on the emulsified B20 biodiesel fuel “did not report any operational issues with the fuel and its use...”

### **(iii) Emulsified Fuel Quality Standards**

Diesel fuels can be a significant operating cost for a company that uses a fleet of engines in vehicles or operating equipment. Thus, typical diesel consumption occurs within days or weeks of its purchase to minimize the working capital requirements of the company. Emulsified fuels are typically designed for a shelf-life of four to eight weeks to conservatively account for production, delivery, storage and fuel dispensing. For this reason, emulsified fuels should not be left in seasonal vehicle or other equipment tanks which will be idle for more than a month.

Water is denser than oil. The dispersed water droplets, especially the larger droplets, will therefore tend to gravitate towards the bottom of the storage tank. Consequently, if the tank stands for more than two or three weeks without agitation, the emulsified fuel at the top and bottom of the storage tank may have lower and higher water content respectively than the average in the entire storage tank. For this reason the European standards for emulsified fuels recommend a gentle circulation on the storage tanks (one tank turnover per day).

Emulsions are vulnerable to aging, which can lead to two forms of deterioration. The first is a physical change termed 'sedimentation', which is easily reversed; and the second is 'phase' instability, not easily reversed nor corrected. Appendix D provides a more scientific explanation of physical change vs. phase instability. APT emulsified biodiesels are designed for four to eight weeks stability by minimizing both the effects listed above. This is accomplished through a combination of surface-active additives and mechanical mixing.

Our studies indicate that the emulsified fuel is comparable to diesel in many of its handling and physical properties. It is possible for example to change the fuel in the vehicle tank from diesel to emulsion and vice versa without adverse consequences. It is recommended that the changeover is carried out when the fuel tank is near empty (below 25% of the volume of the fuel tank).

Emulsified fuels contain surfactants and have a tendency to clean and keep vehicle fuel systems clean, which is viewed as a benefit. However emulsified fuels must never be placed in dirty storage tanks – indeed this is also a recommendation for ordinary diesel fuel; emulsified fuels must therefore be placed in a clean tank, free of debris, fungi and bacterial contamination.

Over the last two decades, APT has developed a comprehensive range of analytical techniques to evaluate and tailor the stability of its emulsions. While many of the analytical techniques are proprietary, APT encourages and assists potential customers to review the various fuel standards specifically designed for emulsified fuels in Europe as well as the underlying analytical techniques. Some of the analytical techniques are summarized in Appendices E and F

Each production run of the emulsified biodiesel produced for the demonstration activity under the TAP program was evaluated using APT internal standards using the test methods referred to in Appendix F. Sampling and testing of the freshly made emulsions and weekly samples of emulsion in storage and in the vehicle tanks were taken and examined in our laboratory. In all cases the minimum quality control acceptance standards were comfortably met.

For the purposes of the TAP demonstration, APT marketed a “shelf life” of the emulsified biodiesel of at least 30 days. In fact, the initial consumption of the target top handlers was lower than anticipated in August and September so the first production batch of emulsified biodiesel manufactured in early August was extended out more than six weeks.

While the fuel continued to pass the APT pass/fail criteria, APT recognized an accelerated deterioration of the samples taken from the field from those retained from the initial production after about one month of in-field storage. At one point, APT suspected a contamination had occurred during transportation or storage of some sort; however, APT ultimately realized that the weekly samples were being taken directly from the fuel dispenser during the regularly scheduled session.

The fuel dispenser was at the end of a long black hose that was connected to the tank. Thus, the residual emulsion left in the hose was exposed to tremendous heat during the day and night. The exposure to heat and direct sunlight accelerated the aging of the emulsified fuel compared to that in the storage tank.

APT promptly rectified the situation by changing the sampling procedure so the sample was not taken of the aged fuel in the hose and also instituted a recirculation mechanism so the emulsified fuel residual from the previous day was re-circulated back into the tank before fueling into the transfer fueling truck, which ultimately fueled the top handlers.

By the time APT identified the source of the issue it had already implemented a process of periodic recirculation of the emulsified fuel in storage. As expected, each time the aged emulsified fuel was re-circulated its characteristics were returned to those comparable to its initial production. (However, its extended life was not the same as a “fresh emulsion”.)

The long-term impact of emulsified biodiesel is a subject that APT is constantly evaluating. Given that B20 as a stand-alone fuel has not been heavily commercialized for an extended period of time, and given the variables in the biofuel portion of the B20, APT is currently evaluating a number of additional testing venues. In fact, APT is attempting to work with the Ports of America to continue their use of the emulsified B20 in their top handlers for an extended period of time among other initiatives.

