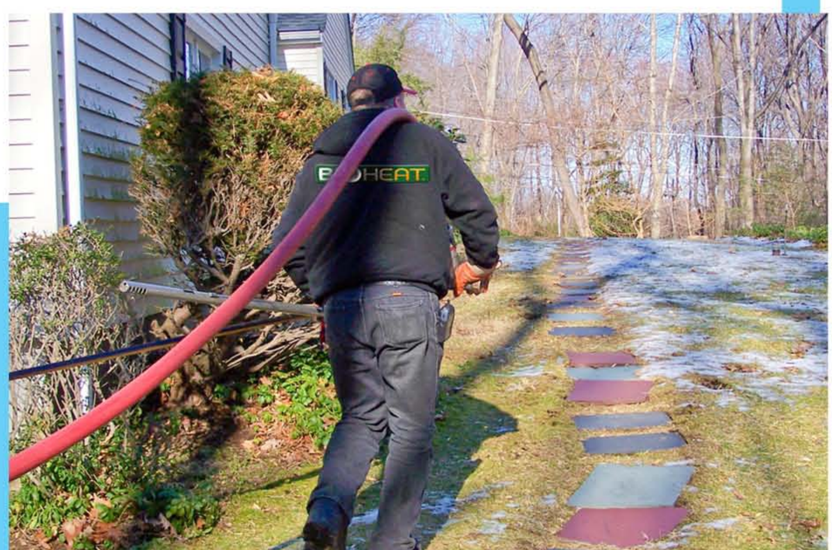
Developing a Renewable Biofuel Option for the Home Heating Sector

A Report to Congress, State Governments and Administrator of the Environmental Protection Agency

MAY, 2015



NORA
NATIONAL OILHEAT RESEARCH ALLIANCE
Research

Executive Summary

Pursuant to Public Law 113-79 (the Agricultural Act of 2014), Congress required the National Oilheat Research Alliance (hereinafter "Alliance") to prepare a report on the utilization rate and analysis of the use of biofuels in Oilheating equipment.

- One of the biggest **transitions in heating oil** has been the move **to ultra-low sulfur heating oil** (ULSHO). This fuel lowers maintenance, **improves efficiency** and **reduces pollution** from heating systems.

- **Biodiesel blends at 20%** (B-20) with **ultra-low sulfur** heating oil (ULSHO) are **lower in Greenhouse Gas Emissions** (GHG) **than natural gas** when evaluated over 100 years, while blends of 2% (B-2) or more are lower in GHG than natural gas when evaluated over twenty years.

- **Biodiesel blended at 5 percent** would **require** approximately **300 million gallons of biodiesel produced per year**. Assuming the biodiesel industry average of 50 million gallons per year per plant**.** **Bioheat®** would be responsible for **6 plants** built and continuously operated. Thus, nearly **270 full time** jobs can be directly attributed to Bioheat®.

- Studies on the operation of **Bioheat®** on the basic burner operation with biodiesel blends at **B-20** (at least) is **the same as with unblended heating oil**

- NORA (the Alliance) and the National Biodiesel Board (NBB) have **communicated the value** of using biodiesel and selling Bioheat®. The Alliance features information about Bioheat® on its consumer website**, OilheatAmerica.com**. The NBB has a webpage, **Bioheatonline.com** that describes the advantages of Bioheat®. Further, the Alliance and its affiliated state associations have worked to **provide education** on this product to consumers and retail oil companies through the use of mass media and informational brochures.

- **State and local governments** have utilized a number of strategies to encourage the use of biofuels in their communities. It is often necessary to **encourage its use** with **incentives or mandates** to develop the infrastructure and overall market acceptance for a new fuel.

I. Background and Information About NORA

Pursuant to Public Law 113-79 (the Agricultural Act of 2014), Congress required the National Oilheat Research Alliance (hereinafter "Alliance") to prepare a report on the utilization rate and analysis of the use of biofuels in Oilheating equipment. In addition to the utilization rate, the report was to provide information on the environmental benefits, economic benefits, and any technical limitations on the use of biofuels in oilheat fuel equipment, as well as describe market acceptance of the fuel. The report and information contained therein would be disseminated to the Federal Government as well as State and local governments that are encouraging the use of biofuels in oilheat fuel utilization equipment

The Alliance was established to, among other things, assist the heating oil industry develop more efficient products; improve training and develop best practices in the industry; provide product information to residential and commercial customers about oilheat and help homeowners and small business owners improve the energy efficiency of their homes and businesses when using oilheat. The Alliance has been working for over a decade to assist in the development of biofuels for the fuel oil industry. Increasingly, fuel customers are demanding a more environmentally sustainable fuel oil and renewable content is essential part of meeting that demand.

Regarding its work to date, the Alliance has primarily focused its work on the viability and utilization of biodiesel in the fuel oil industry. The Alliance's focus on Biodiesel/ Bioheat® has been a cooperative endeavor between the Alliance and the National Biodiesel Board (NBB). Both organizations are supportive of expanding the market presence of a renewable fuel in the heating oil sector.

To achieve this goal, the organizations have worked on a number of key projects:

- **Fuel validation and utilization**: Through research conducted at Brookhaven National Laboratory (BNL), Pennsylvania State University and Underwriters Laboratory (UL), the Alliance and NBB, the organization have concluded that blends up to 20 percent (of biodiesel) can be used with heating oil fuels with performance equivalent to if not better than conventional fuel oil. However, some significant manufacturers believe the elastomers in the small fuel pump typical in heating oil systems, should be replaced if a blend over 5% is used.

- **Fuel properties and characteristics**: The Alliance and NBB have conducted a significant amount of outreach and education with fuel distributors, their employees, and fuel oil service professionals who are installing and assisting with the maintenance of fuel oil appliances in residential homes and light-commercial facilities. Biodiesel blends provide added lubricity and a higher, safer flash point than conventional fuel oils, while having higher cold flow properties and slightly higher viscosity. There are ongoing initiatives, especially with blends over B20, to further study fuel properties and impacts as a complete understanding of fuel oil properties is essential for safety, soundness, and efficiency of its use.

- **Field testing:** The Alliance and NBB have conducted follow-on research of field results of using biodiesel blended with conventional heating oil. This has involved surveys of Bioheat® distributors, equipment analysis, and reviews of particular companies using biofuels.

Description of the Heating Oil Market (Residential and Commercial)

The heating oil market is well established in 23 states represented by the Alliance.
These states include:

Connecticut	**Delaware**	**Idaho**
Indiana	**Kentucky**	**Maine**
Maryland	**Massachusetts**	**Michigan**
Nevada	**New Hampshire**	**New Jersey**
New York	**North Carolina**	**Ohio**
Oregon	**Pennsylvania**	**Rhode Island**
South Carolina	**Vermont**	**Virginia**
Washington	**Wisconsin**	

Heating oil has a very strong market share in many of the New England states such as Maine, Vermont and New Hampshire as heating oil has traditionally provided a very economical way to meet the heating needs of homes, multi-family dwellings, and small businesses. Additionally, the portability of the fuel provides for easy transport to homes and businesses that are in more remote locations, which aren't serviceable from other grid infrastructure.

Heating oil is distributed by thousands of small businesses, the majority of which are family owned. Heating oil retailers generally make four deliveries to a household per year, and typically provide on-going service and maintenance of the fuel oil appliances in the home or business.

II. Environmental Benefits of Biodiesel

Air Emissions Criteria Air Pollutant Emissions Assessment

(NO_X, SO_2, CO, $PM_{2.5}$)

One of the biggest transitions in heating oil has been the move to ultra-low sulfur heating oil (ULSHO). This fuel lowers maintenance, improves efficiency and reduces pollution from heating systems. However, it is also paving the way for the next generation of equipment, which may mean lower cost materials and more compact boilers and furnaces.

As we know, sulfur is an abundant element and is a ubiquitous presence in our natural world as well as being an essential component of all living cells. However, in the industrial setting, the release of sulfur through the combustion of coal, petroleum, gasoline, and diesel fuel has been a challenge for air quality purposes. Historically, this was largely resolved as federal regulations removed most of the sulfur content from these fuels over many years with the final reductions coming with the ultra-low sulfur transportation diesel requirement in 2006.

In the home fuel oil heating context, sulfur dioxide in a heating system's flue products contributes to secondary fine particulate formation in the upper atmosphere by means of photochemistry driven by sunlight. The fine particulate ($PM_{2.5}$) results for the liquid fuel fired heating systems demonstrates the very strong linear relationship between the fine particulate emissions and the sulfur content of the liquid fuels being studied. This is illustrated by the plot contained in **Figure 1** which clearly illustrates the linear relationship between the measured mass of fine particulates per unit of energy, expressed as milligrams per Mega-Joule (mg/MJ) versus the different sulfur contents of four different liquid heating fuels. The fuels included a typical ASTM No. 2 fuel oil with sulfur below 0.5 percent (1,520 average ppm sulfur), an ASTM No. 2 fuel oil with very high sulfur content (5,780 ppm sulfur), low sulfur heating oil (322 ppm sulfur) and an ULSHO fuel (11 ppm sulfur). These results show that as sulfur decreases the $PM_{2.5}$ emissions are reduced in a linear manner. For fuel tested with a sulfur content range in ULSHO (15 ppm sulfur) the amount of $PM_{2.5}$ was reduced dramatically to an average of 0.043 mg/MJ.

