# SUSTAINABLE POWER FOR CITY DEVELOPMENT

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Cities face power requirements for construction, heating/cooling of infrastructure and transportation. Presently, combustion of fossil fuels provides the power for the majority of these requirements. Fossil fuel combustion produces BOTH harmful gas AND solid (particulate) emissions. Harmful gas emissions (NOX) produce smog that affects the quality of urban life. Harmful particulate (PM) emissions adversely affect the pulmonary health of urban residents. There is a proven technology that reduces BOTH emissions AND can INCREASE fuel combustion efficiency. Emulsified Fuel Technology can deliver this "triple-crown" of environmental AND economic benefit. By considering power generation SYSTEMS – that include BIOFUELS – modern cities can be founded, built and grow in harmony with the environment while reaping economic and health benefits for their citizenry. A new appreciation of power SYSTEMS can lead to the development of future citizens that fully comprehend the synergistic benefits that can accrue to the use of clean-burning fuels. This paper will first consider the constitution, production and combustion of Emulsified Fuels. Then, past applications of Emulsified Fuels in the transportation and power sectors of Mexico will be presented. Finally, future uses of Emulsified BIOFUELS and their potential impacts upon city air quality, citizen health and urban economics will be discussed.

## INTRODUCTION

Cities face power requirements for a myriad of energy sectors – from residential, commercial and industrial heating and cooling requirements to the power generation and the transportation sectors – including railroads, vessels, on-highway (autos, trucks, buses) and off-highway (construction) segments. To address these various power requirements, there is a portfolio of both renewable and fossil fuels.

The ideal energy supply system would feature renewable sources that provide reliable energy with minimal fossil power backup and requires a moderate investment. Several factors affect the energy supply selection including power requirements of the locale, the availability of renewable sources, the environmental impacts and the economic costs of the selected system. While there are several advantages to renewable energy sources – primarily NO generation of greenhouse gases - there are also some significant drawbacks – like low power capacity and high initial investment costs.

Presently, combustion of fossil fuels provides the power for the majority of city power requirements. Fossil fuel combustion produces BOTH harmful gas AND solid (particulate) emissions. Harmful gas emissions (NOX) produce smog that affects the quality of urban life. Harmful particulate (PM) emissions adversely affect the pulmonary health of urban residents. There is a proven technology that reduces BOTH emissions AND can INCREASE fuel combustion efficiency. Emulsified Fuel Technology (EFT) can deliver this "triple-crown" of environmental AND economic benefit. By considering power generation SYSTEMS – that include BIOFUELS – modern cities can be founded, built and grow in harmony with the environment while reaping economic and health benefits for their citizenry. A new appreciation of power SYSTEMS can lead to the development of future citizens that fully comprehend the synergistic benefits that can accrue to the use of clean-burning fuels.

In this paper, we shall consider EFT from several viewpoints. First we shall consider the constitution, production and characteristics of Emulsified Fuels. Then we shall consider the combustion of such fuels and the environmental benefits that can accrue to their utilization. Finally, we shall consider past applications of Emulsified Fuels and the future applications for this intriguing technology to BIOFUELS.

## CONSTITUTION OF EMULSIFIED FUELS

An emulsion is a mixture of two immiscible (i.e., not able to be blended) substances. In an emulsion, one substance - the dispersed phase - is uniformly distributed throughout the second substance - the continuous phase. For example, a fuel oil emulsion features water droplets - the dispersed phase – uniformly distributed throughout the fuel oil – the continuous phase. An emulsion takes on the characteristics of the continuous phase. Hence, fuel oil emulsions exhibit characteristics of fuel oil NOT water.

Emulsions are inherently unstable. Over time they tend to “separate” into the stable states of the dispersed and continuous phase materials. Thus, a volume of fuel oil emulsion over time will separate into distinct volumes of water and oil. In order to maintain the composition of an emulsion, surface active agents, i.e., surfactants, are incorporated into the production of an emulsion. In a fuel oil emulsion, these surfactant agents encase the droplets of water distributed throughout the continuous oil phase and prevent the water droplets from coming together and coalescing into larger droplets and ultimately into a significant volume of “separated” water. Because of surface tension, the surfactants act to form a membrane that encases the water droplets within the fuel oil emulsion and forces the droplets into small spheroids of water that are distributed throughout the continuous fuel oil phase. A micrograph of such water spheroids contained within the light (diesel) oil continuous phase of an emulsion is shown in Figure 1.