### **(iv) Conclusions – Phase 3**

The overall functional objectives of this phase of the project were satisfactorily accomplished:

Objective 1 was met and no operational difficulties were reported by operators. There was no perceptible difference between the operations of the Taylor top handlers with the various fuels used during the demonstration.

Objective 2 was met and it was noticed that the incorporation of the DOC unit had no perceptible effect on the operation of the Taylor top handler units.

Objective 3 was met and it was observed that during the field trial with regular B20 fuel, that the regular B20 fuel consumption was as expected from phase 2 trials. Emulsified B20 fuel consumption was also similar to that observed in phase 2 trials and as expected from theoretical estimations.

Objective 4 was met and it was demonstrated that the production, transportation, storage and daily dispensing of the emulsified biodiesel fuel required no significant modifications to the operations other than at the production site for the emulsified fuel in Sacramento and the dedicated tank for its storage in Los Angeles.

Objective 5 was met and a brief overview of the background and methodology of APT quality control and analytical procedures was provided to insure that each batch of the emulsified fuel met APT quality standards. However, it was noted that the unused fuel in the dispensing hose required a special procedure for recirculation of the fuel. Further, it was noted that the emulsions aging over time could be corrected in part with mild recirculation in the storage tank.

## **VI. Overall Conclusions**

This Final Report on the emulsified biodiesel fuel demonstration concluded at the Port of Los Angeles includes information from the three primary activities conducted under the auspices of the port TAP project. In summary those activities were:

### **Phase 1: Engine Laboratory Study of Emulsified Biodiesel Fuels**

This Phase involved operations performed at the Southwest Research Institute Laboratories to determine the relationship between NO<sub>x</sub> Emissions, Biodiesel Concentration and Water Content. It was observed that regardless of concentration of Biodiesel, an emulsion can effectively mitigate the resulting increase in NO<sub>x</sub> emission. It was determined that the optimal composition that would neutralize the NO<sub>x</sub> emissions from an emulsified B20 fuel as compared to regular B20 fuel was approximately 6% by mass of water;

### **Phase 2: Evaluation of the Optimized Emulsified B20 Fuel**

Studies performed at Olsen Ecological Laboratories on the same engine that was to be used in the subsequent field demonstration measured a higher than expected NO<sub>x</sub> increase with a

regular B20 fuel relative to the diesel baseline fuel. However, the emulsified B20 fuel (containing 6% water) completely eliminated this increase and restored the NO<sub>x</sub> emissions to the same level as that experienced with the baseline diesel. Additionally the recorded PM emissions - reduced by the change over from diesel to B20 fuel - were further reduced by the change over from regular B20 fuel to emulsified EB20 fuel – by almost double. All other emissions measured with the optimized EB20 fuel were either lower or equal to the levels recorded with diesel fuel. The inclusion of a DOC after-treatment unit was shown, as expected, to be neutral with respect to NO<sub>x</sub>, emissions and to have a significant beneficial effect on PM, CO and HC emissions.

### Phase 3: Planning and Execution of Real Time Demonstration

During the field trials, the drivers of Taylor top handlers observed no positive or negative influences of using emulsified biodiesel fuel. Emulsified fuel handling logistics required no changes other than a small modification to handle residual fuel in the dispensing line

It is to be noted that the successful demonstration of EmB20 fuel use at the San Pedro Ports described in this final report was a “California Team” effort involving several Golden State commercial entities. The biodiesel base fuel for the project was supplied by the Community Fuels plant in Stockton, CA to the Ramos Oil terminal in Sacramento, CA where it was blended with water and additive to produce the emulsified biodiesel EmB20 test fuels. The EmB20 test fuels were transported to a fuel truck owned by the General Petroleum (GP) Company in San Pedro, CA. GP distributed the EmB20 Fuel to top handler units that were operated by the Ports America Company in the San Pedro Ports. This “California Team” distribution chain that conducted the successful Emulsified Biodiesel Fuel Demonstration Project at the Port of Los Angeles is depicted in Appendix K of this Final Report. By achieving NO<sub>x</sub> neutrality, biodiesel fuel emulsion technology allows the full benefits of a biofuel to be realized. In this regard, it is instructive to consider the CO<sub>2</sub> reductions. Determination of carbon dioxide level reductions utilizing the emissions calculator at the National Biodiesel Board (NBB) website<sup>1</sup> shows that the 12,300 gallons of which 92% i.e., 11,316 gallons is the actual consumption of B20, the rest being water (adjusted for its relatively heavier specific gravity and additive). Emulsified biodiesel fuels consumed during the demonstration period of 118 days helped the port reduce total carbon dioxide emission levels on the order of 36.5K pounds as detailed in Appendix J.