Figure 1) PM 2.5 for Heating Oil Boilers and Furnaces with Varying Sulfur Content[1]

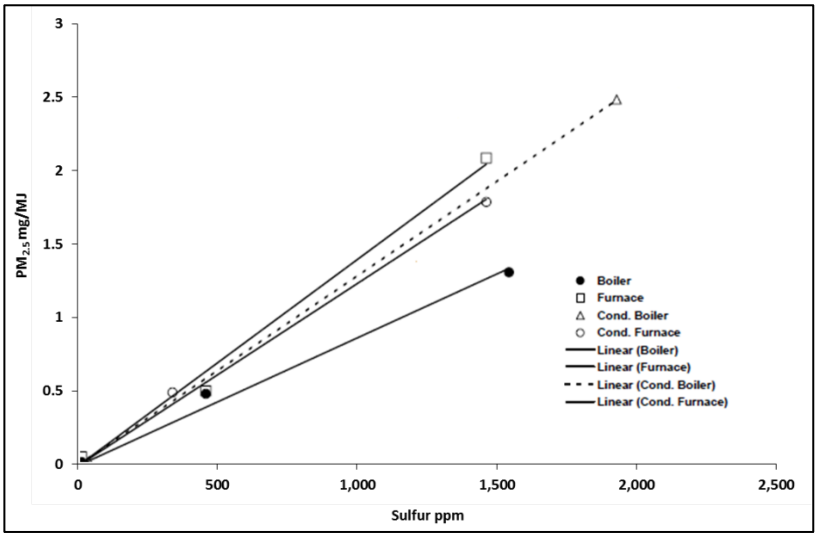


Figure 2) Compilation of Air Pollutant Emission Factors[2]

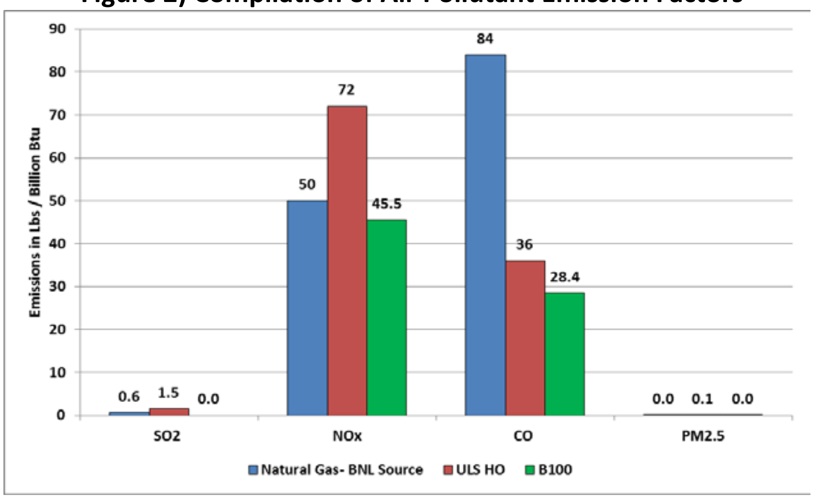


Figure 2 provides the latest comparison available from Brookhaven National Laboratory (BNL). Figure 2 ULSHO contains a maximum of 15 ppm sulfur, is generally deemed equivalent in CO, NOx, SO_2 and $PM_{2.5}$ emissions to natural gas. Also, B100 (100% biodiesel) is cleaner than ULSHO as there is no elemental sulfur in the product.

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[1] "Evaluation of Gas, Oil and Wood Pellet Fueled Residential Heating System Emissions Characteristics", Brookhaven National laboratory, December 2009, BNL-91286-2009-IR

[2] Basis for this graph: EPA AP 42-Compilation of Air Pollutant Emission Factors - http://www.epa.gov/ttn/chief/ap42/index.html Tables 1.3.1, 1.4.1 and 1.4.2 for small boilers (note EPA does not report on residential boilers, however consultation with Brookhaven National Laboratory confirmed the small boiler numbers are representative). Small particles (PM2.5) and SO2 (1,500 ppm) values are from BNL report End Note j.

Sulfur Regulations

The heating oil industry has been working with stakeholders, including regulators and downstream fuel providers to transition the industry to ULSHO as rapidly as technically and economically feasible.

Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, Rhode Island and Vermont all have phase-in periods that require a dramatic reduction in the amount of sulfur present in heating oil. (**Table 1**)

Table 1) State 15 ppm

State	Compliance Date
Connecticut	7/1/2018
Delaware	7/1/2016
Maine	7/1/2018
Massachusetts	7/1/2018
New Jersey	7/1/2016
New York	7/1/2012
Rhode Island	7/1/2018
Vermont	7/1/2018

Other than Maryland and Pennsylvania, both of which have mandated a reduction to 500 PPM sulfur, each of the above states will require no more than 15 PPM. Each state has set its own time table for the transition; the latest date is July 2018.

The cities of New York and Philadelphia have set their own standards with more aggressive transitions. The District of Columbia, not yet having low-sulfur requirement, has proposed 15 PPM sulfur by July 1, 2018.

Field results from New York State have already demonstrated significant improvement in systems operations and emissions.

Additionally, some of the states and New York City have either instituted a biodiesel blend requirement or have proposals in place. The inclusion of biodiesel (a renewable fuel made from agricultural products) in blends over 2% biodiesel, makes up what is known as **Bioheat®.**

Description of Greenhouse Gas (GHG) Reductions

The subject of GHG emissions remains in flux as more data evaluations are made. In fact, as of this writing, the IPCC has published a fifth draft report. The United Nations Intergovernmental Panel on Climate Change (IPCC) report, increased the GHG multiplier for methane from 25 (100 Year Atmospheric lifetime) and 72 (20 Year Atmospheric lifetime) times CO_2 to 28 and 84 respectively. This amounts to a 12% (100 year) and 17% (20 year) increase in GHG impact.

A recent Harvard University study concluded that regional methane emissions due to fossil fuel extraction and processing could be 4.9 ± 2.6 times larger than in EDGAR, the most comprehensive global methane inventory. These results cast doubt on the U.S. EPA's recent decision to downscale its estimate of national natural gas emissions by 25–30%.

Understanding the CO_{2e} emission role of renewable fuels presents a difficult challenge as there are a very large amount of variables which impact the calculation. There has been significant assessment of CO_{2e} net impact analysis for soybean derived biodiesel. The most comprehensive work was done for the Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis published by EPA in February 2010[3]. The approach utilizes consequential approach to life cycle assessment. The model not only assesses CO_{2e} emissions (direct and indirect), it evaluates that soybeans (about 20% oil and 80% meal) are grown for food (meal) and fuel (oil), and further an increase or decrease in price for either component has a significant ripple effect on the complex interactions with petroleum refining and the complete agricultural industry. The National Biodiesel Board analyzed the US EPA data from the RFS2 and developed the following data for use in this report:

Table 2) US EPA Soybean Biodiesel CO_{2e} Emissions Net Impact Based on EPA RFS2

	metric tons					AR4-100	AR4-20
Biodiesel	CH_4	N_2O	CO_2	B gal	MMBtu	lb/MMBtu	
Other (fuel and feedstock transport)	237	6	213,562	0.5	63,720,000	8	8
Domestic Farm Inputs and Fert N_2O	-3,748	2,266	-617,142	0.5	63,656,917	-1	-8
Domestic Land Use Change	0	0	-566,317	0.5	63,656,917	-20	-20
Domestic Livestock	-6,367	0	0	0.5	63,656,917	-6	-16
Domestic Rice Methane	-24,099	0	0	0.5	63,656,917	-21	-60
International Farm Input GHG	138	437	205,926	0.5	63,720,000	12	12
International Livestock	-14,597	-334	0	0.5	63,720,000	-16	-40
International Rice Methane	6,614	0	0	0.5	63,720,000	6	16
Fuel Production - Soybean oil feedstock	2,827	17	773,538	0.5	63,720,000	29	34
Total GHG Impact without Indirect Land Use						-9	-73
Total GHG Impact with Indirect Land Use						86	22

Based on the residential boiler analysis report by ICF International, (ICF)[4] CO_{2e} data and the above biodiesel results, **Table 3** and **4** contain the GHG emissions results for bioblends equivalent to natural gas.

[3] EPA-420-R-10-006

[4] Final Report: "Resource Analysis of Energy Use and Greenhouse Gas Emissions from Residential Boilers for Space Heating and Hot Water", Revised February 2009, ICF International, Submitted to: Consortium of State Oilheat Associations Greenhouse Gas Project

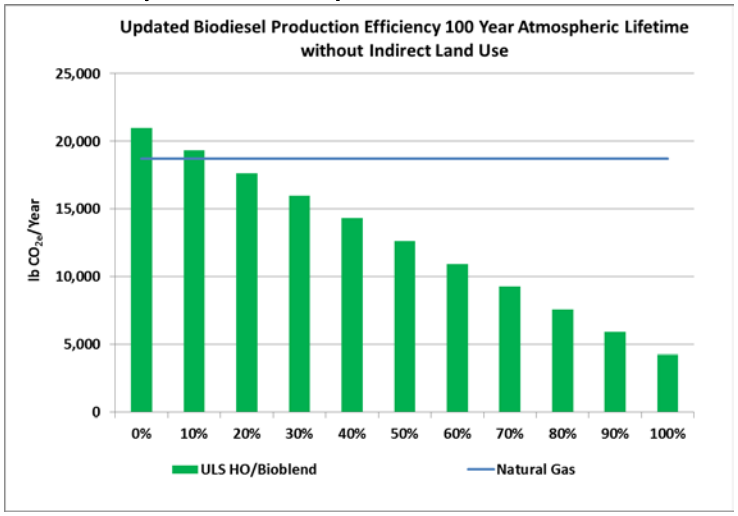
Table 3) Results for Bioblend with Equivalent CO_{2e} Emission to Natural Gas 100 Year Atmospheric Lifetime (IPCC AR4) Annual Emissions Advanced non-condensing Boiler

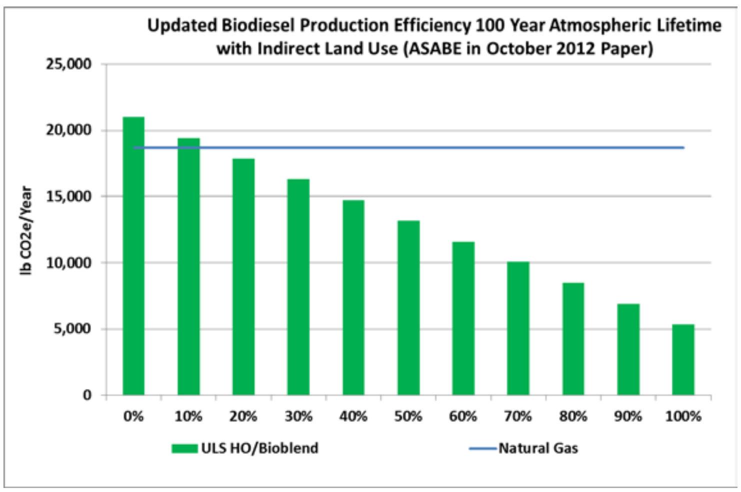
without Indirect Land Use (using ASABE in October 2012 paper data)			
2020			
	lb CO_{2e}/MMBtu	lb CO_{2e}/Year	Bioblend equal emissions to natural gas
Natural Gas	152.73[1]	18,694[1]	
ULS	192.93[1]	20,980[1]	
B100	39.30[2]	4,274[1,2]	
ULS HO/Bioblend	171.91	18,694	**13.7%**
with Indirect Land Use (using ASABE October 2012 Paper Data)			
2020			
	lb CO_{2e}/MMBtu	lb CO_{2e}/Year	Bioblend equal emissions to natural gas
Natural Gas	152.73[1]	18,694[1]	
ULS	192.93[1]	20,980[1]	
B100	49.36[2]	5,367[2]	
Blend		18,694	**14.6%**

[1] "Final Report Resource Analysis of Energy Use and Greenhouse Gas Emissions from Residential Boilers for Space Heating and Hot Water", Consortium of State Oilheat Associations Greenhouse Gas Project, ICF International, February 2009

[2] "Reassessment of Life Cycle Greenhouse Gas Emissions for Soybean Biodiesel", A. Pradhan, et al, American Society of Agricultural and Biological Engineers (ASABE) Transactions, 2012 ISSN 2151-0032 data and National Biodiesel Board Latest Calculations April 2015.