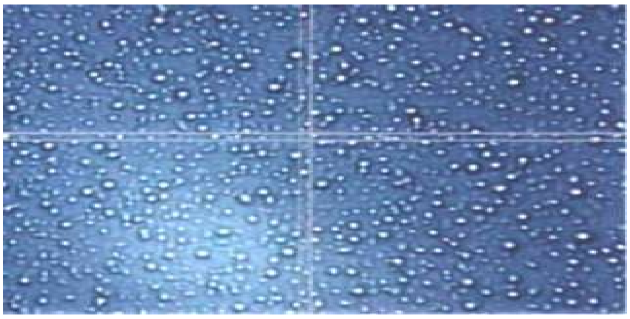


FIGURE 1. -PHOTOMICROGRAPH OF WATER PARTICLES IN A DIESEL OIL EMULSION

## PRODUCTION OF EMULSIFIED FUELS

The production of an emulsion involves both chemical and mechanical operations. As stated previously, a surfactant is incorporated into the production of an emulsion to preserve its stability. The chemical nature of this surfactant is such that it is amenable to both the dispersed and continuous phase materials. The formulation of an emulsion surfactant agent must take into account the need to preserve the stability of the emulsion in both storage and pumping operations as well as the need to render harmless the emission products arising from the combustion of the emulsified fuel. In this regard, it is to be noted that both the additive and the light oil (diesel) emulsified fuel produced by Eco-Energy Solutions (EES) Inc. have been verified by the California Air Resources Board (CARB) and registered with the United States Environmental Protection agency (USEPA).

FIG 2. STATIONARY & MOBILE BLENDING UNITS

The mechanical operation involved in the production of emulsified fuels is that of a high-value (HV) shearing operation. This HV shearing operation is accomplished in a computer-controlled Blending Unit that insures the dispersed phase (water) in an emulsified fuel is sufficiently shattered into micro-scale droplets that will react with a proprietary surfactant agent to produce a maximum dispersion of water spheroids within the surrounding fuel oil phase. In conjunction with this HV shearing action, the proper amounts of water, surfactant and fuel oil must be metered into the shearing volume to preserve the homogeneity of the final emulsified fuel product. Examples of computer-controlled EES Blending Units – both stationary and mobile configurations - that produce light and heavy fuel oil emulsions are shown in Figure 2.

## CHARACTERISTICS OF EMULSIFIED FUELS

While emulsified fuels take on the primary characteristics of the continuous phase material, emulsified fuels differ significantly in some respects from their base constituents. For example, light (diesel) oil emulsions appear white in color as compared to the amber color of base diesel oil. However, diesel oil emulsions do feel “oily” to the touch thus preserving some of the base characteristics of the continuous phase. In contrast, heavy oil emulsions appear black in color – like their base oil – but flow liberally at a somewhat lower ambient temperature than do their base (continuous phase) fuel oil. This lower viscosity aspect of fuel oil emulsions provides added savings in energy usage for their service as combustibles since less power is needed to pump fuel oil emulsions from storage tanks to burner fronts and less heat is also needed to preserve fuel oil emulsions in a proper pumping state within plant storage tank farms.

This aspect of emulsified fuel characteristics is especially pronounced with residual oil emulsions. Residual oil emulsions are made by emulsifying the very heavy liquid “bottom” oils from vacuum tower installations. Instead of “cutting” these vacuum tower bottom” oils by blending them with lighter distillate oils to ultimately make #6 fuel oil, emulsifying these “bottoms” replaces the expensive “cutter” oils with water and an emulsifying surfactant to produce a residual oil emulsion that flows like water (!) at an ambient temperature. Again, these residual oil emulsions can be readily pumped from storage tanks to burner fronts to produce an inexpensive alternative to fuel oil #6 for plant power production.