## VII. Next Steps

Building on the success of this first demonstration of Emulsified Biodiesel Fuel Technology in the San Pedro Ports, APT will pursue an expansion of the technology in three phases:

1. Demonstration of emulsified biodiesel fuel operations in additional top-handler units equipped with Diesel Particulate Filter (DPF) units;
2. Demonstration of emulsified biodiesel fuel operations in additional port equipment, e.g., rubber tire gantry (RTG) cranes;
3. Acquisition of CARB Verification for emulsified biodiesel fuel.

APT will seek to extend the purview of the existent project to include fueling top handler units equipped with Diesel Particulate Filter (DPF) units with emulsified biodiesel fuel. In this way, the emission characteristics of emulsified biodiesel fuel working in conjunction with a complementary after-treatment technology can be cost-effectively analyzed.

The versatility of emulsified biodiesel fuels for port operations will be validated by operating the fuel in RTG cranes at the waterfront. The larger engine power ranges (600 HP+) and different duty cycles experienced by the RTG units will serve to illustrate the full range of emulsified fuel capability to serve in all domains of port operations.

Finally, APT will lay the groundwork for further extension of emulsified biodiesel fuel utilization at port entities by seeking CARB verification of the technology. Building upon previous operations with the port as well as supporting laboratory studies accomplished in support of the introduction of the technology into the San Pedro ports, APT will set a full verification program in motion. In this regard, fundamental verification exercises will be set for execution at the Center for Environmental Research & Technology (CERT) at the University of California, Riverside (UCR).

## References

1. Bertola, A., Li, R., Boulouchos, K., "Influence of Water-in-Diesel Emulsions and EGR on Combustion and Exhaust Emissions of Heavy Duty DI-Diesel Engines Equipped with Common-Rail Injector System". SAE 2003-01-3146.
2. Szybist, J; Simmons, M; Druckenmiller, M; Al-Quarashi, K; Boehman, A; Scaroni, A "Potential Methods for NOx Reduction from Biodiesel". SAE 2003-01-3205.
3. Spataru, A "Emulsion Fuels in Western Europe – An Overview" ARB/ CEC Alternative Fuel Symposium (2003). [www.emfuel.com/elib/elib001.pdf](http://www.emfuel.com/elib/elib001.pdf)
4. EPA, 2002. "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions", U.S. Environmental Protection Agency, Draft Technical Report EPA420-P-02-001, October 2002, <http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf>
5. Yoshimoto, Y., Tamaki, H., "Reduction of NOx and Smoke Emissions in a Diesel Engine Fueled by Biodiesel Emulsions Combined with EGR". SAE 2001-01-0649.
6. National Biodiesel Board statistics, [www.biodiesel.org](http://www.biodiesel.org)
7. European Biodiesel Boards statistics, [www.ebb-eu.org](http://www.ebb-eu.org)
8. CARB, Reducing Air Pollution Programs. <http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm>
9. <http://epa.gov/cleandiesel/verification/verif-list.htm#moa>
10. Internal report. TVA Technology Advancements Report, December 1997.
11. A. Diesel Fuel News, 13<sup>th</sup> October 2003.  
[http://findarticles.com/p/articles/mi\\_m0CYH/is\\_19\\_7/ai\\_n27671337/?tag=content;col1](http://findarticles.com/p/articles/mi_m0CYH/is_19_7/ai_n27671337/?tag=content;col1)  
B. CARB Letter of Verification for CFT Emulsified Diesel Fuel, 9 September 2003
12. EPA Letter of Registration for Emulsified Diesel Fuel, 17 November 2003.
13. Internal report: Southwest Research Institute, Project No. 03.13948, May 2009.
14. Internal Report: Olson-Ecological Engine Testing Laboratories, LLC. " NRTC Testing of CARB base fuel, B20 biodiesel, Emulsified B20 Biodiesel and Emulsified B20 Biodiesel with a DOC on a Tier 2 Cummins QSM11C Engine" (2010), Report R-505.1-00 (for APT).

# APPENDICES

## Appendix A: TAP Scope of Work: Emulsified Biodiesel Fuel Demonstration

**SCOPE OF WORK  
ALTERNATIVE PETROLEUM TECHNOLOGIES, INC.  
EMULSIFIED BIODIESEL FUEL DEMONSTRATION**

Alternative Petroleum Technologies, Inc. ("APT") will demonstrate the use of emulsified biodiesel fuel in cargo handling equipment. The Project proposes to use a low water weight (6%) emulsion of B20 (20% biodiesel in ULSD), in combination with a diesel oxidation catalyst (DOC), on three 2008 (MY) Taylor top handlers equipped with Tier III Cummings engines. Under the recommendation of Ports America, the demonstration partner, the in-field testing will take place at the West Basin Container Terminal (WBCT).