Figure 3) Bioblend GHG Emissions by Blend Percent versus Natural Gas 100 Year Atmospheric Lifetime (with and without indirect land use)





Science of GHGs (20 vs. 100)

The IPCC developed the concept of global warming potential (GWP) as an index to help policymakers evaluate the impacts of greenhouse gases with different atmospheric lifetimes and infrared absorption properties, relative to the chosen baseline of carbon dioxide (CO_2). Scientific advancements have led to corrections in GWP values over the past decade, and it is imperative that our policy decisions reflect this new knowledge. In the mid-90s, policymakers for the Kyoto Protocol chose a 100-year time frame for comparing greenhouse gas impacts using GWPs. The choice of time horizon determines how policymakers weigh the short- and long-term costs and benefits of different strategies for tackling climate change. According to the IPCC, the decision to evaluate global warming impacts over a specific time frame is strictly a policy decision—it is not a matter of science:

> ***"the selection of a time horizon of a radiative forcing index is largely a 'user' choice (i.e. a policy decision)" [and] "if the policy emphasis is to help guard against the possible occurrence of potentially abrupt, non-linear climate responses in the relatively near future, then a choice of a 20-year time horizon would yield an index that is relevant to making such decisions regarding appropriate greenhouse gas abatement strategies."***

Short-lived pollutants that scientists are targeting today, which actually warm the atmosphere, are methane and hydrofluorocarbons which are greenhouse gases like CO_2; trapping radiation after it is reflected from the ground. Black carbon and tropospheric ozone, an element of smog, are not greenhouse gases, but they warm the air by directly absorbing solar radiation. Black carbon remains in the atmosphere for only two weeks and methane for no more than 15 years.

Impact of Biodiesel on Oilheat Emissions

Figure 3 shows that less than 20% biodiesel blend with Ultra Low Sulfur Heating Oil (ULSHO) is equivalent to natural gas with respect to CO_{2e}[5] emissions using a 100 year atmospheric lifetime even accounting for the impact of indirect land use according the latest EPA data from RFS2.

Focusing on near term targets for GHG impacts is both an effective strategy and recommended policy, as it can have a more dramatic effect in the short term than reductions in carbon dioxide, thus providing more time to develop appropriate carbon dioxide reduction strategies. This means shifting from the conventional 100-year atmospheric life-time to atmospheric lifetime assessment methodology to a more focused 20-year atmospheric lifetime assessment. Using the IPCC Fourth Technical Report's 20-year shows that a less than 2% biodiesel blend with ULSHO is equivalent to natural gas with respect to CO_{2e} emissions[6]. **(Table 4)**

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[5] Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (e.g. 20 or 100 years). Carbon dioxide equivalency thus reflects the time-integrated radiative forcing of a quantity of emissions or rate of greenhouse gas emission—a flow into the atmosphere—rather than the instantaneous value of the radiative forcing of the stock (concentration) of greenhouse gases in the atmosphere described by CO_{2e}

[6] Using EPA's indirect analysis to 20yr GWP, the credits from methane reduction seem to overpower the CO_2 penalties for land use change and biodiesel's net emissions become negative (which is very good). To be conservative, given this very positive result as well as questions surrounding indirect land, this calculation has not been factored into the benefit analysis.

Table 4) Results for Bioblend with Equivalent CO_{2e} 20 Year Atmospheric Lifetime (IPCC AR4) Annual Emissions Advanced Non-condensing Boiler without Indirect Land Use

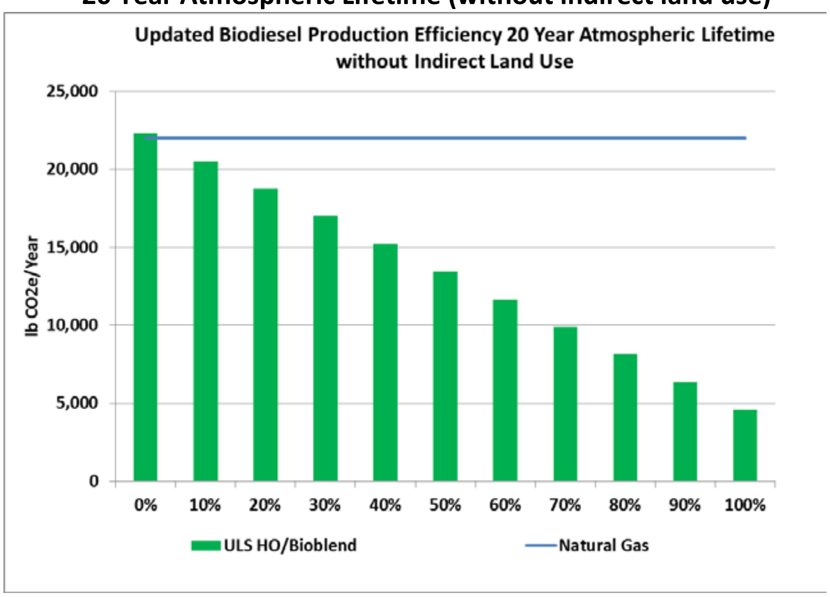
Updated Biodiesel Production Efficiency 20 Year Atmospheric Lifetime without Indirect Land Use			
2020			
	lb CO_{2e}/MMBtu	lb CO_{2e}/Year	Bioblend equal emissions to natural gas
Natural Gas	179.87[1]	22,016[1]	
ULS	205.31[1]	22,326[1]	
B100	42.10[2]	4,578[1,2]	
ULS HO/Bioblend	202.46	22016	**1.7%**

[1] "Final Report Resource Analysis of Energy Use and Greenhouse Gas Emissions from Residential Boilers for Space Heating and Hot Water", Consortium of State Oilheat Associations Greenhouse Gas Project, ICF International, February 2009

[2] "Reassessment of Life Cycle Greenhouse Gas Emissions for Soybean Biodiesel", A. Pradhan, et al, American Society of Agricultural and Biological Engineers (ASABE) Transactions, 2012 ISSN 2151-0032 data and National Biodiesel Board Latest Calculations April 2015.

Figure 4 provides view of the future of biodiesel as technology permits greater fraction of biodiesel, the CO_{2e} comparison between this liquid fuel and natural gas dramatically favors biodiesel.

Figure 4) Bioblend GHG Emissions by Blend Percent versus Natural Gas 20 Year Atmospheric Lifetime (without indirect land use)[7]



[7] EPA's indirect analysis to 20yr GWP, the credits from methane reduction seem to overpower the CO2 penalties for land use change and biodiesel's net emissions become negative (which is good). Given this very positive result, as well as questions surrounding indirect land, this calculation has not been factored into the benefit analysis.

Figure 5**) ULS HO/Bioblend CO_{2e} Reduction versus Natural Gas 20 Year Atmospheric Lifetime without Indirect Land Use**[6]

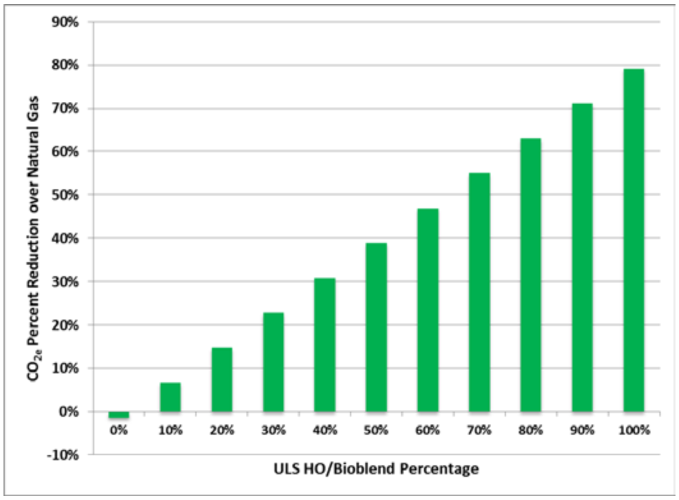


Figure 5 shows that, as technology advances, biodiesel blends with heating oil, CO_{2e} reduction can far exceed conventional natural gas and shale gas. Given that biodiesel blends with heating oil GHG emissions can easily be lower than natural gas GHG emissions, there is no climate change reason for fuel switching from oil to natural gas.

Comparative View of Natural Gas

Focusing on near term targets for GHG impacts is both an effective strategy and recommended policy as it can have a more dramatic effect in the short term than reductions in carbon dioxide, thus providing more time to develop appropriate carbon dioxide reduction strategies. This renewed focus on 20-year GHG targets stimulated a reassessment of the ICF life-cycle study using the AR4 20-year numbers for methane emissions in the production, transportation, delivery and combustion of heating oil, ultra-low sulfur diesel, bio-blends, natural gas and shale gas.

Both wellhead production and local distribution company delivery system leakage have been the subjects of numerous studies and reports. It should be noted that the calculations within this report were based on the conservative ICF approach using EPA data. But, there is significant research underway which could increase the impact of CO_{2e} of natural gas.

A report prepared for United States Senator Edward J. Markey, issued August 1, 2013 titled, "Natural Gas Pipeline Leaks Cost Consumers Billions", highlighted the fact that "Federal and state regulators explained in interviews for this report that there isn't a consistent methodology for calculating lost and unaccounted for gas, and data quality problems are common." This may clearly lead to inaccurate leakage reporting to EPA.