## COMBUSTION OF EMULSIFIED FUELS

Traditional combustion of hydrocarbon fuels in a power plant boiler requires the fuel to be first atomized (either mechanically or with steam or air) to breakup the fuel into small droplets that can be more readily ignited. Once these small fuel droplets enter the high temperature combustion zone of the boiler at the exit plane of the fuel nozzle, they begin to burn in a charring fashion, i.e., from the surface inward to the core of the droplet. Normally, this "char" burning of the fuel droplet is not completed within the high temperature combustion zone of the boiler. As a result, unburned fuel products (particulates) are expelled from the combustion zone and transported in the flow of exhaust gases from the combustion zone to the stack exit of the boiler.

Simultaneous with this generation of particulate emissions, the generation of gaseous emissions proceeds from the exposure of fuel-borne nitrogen and the nitrogen in combustion air to the high temperature refining atmosphere of the combustion zone. Depending upon the completion of the attending combustion, various concentrations of oxides of nitrogen (NOX) as well as carbon oxides (CO and CO2) exit the combustion zone and proceed to the stack exit plane. This process is shown in Figure 3.

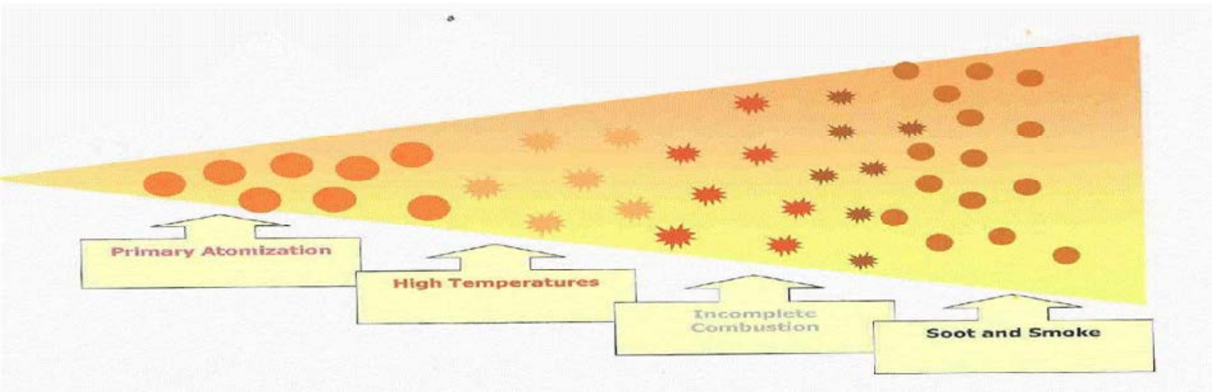



FIG 3. REGULAR FUEL OIL COMBUSTION

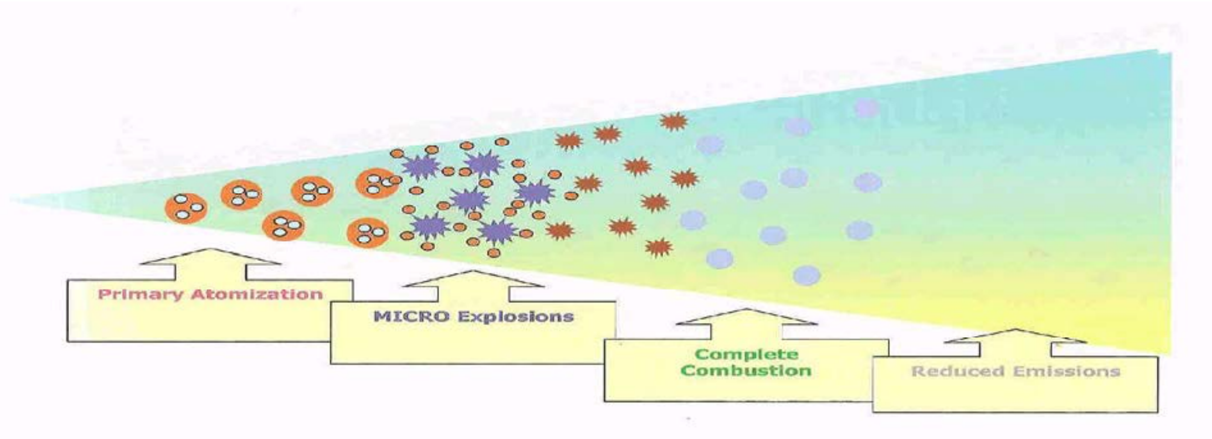



FIG 4. EMULSIFIED FUEL COMBUSTION

In contrast to this foregoing situation, the combustion of emulsified fuels features the introduction of water into the combustion zone along with the base fuel. Introduction of water into the combustion zone produces two profound effects upon the combustion of the emulsified fuel. First, upon expulsion from the exit plane of the burner nozzle, exposure of the droplets of water in the emulsified fuel to the high temperature of the combustion zone causes an immediate evaporation of the water in the droplets to steam – a phenomenon know in the literature as a “micro-explosion” [1] occurs.

Each “micro-explosion” of a water droplet is accompanied by a significant increase in volume of the here-to-fore surfactant-encased water droplet and a subsequent shattering of the surrounding fuel oil medium into numerous auto-ignition centers of combustion. It is akin to the bursting of a balloon and the fracturing of the balloon surface into numerous pieces of balloon surface material in a fire. Each piece of balloon surface material immediately becomes a burning center and causes the surrounding medium to ignite. As such, the surface area of the surrounding material subject to burning is greatly increased and a more complete combustion of the surrounding material – the continuous fuel oil phase of the fuel emulsion – is generated. Hence, the chances of unburned particles of fuel oil escaping from this burning atmosphere are significantly decreased and thus the production of particulate emissions is stifled. An illustration of this process is shown in Figure 4.