	Task Description	Estimated Time Frame from Agreement Execution
Task #1	<p><b>Screen Testing at Southwest Research Institute (SWRI).</b> The screen test will consist of a two-fold process;</p> <p>1) A matrix of various percentages of water and biodiesel formulations will be evaluated to determine the optimum formulation for a 6 to 8 % NO<sub>x</sub> reduction and Level 2 PM reduction.</p> <p>2) Evaluation of selected emulsified biodiesel formulation with a diesel oxidation catalyst (DOC) in preparation for in-service port demonstration.</p> <p>APT, Inc. will work with and utilize a DOC from Engine Control Systems. All testing will be run on the same engine and will be the same procedure used in the CARB interim verification procedure.</p>	2 months
Task #2	<p><b>Develop Test Plan.</b> The Test Plan will consist of three phases; Phase I is the operation of 3 Taylor top handlers using B20 biodiesel approved for sale in California. Phase II is the operation of equipment using the emulsified biodiesel formulation selected during the initial screen test. Phase III will utilize the combination of emulsified biodiesel with a DOC from Engine Control Systems.</p>	2 months
Task #3	<p><b>Perform Demonstration pursuant to Test Plan.</b> The demonstration requires the use of the same 3 top handlers used during all phases of the test plan in Task 2. Demonstration to begin immediately after completion of Task 2 (2 months after agreement execution).</p> <p><b>Data Collection.</b> Establish and compare operational characteristics for all three phases used during demonstration, including; NO<sub>x</sub> emissions, fuel consumption, hours of activity, fuel economy, fuel costs, driver satisfaction and feedback, maintenance costs, and operating costs. Demonstration and data collection shall be for a minimum 5 months.</p>	8 months
Task #4	<p><b>Final Report.</b> A final report must be prepared to review and evaluate the demonstration project.</p>	12 months

## Appendix B: Reconciliation of Scope of Work from Appendix A to Conclusions in the 3 Phases

Task#1	Screen testing was conducted at SWRI and included a matrix of various water percentages and biofuel concentrations ranging from zero to 20% and zero to 99%, respectively. The results demonstrated reductions of more than 6% were achievable for NOx and more than 50% (Level 2) were achievable for PM compared to the baseline for diesel. Further, testing in combination with a DOC demonstrated that all of the critical emissions are neutral or improved. Lastly, the DOC was from a CARB verified DOC manufacturer and the testing was conducted in a format consistent with that which was used for CARB interim verification procedures.
Task #2	<p>The 3-step process delineated in Task #2 was accomplished with the following:</p> <ul style="list-style-type: none"><li>a) Identification of an "optimum" emulsified fuel (B20 with 6% water) for balanced NOx mitigation and peak power consideration,</li><li>b) Selection of 3 Taylor top handlers for their peak power requirements,</li><li>c) Selection of engine make and model comparable to the 3 Taylor top handlers to be tested in a laboratory setting,</li><li>d) Selection of an off-road federal test procedure to be conducted by Olson Technologies,</li><li>e) Emission and performance testing by Olson,</li><li>f) Analysis of emissions and performance,</li><li>g) Use of a B20 from an approved supplier, and</li><li>h) Use of a DOC provided from a CARB verified DOC manufacturer in conjunction with the "optimum" emulsified fuel.</li></ul>
Task #3	Demonstration pursuant to the Test Plan included collection of data from the 3 Taylor top handlers covering fuel consumption, driver satisfaction feedback as well as the distribution chain from the emulsified biodiesel production in Sacramento to its final consumption in Los Angeles. The demonstration covered the five-month period from August 2010 to January 2011.

# Appendix C: Fuel Characteristics Used in Phase 2 Study



Report No: B1003002

**CERTIFICATE OF ANALYSIS**

Sample Name and Description: Biodiesel 100 Lot #: 2010-B001032  
 Ref No. : 120105