The issue of natural gas extraction and processing emissions remains a hot topic. Balancing the latest reports, one can only conclude the University of Texas (UT) narrow focused study did not provide compelling evidence on existing fugitive emissions, while the Harvard study continues to raise compelling questions regarding methane emission levels from processing and production.

The UT and the Environmental Defense Fund study released September 16, 2013 directly measured methane emissions at 190 onshore natural gas production sites throughout the United States, including 27 wells being prepared for continuous production and 489 wells that underwent hydraulic fracturing. The authors found that the emissions measured at wells during completion varied over a large range but were, on average; nearly 50 times lower than previously estimated by the Environmental Protection Agency (EPA). By contrast, measurements of methane emissions from equipment on wells in routine production were comparable to, or higher than, EPA estimates. The authors used the measurements of methane emissions to estimate that the nation's total annual methane emissions from well completions, pneumatic devices, chemical pumps, and equipment leaks are between 757 and 1,157 gigagrams (Gg), comparable to the EPA estimate of approximately 1,200 Gg.

In addition, the UT study contains a major internal contradiction. The well sites in the study were selected with substantial input from the oil and gas industry, which volunteered specific sites. The vast majority of the wells studied used leak-control technology that has yet to be adopted at many, if not most, oil and gas wells, while others were wells that produced very little gas and consequently even serious leaks would produce relatively small emissions. Specifically, the authors noted, those wells had the potential to emit only 0.55% as much as an average well. Although the study's authors acknowledged that their measurements were by no means representative of the average gas well nationwide, they nonetheless chose to use that skewed data to estimate gas leaks nationwide. The methodology that UT chose for making that estimate has drawn criticism in the research community.

Alternatively, and according to a study released November 25, 2013 by Harvard University, methane from fossil fuel extraction and refining activities in the South Central United States are nearly five times higher than previous estimates. The new study takes a top-down approach, measuring what is actually present in the atmosphere and then using meteorological data and statistical analysis to trace it back to regional sources. NOAA and the U.S. Department of Energy collect observations of methane and other gases from the tops of telecommunications towers, typically about as tall as the Empire State Building, and during research flights. The team combined this data with meteorological models of the temperatures, winds, and movement of air masses from the same time period, and then used a statistical method known as geostatistical inverse modeling to determine the methane's origin. The team also compared these results with regional economic and demographic data, as well as other information that provided clues to the sources — for example, data on human populations, livestock populations, electricity production from power plants, oil and natural gas production, production from oil refineries, rice production, and coal production. In addition, they drew correlations between methane levels and other gases that were observed at the time.

For example, a high correlation between levels of methane and propane in the south-central region suggests a significant role for fossil fuels there.

Environmental Conclusion

Biodiesel blends at 20% (B-20) with ultra-low sulfur heating oil (ULSHO) are lower in Greenhouse Gas Emissions (GHG) than natural gas when evaluated over 100 years, while blends of 2% (B-2) or more are lower in GHG than natural gas when evaluated over twenty years. Any ULSHO and biodiesel blend is equally clean in criteria pollutants and particulates. With future research and applications, increasing the biodiesel blend reduces GHG emissions even further. Bioblends for heating oil are a clean responsible alternative to natural gas heating systems and perform admirably against all other heating systems.

III. Economic Benefits of Biodiesel

Implementation with Little or No Cost to the Consumer

As indicated in the previous section, there are a number of environmental benefits to the use of biodiesel in heating oil. As a result, the heating oil industry has been exploring the use of this fuel in its product. Doing so would allow it to respond to the environmental and energy concerns associated with conventional heating oil. Additionally, it would provide a pathway to respond to policies being proposed and implemented by various state agencies to significantly reduce greenhouse gas emissions.

The Alliance, in cooperation with the NBB and others in the industry, have worked to establish a pathway for the use of the biodiesel in heating fuel oil products. This has primarily involved ascertaining the suitability of the use of the fuel in existing heating appliances, and assessing regulatory barriers that could impede its use.

The Alliance's research determined that a blend of 5 percent of biodiesel in heating oil would not impact the operability of heating oil appliances. The research to support this was conducted at Brookhaven National Laboratory and Underwriters Laboratory. Based on this research, ASTM incorporated blends up to 5% biodiesel meeting its D6751 specification as a fungible component in traditional No. 1 or No. 2 heating oils. Blends containing up to B5 are now considered just conventional No. 1 or No. 2 heating oil and, similar to the other components that make up fuel oil, no additional labeling or specific disclosure of the exact biodiesel component content is needed.

Subsequently the Alliance began research on various blend of heating oil and biodiesel, investigating whether different levels of sulfur in the fuel combined with different levels of biodiesel up to 20 percent would impact the operability of the system. The primary focus of the research was on the seal materials present in the fuel pumps. The Alliance conducted an extensive study of these materials in both a lab and in operating conditions, and found no issues associated with biodiesel blending.

ASTM was presented with this data and in December 2014 the standards governing heating oil, ASTM 396, were amended to include a new B6-B20 biodiesel blend grade as part of the D396 heating oil standard.

The research has focused on combustion properties of biodiesel and material compatibility with existing elastomers and fuel system components. To date the research has found blends up to B20 are compatible with existing elastomers and materials and these blends perform as well if not better than conventional fuel oil. Thus, it appears that a variety of blends of biodiesel may be usable in heating oil equipment without system modifications. As the Alliance reviews higher blends of biodiesel in the future, it is anticipated that existing equipment will be able to use significant blends of biodiesel with either no modification or minor modifications that could be accomplished during annual maintenance and tune up normally performed on most home heating oil systems. Further, the Alliance is working to ensure equipment manufactured is designed for and can use higher blends without modification. As that equipment enters the field, it is likely that most consumers of heating oil will incur only minor additional costs for retrofitting their appliance prior to using biodiesel. This provides the oilheating industry a unique opportunity to transition their customers to a renewable fuel with minimal costs to the industry and its consumers.

With regards to pricing, the Alliance has limited information on the pricing of biodiesel l versus conventional heating oil. However, the Alliance does receive periodic pricing reports from a supplier in Pennsylvania. In the last year, the price differential between heating oil and biodiesel has generally ranged between 5 and 13 cents per gallon for a B-20 gallon, although in many instances RFS2 credits or other state incentives allows biodiesel to be priced similar to or lower. If one assumes a 5 to 13 cent differential, the cost of using a B-20 gallon today in a home using 700 gallons per year would be between $35 and $91.

Economic Impacts of Biodiesel Production & Sales

Economic benefits from producing and using biodiesel in the Bioheat® market will be provided by the economic activity associated with jobs supported by the industry. These jobs are associated with the production of biodiesel as well as the fats and oils required as feedstock, and transporting both feedstock and finished diesel fuel. The impact across the value chain for U.S.-produced biodiesel was established via three different metrics:

- **Economic impact** — quantifying the value added to the US economy across the biodiesel value chain.
- **Employment impact** — estimating the number of full-time equivalent (FTE) jobs contributed by biodiesel production, processing and distribution.
- **Wage impact** — evaluating the total wages for individuals employed along the biodiesel value chain.

The economic indicators for each step of the biodiesel value chain are evaluated at three different levels, Direct, Indirect and Induced:

- **As the name suggests, the Direct economic** effect is composed of the economic, employment and wage impacts that can be directly attributed to the biodiesel value chain. These results were calculated first hand by LMC International based on models driven by publicly and privately available data, industry knowledge, and interviews with industry stakeholders.
- **Indirect economic effects are the economic**, employment and wage impacts created by those industries that supply the biodiesel value chain, or by individuals who work at the periphery of the sector.
- **Induced economic effects are those economic**, employment and wage impacts that stem from household spending of the income earned from the biodiesel sector.

Direct economic impacts of biodiesel production are manually evaluated across 11 steps in the value chain — spanning from the production of feedstocks produced specifically for biodiesel production to delivery of biodiesel to the point of sale. The model also allocates impacts across all 50 states, based primarily on these states' share of 1) feedstock production and 2) processing capacity for biodiesel. An understanding of state-level production and demand is particularly important when it comes to determining impacts on transportation.

Value Chain Component	Description
Seed Production	Value of the oil produced for biodiesel feedstock in seed. Given that meal is outside the scope of the biodiesel chain its value is excluded
Animal Processing	Processing and rendering of animal carcasses into feedstocks for biodiesel use
Seed Delivery	Delivery of seeds used in biodiesel to elevation facility
Elevation	Elevation and storage of seeds used in biodiesel production
Oilseed crush (oil share)	Value in removing oil from seed in crush process for use as a biodiesel feedstock
Biodiesel Processing	Collection and processing of feedstocks into biodiesel
Rail deliveries of biodiesel and glycerin for domestic market	Rail shipments of biodiesel and glycerin from surplus to deficit states with most traffic originating in the Midwest
Rail deliveries of biodiesel for export market	Rail shipment of biodiesel to point of export from the US
Barge deliveries	Barge deliveries (primarily from Midwest to Houston) and primarily for the export market
Port activities	Loading ocean-going vessels with biodiesel for shipments to the export market
Trucking to point of sale	Trucking of biodiesel (mostly blended with conventional diesel) from terminal to dealer outlet

The Biodiesel Value Chain

Indirect Impacts of Increased Biodiesel Production & Sales

In addition to direct employment benefits, biodiesel use also has several indirect/ancillary benefits. Specifically, increased production of biodiesel increases the global fuel supply, generates indirect and induced employment impacts, and energy security and health benefits accrue to U.S. citizens.

Indirect & Induced Economic Impacts

The direct effects previously cited of increased biodiesel production on the U.S. economy are significant, but they fail to capture the full impact of the sector.

- There is a ripple effect that the biofuel has on supporting industries. This is known as the indirect effect. For some steps in the biodiesel value chain, the indirect effect can be quite large. This is especially true for capital-intensive aspects of the sector, like crushing of oilseeds and refining crude oil to a usable fuel. To illustrate this point, consider the typical biodiesel facility in the U.S., with an average capacity of 40-60 million gallons annually, which directly employs between 40 and 50 people (although there is considerable variation across the capacity and staffing rates of the country's 100+ operational facilities). This does not include the many jobs associated with keeping that facility operational, from white collar jobs in engineering to trade professions like electricians, plumbers and pipefitters that are done on a contractual basis making the true impact of that facility much higher.
- Similarly, direct effects fail to capture the economic activity stemming from expenditures of households drawing a salary from a given sector. While these "induced" effects are typically smaller than indirect effects, they can still constitute a sizeable economic force, particularly when the sector being evaluated is large, as is the case for biodiesel.