## ENVIRONMENTAL BENEFITS

The introduction of water vapor into the combustion zone tends to decrease the temperature of the combustion zone due to the high heat capacity of the water medium. This decrease in combustion zone temperature leads to a less energetic oxidation of both fuel borne and combustion air nitrogen contents and therefore leads to an overall decline in NOX generation.

As we have seen, the introduction of water - via the fuel emulsification process – leads to a twofold environmental benefit. By fundamentally affecting the fuel combustion process [2], emulsification leads to the reduction of BOTH solid (particulate) AND gaseous (NOX) emissions. Very rarely does a single technology have such a significant set of dual environmental benefits.

The introduction of water into the combustion process has an added benefit from an energy efficiency viewpoint. The added heat content of the water introduced into the combustion zone by an emulsified fuel means that the exhaust gases of the combustion process are more “energetic” than those of conventional fuels. Hence, as these more “energetic” combustion gases traverse the boiler heat transfer zones, they are able to transmit more heat by convection to the steam generating tubes resulting in an INCREASE in fuel efficiency.

This increase in fuel efficiency leads to the final benefit attributable to emulsified fuels – a reduction in hydrocarbon emissions. If indeed emulsified fuels can produce more steam output per fuel input, then the total amount of base (hydrocarbon) fuel input required to produce a required power output is less. If base (hydrocarbon) fuel usage is decreased, the oxides of Carbon resulting from this lessened requirement for base fuel combustion are LESS. Emulsified fuels can thus contribute significantly to the lessening of greenhouse gases generation resulting from existent hydrocarbon fuel combustion.

In summary, the introduction of water into the combustion process by the use of emulsified fuels results in the generation of an enhanced “triple crown” of benefits – the reduction of BOTH gaseous (NOX) and solid (Particulate) emissions, an increase in fuel efficiency AND the reduction of greenhouse gases. As such, emulsified fuel technology is one of the most effective – and cost-beneficial technologies – available to accommodate future requirements for hydrocarbon emission reductions, energy efficiency enhancement and greenhouse gas diminution.

## PAST APPLICATIONS OF EMULSIFIED FUELS

Past applications of Emulsified Fuel Technology (EFT) are now reviewed to emphasize the potential of EFT to provide CLEAN power for city development. These applications include:

- TVA Test of #2 Fuel Oil Emulsion in Combustion Turbine
- Test of Heavy-Duty Diesel Engine at Monash University
- CFT Test of #6 Fuel Oil Emulsion in Crysel Plant Boiler
- Each of these applications is now presented in a summary exposition.