PROPERTY	UNITS	TEST METHOD	ASTM D6751 - 09	CF SPEC	TEST RESULTS
Flash Point (Closed Cup)	°C	ASTM D 93-02a	93 min	140 min	180
Methanol Content	% vol	EN 14110 -03	0.2 max	0.1 max	0.007
Water & Sediment	% vol	ASTM D 2709-96	0.05 max	0.02 max	0.005
Water, Karl Fischer	ppm	ASTM D 6304-04a	N/A	300 max	175.5
Acid Number	mg KOH/g sple	ASTM D 664-06a	0.50 max	0.40 max	0.26
Cloud Point	°C	ASTM D 2500-05	Report	2 max	1.0
Carbon Residue	% mass	ASTM D 4530-06	0.05 max	0.025 max	0.0002
Sulfated Ash	% mass	ASTM D 874-00	0.02 max	0.01 max	Negligible
Copper Strip Corrosion	# - Letter	ASTM D 130-04	No. 3 max	No. 3 max	1A
Kinematic Viscosity, 40°C	mm <sup>2</sup> /s	ASTM D 445-04 e2	1.9-6.0	1.9-6.0	4.01
Cold Soak Filterability For temperatures below 12°C	seconds seconds	ASTM D 6751-07 Annex A1	360 max 200 max	200 max	112
Oxidation Stability	hours	EN 14112-03	3 hrs	6.0 hrs	7.02
Cetane Index (Calculated)	number	ASTM D 613-03b	47 min	47 min	48.4
Simulated Distillation -90%	°C	ASTM D 2887-06a	360 max	360 max	352.7
Free Glycerin	% mass	ASTM D 6584-07 e1	0.020 max	0.01 max	0.009
Total Glycerin	% mass	ASTM D 6584-07 e1	0.240 max	0.18 max	0.163
Monoglycerides	% mass	EN 14105-03	N/A	0.6 max	0.507
Diglycerides	% mass	EN 14105-03	N/A	0.2 max	0.106
Triglycerides	% mass	EN 14105-03	N/A	0.1 max	0.065
Sulfur	ppm	ASTM D 5453-05	15 max	15 max	0
Phosphorous Content	ppm	ASTM D 4951-02	10 max	10 max	1
Sodium/Potassium, Combined	ppm	EN 14538-06	5 max	5 max	3
Calcium/Magnesium, Combined	ppm	EN 14538-06	5 max	5 max	3
Ester Content	% mass	EN 14103-03	N/A	96.5 min	98.8
Linolenic Acid Methyl Ester	% mass	EN 14103-03	N/A	12.0 max	10.0

Checked and Approved by:

  
 Rizza Abd. Eejid  
 QC/Laboratory Manager

**AMERICANBIODIESEL .INC**

Stockton Facility: 809-C Snedeker Ave., Stockton, CA 95203, Rough & Ready Island, Port of Stockton

Tel No: (209)- 466-4823

Page 1 of 1

**Table C.1: CoA for B99 Biodiesel fuel used to make B20 blend**

## Appendix D: Stability of Emulsions; Sedimentation vs. Phase Instability

Two concepts will be discussed here under the term 'stability'. The first is a physical change termed 'sedimentation', which is easily reversed; the second is a 'phase' instability and not easily reversed nor corrected.

The types of emulsion under consideration are macro emulsions – they render the diesel and biodiesel blend opaque with a white opalescent appearance. The dispersed phase (water) is typically sub-micron (all the particles have a particle size below  $1\mu\text{m}$ ), typically with a mean of around 200 -  $500\mu\text{m}$  when freshly made.

On standing for several days in a quiescent environment these emulsions will form a 'sediment layer', which is easily re-dispersed with gently agitation. The sediment is formed by the action of gravity on the larger droplets which, on account of their greater density, fall to the bottom of the container.

The equation which describes this phenomenon is called 'Stokes' Law'. It is for this reason that the Italian National standard requires that storage containers of emulsion fuels must be fitted with recirculation pumps able to turn over the tank content once a day. This ensures a degree of homogeneity when dispensing the fuel which is neither dependent on the depth of fluid in the vessel nor on the age of the fuel.

The second type of 'instability' ('phase' instability) has to be guard against and this relies upon good design of the system at the development stage. Emulsions, indeed any type of dispersed system, are inherently meta-stable. Over time (and this can be a very long time or a very short time) the suspended particles will attract one another and merge to form larger ones.

Larger particles will sediment faster attracting and agglomerating with smaller particles on the way until they eventually give rise to the formation of a 'free' water phase at the bottom of the container. This process is the result of an inadequate stabilizing surfactant system and is not reversible.