To capture indirect and induced effects, economists use multipliers, which are developed from "input-output" tables, which in turn measure the impact on the broader economy from some kind of exogenous shock to a specific sector of the economy. Because input-output tables and economic multipliers are the convention when estimating indirect and induced effects, they are available for many economies globally. In the case of the United States, multipliers are made available by the U.S. Department of Commerce's Bureau of Economic Analysis across 406 detailed industries and, in most cases, all 50 states.

Based upon analysis by LMC International, 1.7 billion gallons of biodiesel production supports $16.8 billion in total economic impact, more than 62,000 jobs, and $2.6 billion in wages paid. If biodiesel is blended at 5 percent, that would be approximately 300 million gallons of Bioheat® produced per year. Thus, almost 18% of the benefits cited by LMC could be attributed to the growing Bioheat® market.

Biodiesel processing

Biodiesel production adds value to the American economy by processing crude vegetable oils, animal fats and waste oils into a usable fuel.

The first step in determining the value added in biodiesel production is to determine the total value of biodiesel produced and that of its primary by-product glycerin. Biodiesel production figures were obtained by the Energy Information Administration (EIA) of the U.S. Department of Energy. For glycerin, it was assumed that it was produced at a ratio of one to ten relative to biodiesel. The total value of U.S. biodiesel and glycerin production were then determined as the product of volumes and prices which were obtained for biodiesel and glycerin from the EIA and “The Jacobson” newsletter.

Soybean Oil

The breakout of feedstocks used in biodiesel production was obtained from the EIA, which reports data back to 2011, and the U.S. Census Bureau, which reported data for previous years. The unit cost of these feedstocks was obtained from various sources, with the USDA being the primary source of data. The total cost of these feedstocks to the biodiesel industry was then determined by multiplying volumes by price. The value added in biodiesel production (Direct economic impact) was then determined as the value of biodiesel and glycerin produced minus the total costs of feedstocks.

Seed Production, Delivery and Elevation

Economic impacts of biodiesel production extend downstream into farming by way of the demand that biodiesel creates for vegetable oil and ultimately the seeds from which this oil is derived.

For all plant feedstocks used in biodiesel production, however, oil is just of one of the products produced in processing. For soybeans and canola, meal represents a significant share of the value, while in the case of corn; inedible corn oil represents just a fraction of the total value relative to ethanol and distilled dried grains with solubles (DDGS). However, the value of the oil is important in evaluating the total return on investment in any crop decision.

Prior to being used for biodiesel, oilseeds must first be crushed to separate crude oil from protein meal. Crush margins represent the value created by purchasing seed and selling its component parts. Estimates for biodiesel’s impact on crushing employment were made by dividing the oil share of seed crushed for biodiesel by the total amount of seed crushed in the U.S. annually. It is estimated that roughly half of the plant-based biodiesel production in the U.S. is backward integrated into crushing, with the remainder of biodiesel facilities purchasing their crude oil from independent crushers. Regardless of where the oilseed crushing takes place, the employment impact is important.

Animal Processing

Economic impacts from biodiesel were not assessed at the level of animal processing for a number of reasons. Inedible fats in animal carcasses have relatively little value in comparison with the more valuable parts of the animal, but what value there is, is created only by ranchers and processors rather than upstream industries. Lastly, even if one were to attempt to assign an economic benefit to the livestock sector from biodiesel, it would be quite small, given that waste fats and greases comprise such a small share of the value of the industry’s output. One can, however, make a case that biodiesel represents a share (albeit a small one) of the roughly half a million jobs in the U.S. attributed to poultry and livestock slaughter and processing. Rail deliveries of biodiesel for domestic consumption

In modeling long-range biodiesel distribution, we made a number of simplifying assumptions. First, it was assumed that all long-range deliveries of biodiesel were made by rail, when in reality, small amounts are delivered by truck or pipeline. Additionally, that very few long-range deliveries of biodiesel take place within the region. Instead it is assumed that all long-range biodiesel shipments originate in the geographic center of the Midwest and terminate at the population centers of the five remaining PADDs.

IV. Technical Limitations

The Alliance and Brookhaven National Laboratory have been studying biodiesel and blends into heating oil for several years. Most of the physical and chemical properties of biodiesel are fairly well known, since ASTM has had specifications for B100 as a blend stock with diesel fuel since 2001. The key properties needed for heating oil equipment and handling purposes, and some of the key attributes of biodiesel and its blends with heating oil, are discussed in more detail below

Fuel Properties

The fuels used for heating boilers and furnaces in the residential and commercial sectors are defined in the ASTM D396 standard[8]. This standard defines fuels ranging from kerosene to residual oils. This standard defines a range of acceptable properties of the fuel which affect their performance in burners in the field including:

- **Flash Point** – a minimum flash point is defined and this relates to storage safety and fire prevention.
- **Water and Sediment** – these contaminants can cause problems with pumps, flow control, and burner components and a maximum is defined.
- **Distillation Temperature** – in a burner operating in steady state, sprayed fuel is vaporized before being mixed with air and burned. For any burner to operate as designed the fuel should have a vaporization / temperature characteristic within some predictable range.
- **Viscosity** – This is a measure of the flow resistance of a fuel. In a spray burner, a fuel with a high viscosity will produce larger drops, leading to the potential for poor combustion.
- **Ash** – Typically very low in heating fuels, this can affect the rate of fouling of boiler and furnace heat transfer surfaces downstream of the flame.
- **Sulfur** – This affects air pollutant emission potential as well as heat exchanger surface fouling potential. Most of the sulfur in heating oil is emitted from the exhaust vent as sulfur dioxide. A very small fraction (~ 1%) transforms to sulfuric acid aerosol. This acid can deposit on heat exchanger surfaces leading to corrosive attack and scale formation. The balance of the sulfuric acid aerosol, not deposited as aerosol, is emitted as a fine liquid particulate. These liquid aerosols emitted, while very small in amount, are the most significant source of measureable particulate emissions with the lighter oils. New York State has recently required a maximum sulfur level of 15 ppm in heating oil, a 99% reduction from earlier typical levels. Other states are also implementing sulfur reduction regulations. This is particularly important for biofuels because these must now meet the new and changing sulfur limitations.
- **Pour Point** – This is a measure of the lowest temperature at which the fuel will reasonably flow. This parameter is very important in colder climates, particularly where outdoor fuel storage may be used.

[8] American Society for Testing and Materials, "Standard Specification for Fuel Oils D396-13," ASTM Inc., Coshohocken, PA, 2013.

For each of the defined properties a standard test method and limits are included. The ASTM D396 standard includes grades 1 through 6 but for some of these grades two different types are defined, leading to a total of 9 different fuels in the 2013 version of the standard. Grade 1 is the “lightest” grade with the lowest viscosity and the lowest temperature range for distillation. Grade 6 is the heaviest grade and is used only in large industrial boilers with fuel heating provision. The grade most commonly used in residential and commercial sector heating applications is No. 2 oil. In 2008 the definition of No. 2 oil in ASTM D396 was changed to allow up to 5% biodiesel content with the resulting blend being considered fully equivalent to No. 2 oil.

Biodiesel is the most widely available and widely used biofuel in the residential and commercial heating market. The properties of biodiesel as a fuel blend stock are formally defined in ASTM Standard D6751. Having a formal specification for this biofuel greatly facilitates control of the quality of this biofuel in the marketplace. Biodiesel is naturally ultra-low in sulfur content, naturally high in fuel lubricity (which may become more important as heating oil transitions to ultra low sulfur fuel oil which could have lubricity issues), contains zero aromatic compounds and 11% oxygen. The presence of oxygen and the lack of sulfur and aromatics provides a fuel that reduces emissions compared to traditional fuel oil. In addition, NBB has developed a quality management program, labeled BQ-9000 (National Biodiesel Board), which defines management practices to ensure production and delivery of fuels which meet ASTM standards.

Table 4) provides a summary of typical properties of No. 2 home heating oil, unblended biodiesel (B-100 or 100% biodiesel) and a 20% blend of biodiesel in heating oil (B-2) as well as the limits for properties as specified in ASTM D396 for No. 2 heating oil. Blends of biodiesel and No. 2 heating oil will have properties between those of the unblended fuels approximately in proportion to the blend ratio and this has been done for the B-20 properties in Table 5..

Table 5 shows that the properties of B-100 fall out of the accepted limits for No. 2 heating oil but the properties of B-20 do not.

Figure 6 illustrates a typical small heating system and highlights the points in the system were there could be concerns with blends of No. 2 heating oil and biodiesel or other biofuels. Fuel storage tanks could be outside, underground, or indoor. For all locations the fuels must be capable of being delivered over the whole range of outdoor temperatures which may be experienced in a specific region. Fuels which have high pour points may “freeze” into a waxy solid at very low temperatures and special handing considerations may be required.

A typical heating fuel tank would be filled four times during the heating season. For a furnace or heat only boiler, there would be no fuel turnover during the summer months and partially-filled tanks simple sit idle. Fuel tanks are not emptied prior to refills. This leads to the lifetime of a fuel in a storage tank on the order of a year. Biofuels must have sufficient stability to be stored for this time.

Table 5) Comparison of Typical Fuel Properties, No. 2 Heating Oil and Biodiesel

Property	No. 2 Heating Oil	Biodiesel (B100)	B-20 Blend	ASTM Limit for No. 2 Heating Oil
Standard	ASTM D 396	ASTM D 6751	[1]	ASTM D 396
Higher Heating Value (Btu/gal)	139,200	125,000	136,360	-
Kinematic viscosity (mm^2/s@ 40 F)	2.7	4.0 – 6.0	3.0	4.1(max)
Specific gravity (kg/liter @ 60 F)	0.86	0.88	0.86	.876 (max)
Density (lb/gal)	7.1	7.25	7.1	7.31 (max)
Carbon (wt%)	86.6	77.0	84.7	-
Hydrogen (wt%)	13.6	12.0	13.3	-
Oxygen (wt%)	0.1	11.0	2.3	-
Sulfur (ppm)	500[2]	5	400[4]	500[3]
Flash Point (F)	120 to 210	300	120 to 210[5]	100 (min)
Cloud Point (F)	10	26 to 54	15	-
Pour Point (F)	5	5 to 50	8.6[6]	21.1 (max)

Notes –

[1]At the present time a specification for a B-20 heating fuel has not been published. Recently the ASTM D-396 subcommittee voted to approve such a standard and it is expected to be published early in 2015.