1. The Tennessee Valley Authority tested a Diesel Oil Emulsion (DOE) in a General Electric Frame 7 Combustion Turbine located at its Colbert Power Plant in Huntsville, AL, USA [3]. The unit had a base load capacity of 44 MW in the summer. The test project was conducted for approximately 9 hours, and generated just under 302,000 kWh of uninterrupted electric power.

Tests were run on three different fuels – base Diesel Fuel (Series 100 tests in Figure 10) and two Diesel Oil Emulsion (DOE) blends. The compositions of the two DOE blends were:

67.5% diesel, 30% water, 2% alcohol, 0.5% DOE additive (Series 200);

b. 62.5% diesel, 35% water, 2% alcohol, 0.5% DOE additive (Series 300).

The No. 2 diesel fuel used for the test was the same base Diesel Fuel that was regularly burned in all of the Colbert station combustion turbines. The purified water used to produce the DOE Fuels was taken from the boiler water make-up system for the pulverized coal units at the station.

Nitrogen oxide emissions were determined based on the NOX concentration measured in the exhaust gas leaving the turbine exhaust stack. Total NOX emissions were calculated using the procedure given in the United States Environmental Protection Agency Code of Federal Regulations, 40 Part 60, Appendix A, Method 19 (EPA Method 19). The F-Factors (Fd and Fc) for No. 2 diesel fuel and the A-55 fuel blends were calculated based on laboratory analyses of the fuels. The F-factors are the ratio of the gas volume of the products of combustion to the heat content of the fuel. **Figure 5 from the Colbert Report (shown below) displays the dramatic drop in NOX emission level as DOE fuel is introduced into the turbine unit.**

Figure 5. Changes in the Flue Gas NOx Levels During the Transition to A-55

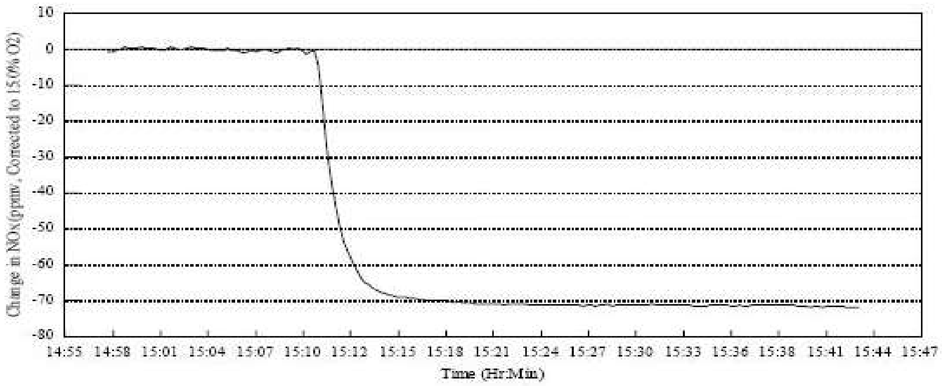



Figure 10. NOx Emissions Versus Gross Output

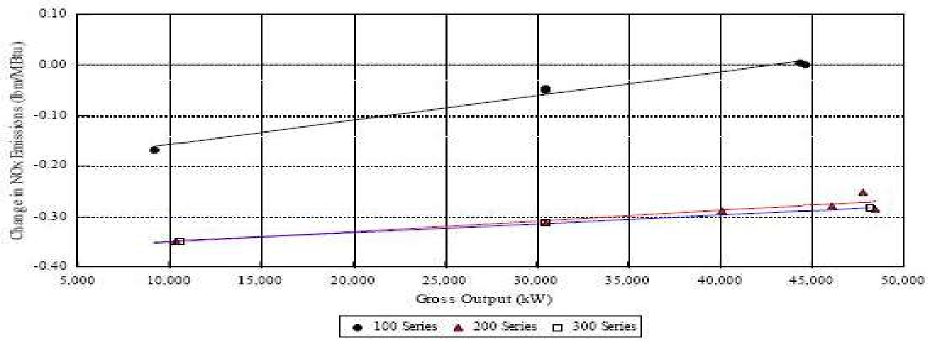



Figure 10 from the Colbert test report (shown above) is a plot of NOX emissions (lbm/MBtu) versus gross electrical output. As can be seen, NOX emissions with the unit firing Diesel Oil Emulsions were significantly lower than when the unit was firing base diesel fuel (Series 100 test data in Figure 10). Based on the results of the test burn, NOX emissions were 53.0% lower on DOE fuels containing 30% water by volume (Series 200 test data) and 55.3% lower on DOE fuel containing 35% water (Series 300 test data) by volume. The reductions in NOX emission levels is thought to be due to the reduction in the DOE fuels' firing temperatures as compared to that of the base diesel fuel.