There are various theories and models which describe the forces of attraction and repulsion between dispersed particles, such as emulsions and which determine the phase stability. One useful theory is the DLVO theory. Others have been mooted and a good discussion can be found in various books and papers (e.g. Schramm, L; *Emulsions, Foams, and Suspensions: fundamentals and applications*. Chapter 5, Wiley-VCH, 2005, Strauss GmbH, Morlenbach)

## Appendix D: Stability of Emulsions; Sedimentation vs. Phase Instability

Sedimentation	Phase Instability
<p>The types of emulsion under consideration are macro emulsions – they render the diesel and biodiesel blend opaque with a white opalescent appearance. The dispersed phase (water) is typically sub-micron (all the particles have a particle size below 1µm), typically with a mean of around 200 - 500µm when freshly made. On standing for several days in a quiescent environment these emulsions will form a 'sediment layer', which is easily re-dispersed with gently agitation. The sediment is formed by the action of gravity on the larger droplets which, on account of their greater density, fall to the bottom of the container. It is for this reason that the Italian National standard requires that storage containers of emulsion fuels must be fitted with recirculation pumps able to turn over the tank content once a day. This ensures a degree of homogeneity when dispensing the fuel is not dependent on its age.</p>	<p>The second type of 'instability' ('phase' instability) has to be guarded against and this relies upon good design of the system at the development stage. Emulsions, indeed any type of dispersed system, are inherently meta-stable. Over time (and this can be a very long time or a very short time) the suspended particles will attract one another and merge to form larger ones. Larger particles will sediment faster attracting and agglomerating with smaller particles on the way until they eventually give rise to the formation of a 'free' water phase at the bottom of the container. This process is the result of an inadequate stabilizing surfactant system and is not reversible.</p>

## Appendix E: CEN CW 15145: 2004 Fuel Standards Summary

	<b>CW 15145</b> <b>Parameter</b>	<b>Units</b>	<b>Grade A</b>		<b>Grade B</b>		<b>Test Method</b>
			<b>Min</b>	<b>Max</b>	<b>Min</b>	<b>Max</b>	
<b>1</b>	Density	kg/m <sup>3</sup>	828	880	825	865	EN ISO 12185
<b>2</b>	Water content <sup>a</sup>	% (m/m)	≥ 8	15	5	< 8	NF M 07-104
<b>3</b>	Stability at Production (rcf 4200, 5 min), sediment	% (V/V)	-	9	-	7	M.U. 1548
<b>4</b>	Free Water	% (V/V)	absent		absent		-
<b>5</b>	Viscosity at 40°C	mm <sup>2</sup> /sec	2.00	5.50	2.00	5.50	EN ISO 3104
<b>6</b>	Sulfur content	% (m/m)	-	b	-	b	EN ISO 20884 EN ISO 20846
<b>7</b>	Total contamination	mg/kg	-	24	-	24	EN 12662 <sup>c</sup>
<b>8</b>	Copper strip corrosion (3h at 50°C)	index	Class 1		Class 1		EN ISO 2160
<b>9</b>	Flash point (Cleveland)	°C	70	-	70	-	EN ISO 2592
<b>10</b>	Total nitrate (2-ethyl- hexyl-nitrate) EHN	% (V/V)	0.07	-	0.05	-	EN ISO 13759
<b>11</b>	Lubricity, corrected wear scar diameter (wsd 1,4) at 60°C	µm	-	400	-	400	EN ISO 12156-1
<b>12</b>	CFPP	°C	according to EN 590				EN 166 <sup>d</sup>

NOTE: Users are aware of the fact that initial work at low sulfur levels has indicated matrix-effects for both sulfur test methods.

**a.** The water portion of the emulsified fuel shall be demineralized to a maximum conductivity of 3 mS/m according to EM27888

**b.** The maximum amount of sulfur ( $S_{max}$ ) depends on the required limit of sulfur in the diesel component ( $S_d$ ) according to the current EN590 and the maximum water content ( $wc$ ) as indicated in Table above. It is derived following the equation:  $S_{max} = S_d (100-wc)/100$ .

**c.** Use of an alternative appropriate filter is required

**d.** The recommended mode is manual, as some automatic instruments need manual sensitivity adjustments for emulsion fuels.

## Appendix F: Select Analytical Techniques Used by APT for Assuring Consistent Quality of Emulsified Fuel

The following additional methods are commonly used by APT to describe the emulsion fuel characteristics:

**Optical microscopic.** Examination of the emulsion using up to 400 x magnifications with a calibrated reticule for sizing of individual particles is routinely carried out to evaluate subjectively the size and population of the larger droplets.

**Centrifuge.** The French and Italian national standards as well as CEN WS15145:2004 define a method (MU 1548) where a 50cm<sup>3</sup> sample of the emulsion is placed in a graduated tube and centrifuged for 5 minutes at 4200 rcf (relative centrifugal force). The passing criteria are (a) no free water; and (b) a maximum white sediment band of 7% and 9% (vol.) for the 8% and 15% (mass) maximum water emulsions respectively. This test was originally conceived as a predictor of future emulsion stability (an accelerated aging test). The centrifuge test can accelerate the sedimentation process but it cannot be used to predict the aging of the surfactants.