[2]This is based on the limit of the S500 (low sulfur) category for No. 2 heating oil. As noted in the body of the report, some states are requiring even lower sulfur heating oil. New York requires all heating oil to be at 15 ppm sulfur or less.

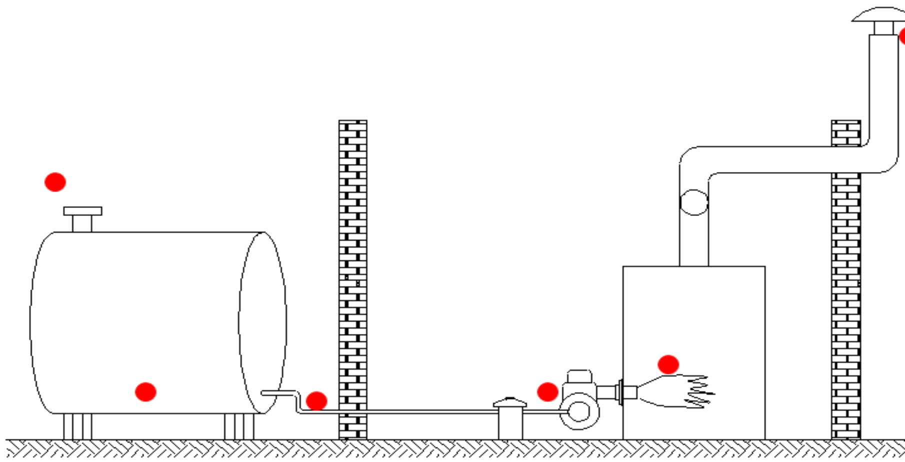
[3]This is based on the limit of the S500 (low sulfur) category for No. 2 heating oil.

[4] Based on a heating oil with 500 ppm sulfur. If the heating oil meets the New York limit of 15 ppm, the B-20 blend would be well under 15 ppm.

[5] Based on the No. 2oil part of the blend.

[6] The cloud and pour points of biodiesel depend strongly on the feedstock used. These are offered as typical values of a fuel that would be sold for winter use.

Figure 6) Illustration of a typical oil-fired central heating system and the aspects of the system which can be affected by the use of a biofuel or biofuel blend.



Fuel storage tanks have a service life of 20-30 years and in some cases longer. Over years of use, with No. 2 heating oil, it is very common for a layer of water and degradation products to develop. These products are typically polymeric oxidation products ("sludge" or "gum"). During a fill event it is common for the deposit layer on the bottom to be mixed into suspension for some hours. Burner system concerns such as filter and fuel spray nozzle blockage may occur as a result of this. The interface between the water layer and the fuel layer at the bottom of a tank provides an environment in which biological growth can occur. This growth can create additional polymeric deposits and an acidic environment which can accelerate corrosion of the tank bottom. Ideally, a candidate biofuel should not accelerate any potential biological growth.

The fuel piping system between the tank and the burner includes a copper fuel line (typical), shutoff valves and, commonly, a filter assembly. Elastomer materials used for sealing there components vary but nitrile rubber is common. Any candidate biofuel must not interact negatively with any of these components.

Burner components include a gear pump with integral pressure regulator, often a solenoid valve, the connecting fuel line and a spray nozzle which might be either brass or stainless steel. In the pump different types of elastomeric seals are used but nitrile rubber is common. Like all elastomeric seals, even within a general categorization such as nitrile, the exact composition and use of additives which may affect operating performance are different.

In a combustion chamber, any biofuel or biofuel blend is expected to provide rapid ignition on startup, a stable flame, a flame length and pattern similar to that for No. 2 oil and low emissions of smoke and carbon monoxide.

Oil-fired heating systems are not a significant source of emissions of oxides of nitrogen (NO_x) and, for this reason; these burners are not subject to NOx emission limits in the states which typically use heating oil.

Biodiesel – Storage

Because of the structure of the biodiesel molecule, this fuel may have greater potential for oxidative degradation than No. 2 fuel oil does. This depends strongly on the base vegetable oil used to produce the biodiesel. Additives can be effectively used to enhance the stability of biodiesel.

In response to stability concerns, a stability specification has been included in the ASTM Standard for B-100 blend stock (ASTM D6751). There is no stability specification in the definition of No. 2 heating oil (ASTM D396) even though there are defined test methods and it is well known that No. 2 oil can experience degradation in the field. The stability specification included in ASTM D6751 is expected to provide at least 6 months of storage duration without concern.

The storage stability of biodiesel blends is strongly affected by the type of oil or fat used in biodiesel production. It has been clearly shown that additives can be used to extend the storage life of biodiesel[9]. Under ideal conditions some biodiesel blends can be stored for three years. It has also been shown that additives can be used to extend the storage stability of biodiesel blends which have partially oxidized.

While the available results are encouraging, with expanded use of biodiesel and the addition of alternative feedstocks into the market mix, continued attention on the monitoring of the degradation of fuels in long term storage situations and improved measures of the oxidation potential of biodiesel are needed.

Biodiesel – Elastomer Compatibility

For an alternative fuel to be used safely in home heating systems compatibility with the elastomeric seal materials in use is required. Seal changes, in the case of a non-compatible fuel are technically feasible but, with some eight (8) million home oil-fired systems, the requirement of a seal change would represent a potential market acceptance barrier.

In existing heating systems, the dominant seal material is nitrile (acrylonitrile butadiene rubber or NBR; an unsaturated copolymer constructed of acrylonitrile and butadiene monomers). The presence of the acrylonitrile monomer imparts permeation resistance characteristics to a wide variety of solvents and chemicals, while the butadiene component in the polymer contributes toward the flexibility[10].

Like any given polymer, the mechanical properties of nitrile butadiene rubber (NBR) vary depending on its constituents. Differences in composition may be based on the acrylonitrile content used in synthesis (commercial nitrile rubber can vary from 25% to 50%), reinforcement fillers, plasticizers, antioxidants, processing aids, and cross-linking agents[11,12].

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[9] E. Christensen and R. L. McCormick, "Long-term storage stability of biodiesel and biodiesel blends," Fuel Processing Technology, vol. 128, pp. 339-348, 2014.

[10] Reichhold Chemicals, Inc., "What is Nitrile?", Technicare Bulletin.

[11] S. Chakraborty, S. Bandyopadhyay, R. Ameta, R. Mukhopadhyay and A. Deuri, "Application of FTIR in characterization of acrylonitrile-butadiene rubber (nitrile rubber)," Polymer Testing, vol. 26, pp. 38-41, 2007.

[12] T. Yasin, S. Ahmed, M. Ahmed and F. Yoshii, "Effect of concentration of pluyfunctional moomers on physical properties of acrylonitrile-butadiene rubber under electron-beam irradiation," Radiation Physics and Chemistry, vol. 73, pp. 155-158, 2005.

In the process of obtaining a listing approval for a burner for application in this market testing is typically done guided by standard UL 296 which incorporates a material compatibility test for elastomeric materials, UL 157. This test involves an immersion period of 70 ±1/2 hours at 23 ± 2 ºC (73.4 ± 3.6 ºF). Suitable elastomers are required to retain more than 60% of their unconditioned tensile strength and elongation and volume swell must fall within the range of -1 to + 25%.

In a study published in 1997[13,14], Southwest Research Institute reported on their evaluation of a range of different elastomer types exposed to biodiesel / petroleum blends. Fuels included in this study included JP-8, B-100, low-sulfur diesel fuel, “reference” diesel fuel and blends at the B-20 and B-30 level. Samples were immersed at 51.7 °C (125 ºF) for 0, 22, 70, and 694 hours.

In a more recent study[15], Southwest Research Institute and the National Renewable Energy Laboratory (NREL) evaluated the compatibility of several elastomers including 3 different types of nitrile in B-20 blends and ethanol-diesel blends. The nitrile materials included a general purpose NBR, and high aceto-nitrile content rubber, and a peroxide-cured nitrile rubber. These materials were selected as being typical of materials used in automotive applications. Samples were immersed at 40 °C (104 °F) for 500 hours.

Tests reported in the early study by Southwest Research Institute for elastomers common to diesel engines showed some effect of the biodiesel blend on the nitrile materials. This included volume swell in the 20% range and a reduction in tensile strength as high as 38%. These tests were done at much higher temperature and for much longer times than required by UL 157, but the magnitude of property change reported was still within the acceptable range under UL 157, although marginally. The later study reported on by Southwest Research and NREL[9] showed no significant effect of the biodiesel blends on the NBR materials studied, leading to the conclusion “...all of these elastomers appear to be fully compatible with 20% biodiesel blends”.

In another, potentially relevant, study done by UL [16] the compatibly of B-5 blends with elastomers typically used in oil burner applications was studied in compliance with the UL157 standard. Two specific nitrile materials were included. The study conducted by UL at the B-5 blend level also showed no significant effect of the biodiesel blend on the materials tested.

As part of a new study[17] to evaluate the practical upper limit of biodiesel content in a blend with home heating oil, BNL has completed compatibility tests with NBR at blend levels from 0 to B-100. In collaboration with the dominant manufacturer of pumps on legacy oil burners in the U.S., one specific NBR material commonly used in the heating oil industry was identified for evaluation. This is

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[13] E. Frame, G. Bessee and H. Marbach, "Biodiesel Fuel Technology for Military Application," Southwest Research Institute, 1997.

[14] G. B. Bessee and J. Fey, "Compatibility of elastomers and metals in biodiesel fuel blends," Society of Automotive Engineers paper 971690, 1997.

[15] E. Frame and R. McCormick, "Elastomer compatibility testing of renewable diesel fuels," National Renewable Energy Laboratory NREL/TP-540-38834, 2005.

[16] Underwriters Laboratories, "Report on the Interchangeability of B5 biodiesel within Residential Oil-Burner Appliances Intended for Use with No. 2 Fuel Oil," UL Report File MP4132, 2007.

[17] T. Butcher, "Limit Blend for Biodiesel in Heating Oil," in Biodiesel Technical Workshop, Kansas City, 2013.

a high aceto-nitrile material used for the critical pump shaft lip seal. Slabs of this material were obtained from the manufacturer for use in these tests. Immersion was done for 670 hours at 51.7 °C (125 °F), conditions much harsher than that normally used to qualify seals per UL 157.