Table 9-1. Corrected Gross Output

| Load | Baseline kW | A-55 with 30% Water kW | A-55 with 35% Water kW |
|---|---|---|---|
| Base Load | 44,665 | 46,711 | 46,868 |

Corrected to 80 °F and 14.170 psia.

Table 9-1 from the Colbert Report (shown above) indicates that gross electrical power output increased a little over 2 MW (4%) from a base load of 44.6785 MW with the use of DOE fuels. This increase in power output arises from the fact that the emulsified fuels produced "heavier" working fluids, i.e., WET combustion gases versus the DRY combustion gases of regular diesel fuels. All data points herein were corrected to standard temperature and pressure values

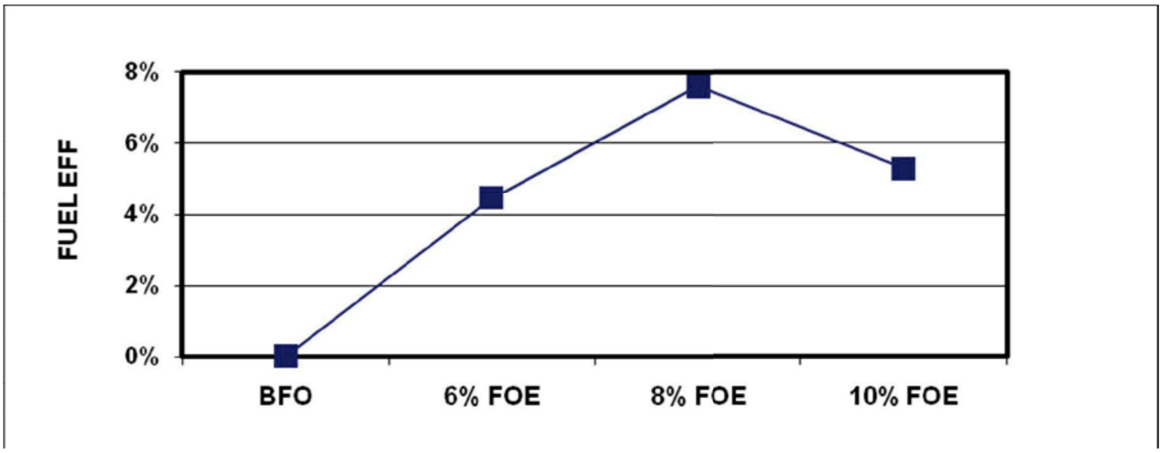
2.Tests were carried out in a 41 KW industrial diesel engine-generator at Monash University in Victoria, Australia [4]. NOX emissions were reduced by 29-37% and HC emissions exhibited large reductions in the range 60-90% when operating on Diesel Oil Emulsion (DOE). As shown in Table 6 from this university report (shown below), the thermal efficiency of the diesel-generator system operating on DOE was consistently higher than when it was operating on conventional diesel fuel (CDF).

| ENGINE DATA | | | CDF | | DOE | |
|---|---|---|---|---|---|---|
| Torque | Speed | Power | BSFC | EFF | BSFC | EFF |
| NM | RPM | KW | G/KWHR | % | G/KWHR | % |
| 150 | 1800 | 28.3 | 217.8 | 36.7 | 273.6 | 36.8 |
| 200 | 1800 | 37.7 | 211.0 | 37.9 | 263.7 | 38.2 |
| 150 | 2200 | 34.5 | 232.4 | 34.4 | 285.9 | 35.3 |
| 200 | 2200 | 48.1 | 221.3 | 36.2 | 270.0 | 37.3 |

Operation with the emulsion caused a significant decrease in gas pressure near piston top dead center without loss of indicator cycle work and efficiency. This and the decreased rates of pressure rise result in quieter operation of the engine when running on DOE and could have beneficial effect in the long run with regard to engine component durability. In keeping with the lower cylinder pressure, in-cylinder temperatures have also been found to be lower, although the differences reduce with increasing engine speed and engine load. The reduction in NOX emissions resulting from use of the emulsion appears to correspond with the reductions in cylinder temperatures.