A storage stability test which involves placing a sample (usually 100 cm<sup>3</sup>) in a tall, clear glass, flat bottomed seal tube. Observations are made for (a) signs of 'free' water; droplets or layers formed at the bottom of the tubes; (b) the volume of 'white' sediment band formed at the bottom of the tube which is measured with a ruler and expressed as a % of the total height of the fluid in the tube; (c) the volume of 'clear oil' formed at the top of the sample. This is also expressed as a % volume.

**Particle Size Analysis by Laser Diffraction.** The use of a Polarization Intensity Differential Scattering (PIDS) system has proven helpful for less subjective analysis than microscope. The PIDS assembly provides the primary size information for particles in the 0.04 µm to 0.4 µm range. It also enhances the resolution of the particle size distributions up to 0.8 µm. The combined PIDS and laser assembly enables size distribution from 0.04 microns to 2000 microns to be observed.

## Appendix G: Phase 1 Study - NOx and PM Emissions

	Ref	%B vol.	%W mass	NOx	PM
				<i>g / bhp-hr</i>	
1	B0-1	0	0	4.9	0.241
2	B0-2	0	3.2	4.63	0.195
3	B0-3	0	9.1	4.34	0.123
4	B0-4	0	13.7	4.25	0.101
5	B0-5	0	21.3	4.02	0.086
6	B20-1	20	0	4.92	0.198
7	B20-2	20	8.6	4.43	0.118
8	B20-3	20	14.9	4.27	0.077
9	B20-4	20	20.8	3.99	0.075
10	B50-1	50	0	5.04	0.14
11	B50-2	50	11	4.41	0.077
12	B50-3	50	15.7	4.34	0.071
13	B50-4	50	19.8	3.96	0.075
14	B99-1	99	0	5.28	0.075
15	B99-2	99	5.8	4.88	0.072
16	B99-3	99	12	4.42	0.074
17	B99-4	99	19.7	4.1	0.069
18	B0-OC1	0	0	4.8	0.206
19	B0-OC2	0	8.25	4.39	0.101
20	B0-OC3	0	12.52	4.29	0.066
21	B20-OC1	20	0	4.85	0.163
22	B20-OC2	20	9.43	4.42	0.071
23	B20-OC3	20	14.22	4.25	0.048
24	B50-OC1	50	0	4.92	0.108
25	B99-OC1	99	0	5.15	0.051

**Table G.1: Phase 1 Study - NOx and PM Emissions**

## Appendix H: Phase 2 Study – Olson EcoLogic Data

TEST NO.	WEIGHTED GRAMS PER BHP-HR						PM	BSFC Fuel
	HC	CO	NO <sub>x</sub>	NO	CO <sub>2</sub>	NMHC		
<b>Baseline Diesel Fuel</b>								
ALTP01	0.252	1.245	4.93	4.75	619.83	0.249	0.12	0.395
ALTP02	0.245	1.231	4.872	4.701	634.08	0.244	0.12	0.396
<b>Test Average</b>	<b>0.249</b>	<b>1.238</b>	<b>4.901</b>	<b>4.726</b>	<b>626.96</b>	<b>0.247</b>	<b>0.120</b>	<b>0.396</b>
<b>Regular B20 Biodiesel Fuel</b>								
ALTP10	0.212	1.231	5.215	5.03	618.82	0.21	0.101	0.405
ALTP11	0.215	1.25	5.148	4.961	620.30	0.213	0.092	0.407
<b>Test Average</b>	<b>0.214</b>	<b>1.241</b>	<b>5.182</b>	<b>4.996</b>	<b>619.56</b>	<b>0.212</b>	<b>0.097</b>	<b>0.406</b>
<b>% Chg fm Base</b>	<b>-14.08%</b>	<b>0.20%</b>	<b>5.72%</b>	<b>5.71%</b>	<b>-1.18%</b>	<b>-14.20%</b>	<b>-19.58%</b>	<b>2.65%</b>
<b>Emulsified B20 Biodiesel Fuel</b>								
ALTP12	0.241	1.259	4.915	4.731	611.48	0.239	0.086	0.437
ALTP13	0.23	1.203	4.944	4.754	604.52	0.229	0.084	0.437
<b>2 Test Average</b>	<b>0.236</b>	<b>1.231</b>	<b>4.930</b>	<b>4.743</b>	<b>608.00</b>	<b>0.234</b>	<b>0.085</b>	<b>0.437</b>
<b>% Chg fm Base</b>	<b>-5.23%</b>	<b>-0.57%</b>	<b>0.58%</b>	<b>0.36%</b>	<b>-3.02%</b>	<b>-5.07%</b>	<b>-29.17%</b>	<b>10.49%</b>
<b>% Chg fm B20</b>	<b>10.30%</b>	<b>-0.77%</b>	<b>-4.86%</b>	<b>-5.06%</b>	<b>-1.87%</b>	<b>10.64%</b>	<b>-11.92%</b>	<b>7.64%</b>
<b>Emulsified B20 Biodiesel Fuel w/DOC Unit</b>								
ALTP14	0.113	0.285	4.883	4.124	597.38	0.11	0.072	0.436
ALTP15	0.111	0.294	4.934	4.092	602.64	0.109	0.073	0.435
<b>2 Test Average</b>	<b>0.112</b>	<b>0.290</b>	<b>4.909</b>	<b>4.108</b>	<b>600.01</b>	<b>0.110</b>	<b>0.073</b>	<b>0.436</b>
<b>% Chg fm Base</b>	<b>-54.93%</b>	<b>-76.62%</b>	<b>0.15%</b>	<b>-13.07%</b>	<b>-4.30%</b>	<b>-55.58%</b>	<b>-39.58%</b>	<b>10.11%</b>
<b>% Chg fm EB20</b>	<b>-52.44%</b>	<b>-76.48%</b>	<b>-0.43%</b>	<b>-13.38%</b>	<b>-1.31%</b>	<b>-53.21%</b>	<b>-14.71%</b>	<b>-0.34%</b>