The studies at BNL showed full compatibility between the NBR material used in common oil burner seals and biodiesel blends up to B-100. **Figure 7** below, for example illustrates the effects on volume swell. Results are similar for tensile strength, hardness, and compression set over the 670 hours regardless for petrodiesel and all biodiesel blends up to B100.

In an interesting part of the BNL study the effects of elevated acid number on NBR material properties was evaluated. It was shown that acid numbers well above the specification limits does lead to significant interaction with the NBR materials. In this test acid number was increased through the addition of decanoic acid and this effect is illustrated in **Figure 8**. It is postulated that elevated acid number caused by accelerated testing degradation contributed to observed effects of biodiesel on NBR materials in the earlier reported tests, especially since many of these earlier tests were completed prior to the addition of a stability specification for B100 and other changes to the B100 specifications which were implemented to secure the ASTM approval for biodiesel blends in 2008.

Figure 7) Results from BNL study - impact of biodiesel blend level on swell of common pump elastomer seals

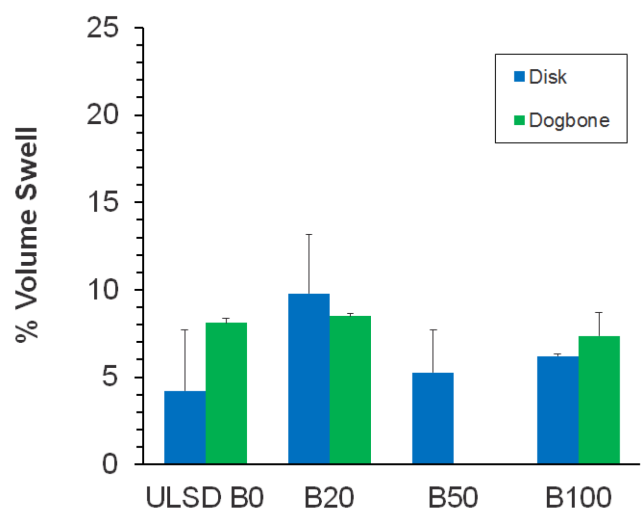
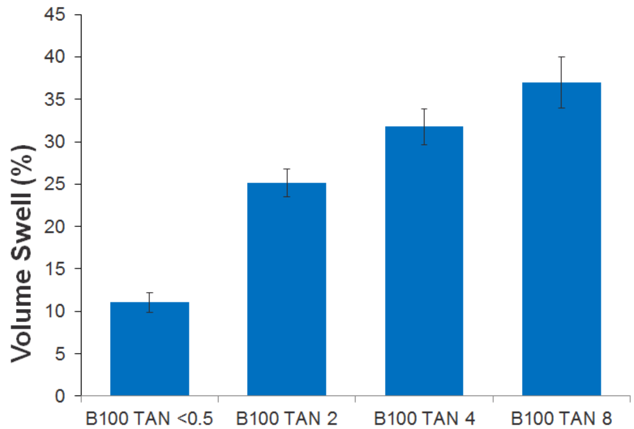


Figure 8) Example results, tests at Brookhaven National Laboratory. Impact of acid number on NBR material volume swell in B-100.



Biodiesel and Pump Performance

A critical component in the fuel system of an oil-fired heating system is the burner pump. This unit performs the following functions:

1. Lifting the fuel from underground storage, clearing the fuel line air rapidly during initial operation;
2. Creating and regulating the required pressure for proper atomization, typically 100-150 psi.
3. Providing a "sharp" turn-on and turn-off of flow to the nozzle to prevent after-drip or injection of fuel under a low pressure, poor atomization condition.

The dominant manufacturer of the pumps in use in existing equipment in the field is Suntec Industries, with an estimated 90% market share for these installed units. This gear-pump includes a NBR lip-seal on the rotating input shaft. Potential leakage of this seal with biodiesel blends has been identified as a high priority area for evaluation in considering higher levels of biodiesel in heating oil.

Detailed bench level compatibility studies overviewed in Part 1 using elastomer slab samples provided by the pump manufacturer showed no impact of biodiesel blends up to B100 compared to conventional heating oil. To compliment these basic materials studies, a decision was made to undertake long term, cyclic durability tests with pumps. In the field, these burners and pumps cycle on/off 5,000 to 10,000 times annually, and it was desired to confirm the performance of the seals in actual pump operation.

Figure 9) Photo of pump test

The pump test was implemented at the Energy Institute of Penn State University with oversight by the industry's Bioheat® Technical Steering Committee. The pump manufacturer was involved with the definition of the test setup and evaluation protocol. The methods were based on established methods used to evaluate candidate seal materials.

The testing was planned to involve a 5-gallon fuel supply for each pump, setup in a continuous loop with a 5 minute on/ 1 minute off controlled cycling pattern. The piping was arranged without a fuel spray nozzle but the pump developed its full operating pressure each cycle. A photo of the setup is provided in .

In the test program, a key performance measurement parameter was observed seal leakage rate. The project was started in 2010 but upon reviewing the initial results it was discovered there was some confusion regarding the leakage rates measurements. The measurements were being done differently than that being used by the manufacturer. This was corrected, and all new pumps were installed and the test restarted.

The testing was done with two base fuels—a conventional No. 2 heating oil at 1500 ppm sulfur content and an ultralow sulfur heating oil at 15 ppm. Three different biodiesel blend levels were studied for each fuel – 0, 12, and 20%. The biodiesel was a commercial blended-feedstock fuel provided by Hero BX. This fuel met all requirements of ASTM D-6751-11. For each fuel blend a total of 7 pumps were run in this 7,000 hour test. Quality of all fuels was monitored throughout the project to insure the fuel had not degraded significantly during the test due to the stressing of the fuel in the test. Acid number was considered the primary criterion for this. High acid numbers were not observed, and thus the test considered acceptable from that standpoint.

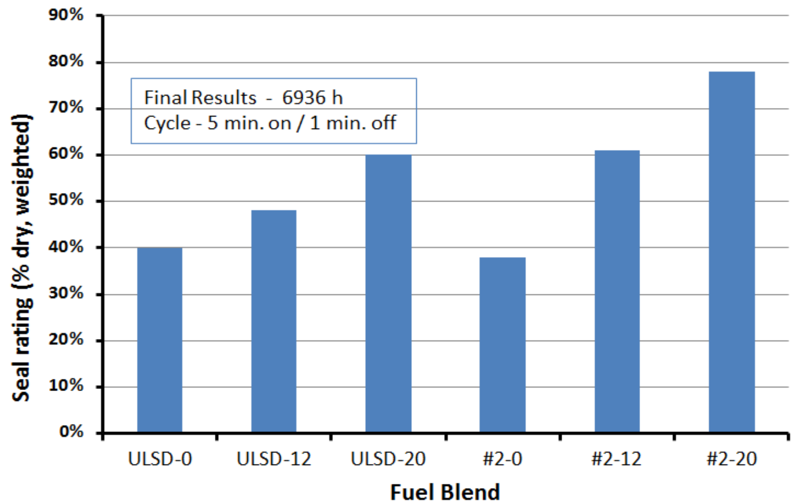
Fuel pump shaft seal observed leakage was a key performance measure and this was monitored on a regular basis. The manufacturer provided a scale from 1 to 4 based on observed leakage. These are all very low leakage rates. For example a No 2 leak is described as “wet seal with a slight accumulation in the seal cavity area”. A No 4 (highest) leak is actual fuel running down over the hub face. These leak rates likely would not be noticed in the field. A seal leak metric for the entire set of pumps was based on a weighted-percent-dry metric. The weighting penalizes a leak situation to a greater degree if it occurs early in the 7,000 hour test period.

Figure 10 provides a summary of the test results. In this figure the Seal Rating is used – a higher value indicates better performance. The most significant conclusions are:

- Seal performance improves with increasing biodiesel content
- Seal performance is equivalent at B0 for both 15 and 1500 ppm sulfur fuels
- Seal performance is better with 1500 ppm sulfur fuel than with the ULSD fuel at the same biodiesel level.

Two pumps “bound-up” in the 4600-5000 hour time frame. These were both at the B-12 blend level and both base fuels were involved. Other than this occurrence no operational problems were observed. Following these tests the pumps were all shipped to Brookhaven National Laboratory for internal inspection. No unusual conditions or fuel related issues were noted from the inspection. Thusly, while both the seizures were with B12, it is not believed they were fuel-related.

Figure 10) Overall results of pump stand testing. These results illustrate better performance (higher seal rating) as biodiesel content in blend increases.



Biodiesel – Combustion and Emissions

Aspects of acceptable combustion performance include: reliable ignition under field conditions, flame stability, low air pollutant emissions, low potential for formation of coke on burner heads, and safe/reliable operation of the burner sensors and controls. Several important laboratory studies have been done on the combustion performance of biodiesel/heating oil blends in North America. An overview of the key findings with an emphasis on blends at the B-20 level is presented below:

Laboratory Studies—Initial laboratory testing of biodiesel as a fuel was done by the R.W. Beckett Corporation in 1993. Using conventional burners this involved a simple comparison of B-100 and normal heating oil of the S5000 sulfur grade with nominal sulfur level of 1500 ppm. In a later study at Beckett (Turk, 2002) a comparison was done of the NO_x and SO_2 emissions of heating oil, B-20, and B-100.

Results of testing with a variety of space heating appliances were reported by Batey in 2003 (Batey, 2003). This study directly compared performance of a conventional heating oil with a B-20 blend of soy-based biodiesel blended into 500 ppm sulfur oil. Equipment evaluated included a commercial steam boiler, an older residential hot water boiler, a compact residential hot water boiler, an older residential warm air furnace, and two additional typical residential hot water boilers. The work focused on steady state CO, smoke number, and NO_x emissions.