3. A #6 Fuel Oil Emulsion (FOE) was tested in the boiler plant of the Crysel facility in Guadalajara, Mexico [5]. Boiler Number 5 at the plant was a Cerry type A boiler with a Coen Burner. Installed in 1985, it was a dual fuel boiler capable of operation on gas and heavy oil. It was equipped with a rotary air heater and a super heater section and has a capacity of 40 metric Tons-per-Hour. In the tests at the Crysel plant, the water content of

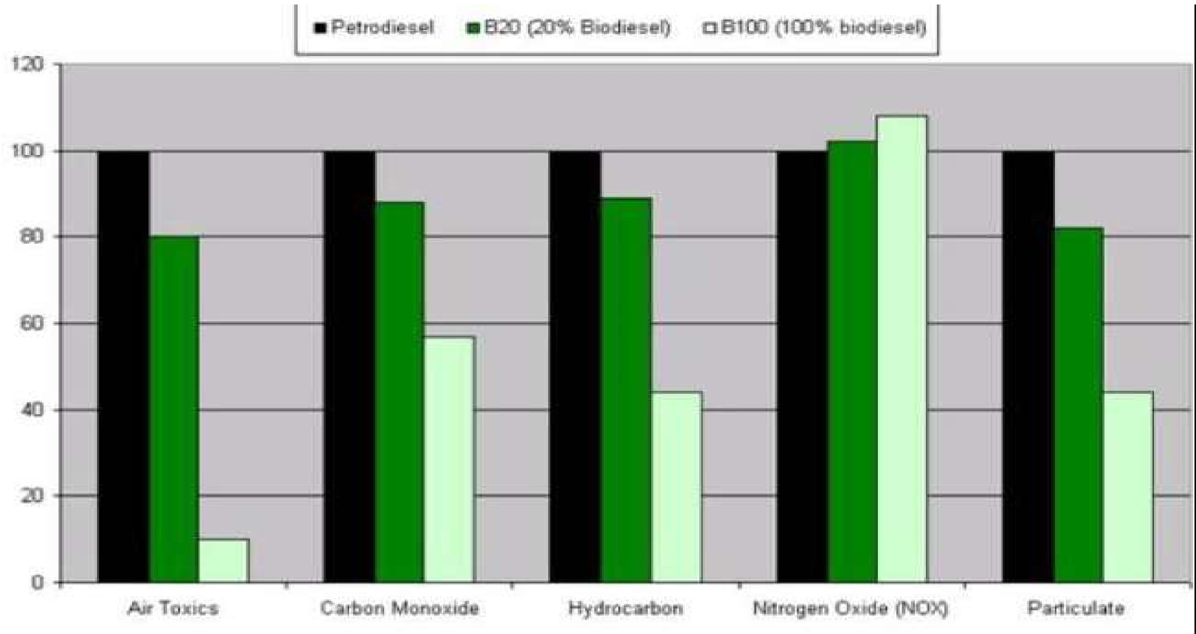
the FOE was varied from 6% to 10% (by volume). In the graph from this Crysel report (shown below), the maximum fuel efficiency occurred at a water content of 8% (by volume). This result reflects the effect of FOE water content upon the radiative and convective heat transfer modes bewtween the working fluid (FOE combustion gases) and the boiler steam generation tubes in the radiative and convective heat transfer zones within the boiler. The water content of the FOE decreases the fuel combustion temperature by “stealing” heat from the combustion zone due to the higher specific heat capcity of the “wet” combustion gases of FOE as compared to that of the relatively “dry” combustion gqases of regular fuel oil.