## Appendix I: Letter from Ports America on Emulsified Biodiesel Fuel Demonstration Using Three Taylor Top Handlers Units



Date: January 26, 2011

From: Ken Pope  
Area Equipment Manager  
Ports of America  
2050 John S. Gibson Boulevard  
San Pedro, California 90731

To: Port of Los Angeles

Ref: Agreement No. E6535 between The City of Los Angeles and Alternative Petroleum technologies, Inc.

To whom it may concern,

From September 2, 2010 to January 21, 2011, Ports America used Alternative Petroleum Technologies emulsified biodiesel fuel on Top Handlers. During the trial period (4 months) the operators did not report any operational issues with the fuel and its use in the top Handlers.

*Kenton R. Pope*

*Area Equipment Services MGR.*

*Ports America*

*2001 John S. Gibson Blvd.*

*San Pedro, Ca. 90731*

*Phone 310/519/2341*

*FAX 310/732/5509*

[kenpope@portsamerica.com](mailto:kenpope@portsamerica.com)  
[www.portsamerica.com](http://www.portsamerica.com)

## Appendix J: Carbon Dioxide Emission Benefits from Use of Emulsified Biodiesel Fuel in Waterfront Trials

<b>CARBON DIOXIDE (CO<sub>2</sub>) EMISSION LEVEL CALCULATIONS</b>
1. The actual biofuel consumption for <b>3 top handlers</b> during <b>118 days</b> of activity was 11,316 GAL Entering this value of Fuel Usage into the NBB computer model gives CO <sub>2</sub> reduction of 36,485 LBS.
2. <b>Annualized</b> EBIOD fuel consumption for <b>3 top handlers</b> is: $11,316 \times (365/118) = 35,002$ GAL. Entering this value of Fuel Usage into the NBB computer model gives CO <sub>2</sub> reduction of 112,857 LBS.
3. <b>Annualized</b> EBIOD fuel consumption for <b>100 top handlers</b> is: $35,002 \times (33) = 1,155,095$ GAL. Entering this value of Fuel Usage into the NBB computer model gives CO <sub>2</sub> reduction of 3,724,228 LBS.

**Table I.1: Emulsified Biodiesel Fuel CO<sub>2</sub> Emissions Calculations**

By extending these initial calculations to consider the application of emulsified biodiesel fuel to the test fleet of three (3) top handler units – for a period of one year – this initial value of 36.5K pounds advances to a value of 112,867 pounds of CO<sub>2</sub> emissions reductions. Finally, by considering the extension of the emulsified biodiesel fuel to a fleet of 100 top handler units for one-year, the NBB emissions calculator (<http://www.biodiesel.org/tools/calculator/default.aspx>) indicates that a CO<sub>2</sub> emissions reduction on the order of 3.7 million pounds is plausible. Note that this significant CO<sub>2</sub> emissions reduction would be accompanied by an equally significant reduction in PM levels and a neutralization of the NO<sub>x</sub> emission increases - that normally result from the use of a biodiesel fuel instead of a ULSD fuel - if the fuel of choice would be emulsified biodiesel fuel. APT would recommend that a case-specific analysis be done before reaching any conclusions of the overall CO<sub>2</sub> reductions; however, this analysis is included for reference purposes only.

## Appendix K: Operational Photos of APT Distribution Chain for Emulsified Biodiesel Fuel Supplied to Port of Los Angeles