Since combustion temperature is lowered, radiative heat transfer from the combustion zone is decreased. Meanwhile, the “wet”, higher density, more “energetic” combustion gases from FOE combustion that contain a relatively higher heat content than the “dry” , lower density, less “energetic” combustion gases of regular fuel oil, traverse the convective heat transfer paths within the boiler and generate more heat transfer by convective heat ransfer. It is this fine balance between radiative and convetive heat transfer within the boiler that is affected directly by the water content of an emulsified fuel. While these fine engineering considerationss on boiler heat transfer are worthy of attention, what should not be lost is the very evident fact that FOE delivers an INCREASE in fuel efficiency while also delivering significant reductions in exhaust emissions – BOTH gaseous (NOX) AND solid (PARTICULATE) – types of emissions. Very rarely, if ever, does a technology evcer deliver such an enviable “triple-crown” of environmental, economic and health benefits. Emulsified Fuel Technology is unique in this record of accomplishment!

All of the foregoing applications of EFT show that its application to both the transportation (engines) and power (turbines, boilers) sectors can deliver significant emission reductions AND efficiency increases for hydrocarbon fuels. The application of EFT to BIOFUELS promises even more environmental and economic benefit by coupling the “triple crown” of hydrocarbon fuels to the reduction of greenhouse gases. This aspect of Emulsified Fuel Technology is considered in the following section of this paper.

## EMULSIFIED BIOFUELS




The graphic shown above is from the website of the Agra Biofuels Company located in Middletown, Pennsylvania [6]. It shows the tremendous promise of biofuels and the meddlesome shortcoming of biofuels with respect to NOX emissions.

A study at Yale University in 2006 considered the formation of NOX in biofuel combustion in a diesel engine [7]. The study proffered that NOX generation has three different forms – thermal NOX, prompt NOX, and fuel NOX. Thermal NOX is formed at high temperatures in the combustion chamber along the flame boundary, where oxygen combines with nitrogen from the air. The rate of this reaction is highly dependent on temperature, so that thermal NOX production will speed up rapidly as the cylinder temperature increases. This explains why NOX values peak sharply when engine load is increased. Prompt NOX forms as the result of hydrocarbon fragments reacting with nitrogen to form HCN, which then reacts with atmospheric nitrogen again to produce NOX. However, it has been found that prompt NOX formation is only prevalent in rich combustion. Because diesels run lean, the prompt NOX contribution will be small. The last kind of NOX, - fuel NOX - forms when nitrogen in the fuel combines with excess oxygen during combustion. Because vegetable biodiesel contains NO nitrogen, this component of NOX formation can be disregarded in diesel combustion of biofuels.

As is evident from the Yale study, the primary NOX production in diesel combustion arises from high cylinder temperatures. Since the primary effect of emulsified fuel combustion is the LOWERING of cylinder temperatures, it can be expected that the combustion of EMULSIFIED biofuels in a diesel engine will NOT exhibit the increased level of NOX emissions as experienced in the combustion of CONVENTIONAL biofuels.

## SUMMARY

As portrayed herein, Emulsified Fuel Technology (EFT) is a proven technology that summarily delivers on the promises of emissions reductions – BOTH gaseous AND solid emissions reductions – plus an increase in operational efficiency. Moreover, in addition to operational efficiency enhancements, EFT can contribute significantly to the ultimate lessening of overall system maintenance costs. This last advantage arises from the fact that emulsified fuels generate energetic steam gases in the combustion zone that sweep through the combustion and exhaust chambers of a boiler or an engine and effectively clean the heat transfer surfaces therein. Such "steam cleaning" actions give rise not only to a more immediate efficient operation but ultimately contribute to the diminishment of the time and effort that needs to be devoted to cleaning these surfaces in normal outage situations

The applications of EFT are widespread. In addition to the diesel and fuel oil emulsion applications portrayed in this paper, EFT can be readily applied to residual oils to produce usable combustion products from such diverse stocks as vacuum tower bottom oils and pitch blends. In all instances, EFT presents a significant opportunity to fully utilize hydrocarbon fuels – in all "flavors" - to their maximum operational potential without fear of contributing exceptionally to harmful emission levels. As such, EFT is an enabling technology that has a significant market potential. Furthermore, as it has the potential to diminish the NOX emission level increases associate with biofuels, it has an enviable position in the quiver of modern technologies in that it is able to deliver an immediate impact on global warming and community health.

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