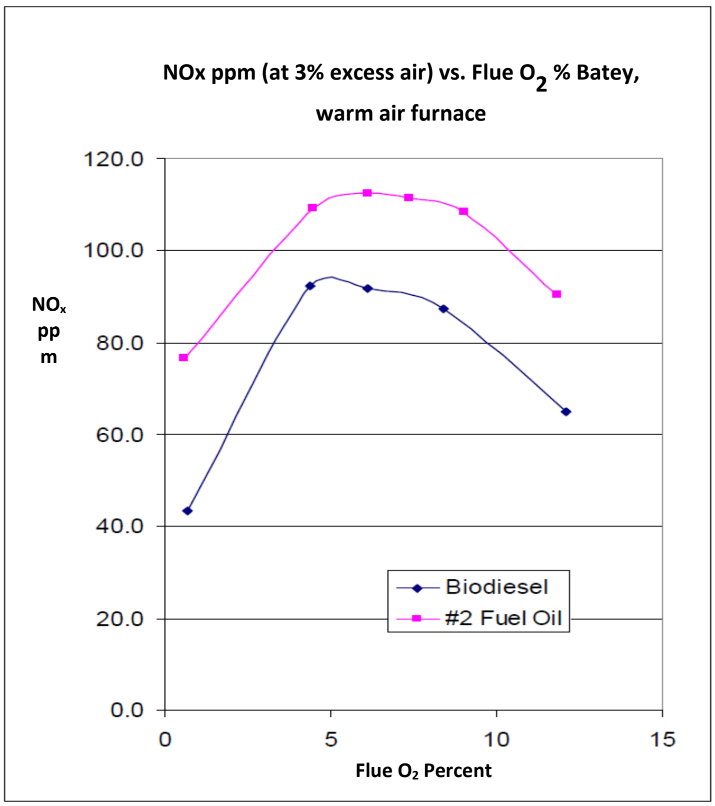
In another lab study, reported by Krishna et.al, in 2001 (Krishna, Celebi, Wei, Butcher, & McDonald, 2001) both startup and steady state performance of biodiesel blends and conventional heating oil were studied using a conventional residential boiler. Blend levels to B-100 were included. In the transient part of this study CO emission profiles from cold start were compared. High startup CO emissions are an indicator of poor ignition performance, and were compared and found to be independent of biodiesel content. Cold start in this case was with the boiler at 55 F, much colder than typical in normal field operation.

Win Lee et al (Lee, 2004) conducted a set of careful measurements in a test facility in Ottawa, Canada using a cast iron, residential hot water boiler. Tests were run on the baseline fuel oil and on a B20 blend made from a commercial soy biodiesel. These studies included particulate emissions as well as gas-phase emissions.

Key Results— A common result from all of the studies is that basic burner operation with biodiesel blends at B-20 (at least) is the same as with unblended heating oil. Observations are that startup behavior and flame stability are seamless. This general observation was specifically documented in the transient CO measurements made by Krishna et.al. (Krishna, Celebi, Wei, Butcher, & McDonald, 2001). Another observation is that smoke number and CO emissions in steady state are either the same or lower than with unblended heating oil. **(Figure 11)**

Most of the studies showed that NO_x emissions are lower with B-20 although in some cases, at some excess air levels similar NO_x levels were reported.

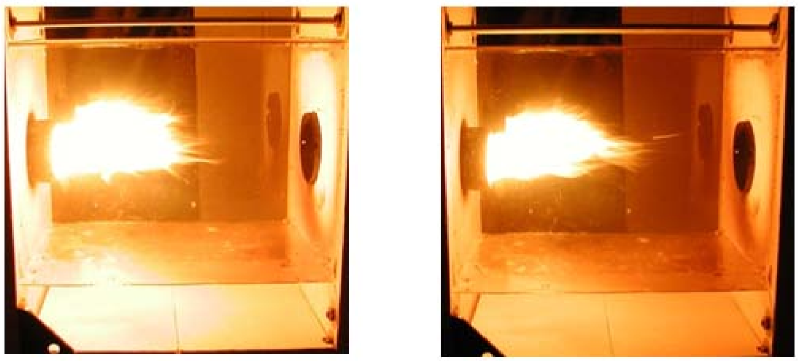
Figure 11) Example comparison of NOx emissions, B-20 and unblended heating Oil



Sulfur dioxide emissions are a function only of the sulfur content of the fuel. Relative to unblended heating oil, biodiesel can be considered nearly sulfur-free and so reductions in SO_2 were observed in proportion. Similarly, it has been shown that most of the fine particulate emissions from small oil burners are due to sulfates and these emissions are directly proportional to fuel sulfur content. Again, this leads to lower emissions with the biodiesel blends.

In tests at much higher blend levels, to B-100, it was shown that the amount of visible light produced by a biodiesel flame is lower than that of a flame from unblended heating oil. This is most likely due to the lower particulate emission and cleaner burning nature of biodiesel. The practical implication of this is that it could impact the ability of the flame sensor to detect a viable flame with higher concentrations of biodiesel and shut off the burner unnecessarily. The flame sensor is part of the flame safety control system whose function is to determine if there is a viable flame when fuel is flowing through the burner nozzle. This helps ensure unburned fuel does not accumulate in the burner chamber. If high biodiesel blends are used, the flame sensing system may need to be modified to insure the unit does not shut off due to a cleaner, non-detectable flame with high concentrations of biodiesel. There have been no reports of this as a concern at the B-20 level.

Figure 12) Comparison of the flame from a biodiesel blend and no. 2 oil



Biodiesel blend   Unblended No. 2 oil

V. Market Acceptance

Bioheat® Trademark

In an effort to clearly establish and provide guidance to consumers and the industry as to what is an acceptable fuel, the Alliance and NBB acquired the rights to use the trademarked term Bioheat®. This term of use is restricted to blends of biodiesel of at least 2 percent. Retail oil dealers and other distributors are provided with a no cost license to use this term if they are selling the fuel. At this time over 300 parties are using the Bioheat® trademark.

Efforts on Marketing

Over the years, the Alliance and NBB have communicated the value of using biodiesel and selling Bioheat®. The Alliance features information about Bioheat® on its consumer website, OilheatAmerica.com NBB has a webpage, Bioheatonline.com that describes the advantages of Bioheat®. Further, the Alliance and its affiliated state associations have worked to provide education on this product to consumers and retail oil companies through the use of mass media and informational brochures.

NBB has undertaken similar efforts. NBB has sponsored dealer and technician training for several years, and has participated in conferences throughout the northeast and Midwest Additionally, NBB has sponsored communication efforts on Bioheat® including designing a website focused on Bioheat®, and direct consumer outreach using mass media.

Dealer Survey

In conjunction with BNL, the Alliance conducted a survey of retailers who were distributing Bioheat®. The survey was to better understand the different blends being used, and whether heating oil companies had identified issues with using biodiesel blends.

In evaluating the results, the Alliance was surprised by the wide distribution of different levels of fuel being used and the number of households using high blends. This information has been utilized to better understand and evaluate higher blends.

Figure 13) Surveyed Bioheat® Customers by Bioblend Percentage

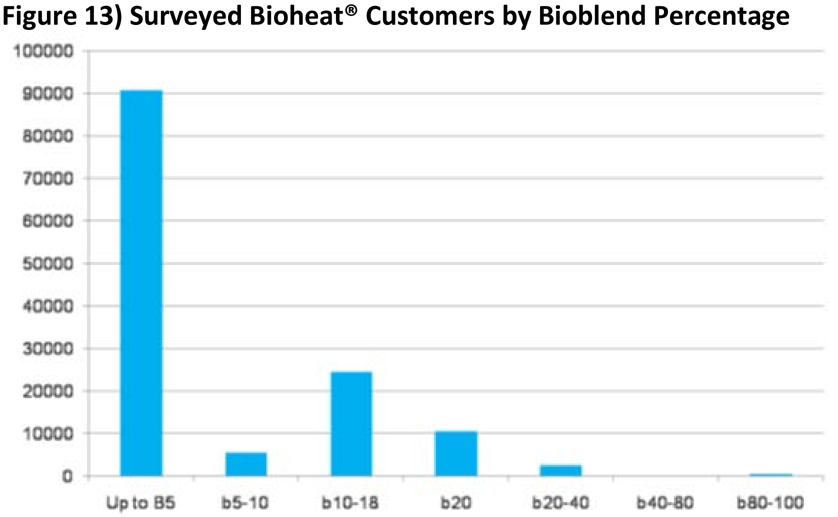


Table 6) Surveyed Bioheat® Customers by Bioblend Percentage

Bioblend Percent	Customer Count	Percent of Total
Up to B5	90,711	67.9%
B5-10	5,328	4.0%
B10-18	24,521	18.3%
B20	10,330	7.7%
B20-40	2,397	1.8%
B40-80	4	0.0%
B80-100	380	0.3%

Marketing in the Industry

Information about Bioheat® is widely distributed in the heating oil industry. There are three principal conferences each year, New England Fuel Institute, Atlantic Region Energy Expo, and the Oil and Energy Service Professionals. Each of these conferences highlights the role of Bioheat®. in the industry each year. Additionally the trade magazines, Indoor Comfort Marketing, and Oil and Energy provide continuous information on the use of Bioheat®.

The Alliance and the NBB have also highlighted the role of individual companies in distributing the fuel. NBB provided a glossy featuring the use of biodiesel and the impact on companies. Two heating oil retail companies were prominently featured in this significant publication. http://www.industry-publications.com/NBB/biodieselsuccessstories.pdf. These retail companies described how important the use of biofuels was in repositioning their companies as market leaders, and demonstrated to their communities their support for renewable fuels.

VI. State and Local Initiatives

State Mandates or Incentives

State and local governments have utilized a number of strategies to encourage the use of biodiesel in their communities. To have an alternative fuel enter a market, it is often necessary to foster its use with incentives or requirements. This leads to the development of infrastructure and overall market acceptance.

The true leader in that effort is the City of New York. New York City currently requires that at least 2 percent of all heating oil sold in the City be biodiesel. Additionally, buildings owned by the City are to use various blends of biodiesel at a blend level of 5 percent.

The State of Rhode Island recently adopted and implemented a similar requirement. Currently all heating oil in that state must be blended with 2% biodiesel. That percentage will increase steadily until it reaches 5% by 2017.

Massachusetts was the first state to pass into law a statewide biodiesel requirement. However, it has not been implemented.. The state was concerned with the overall greenhouse gas emissions from biodiesel and the practicality of a Massachusetts program implemented separate and apart from the other states in New England. With new information on biodiesel's environmental advantages and the successful implementation of requirements in Rhode Island and New York City, it is likely that Massachusetts will reexamine its position.

Similar to Rhode Island, Connecticut and Vermont have enacted requirements for the use of Bioheat®. However, the policies are dependent on adjacent states adopting similar requirements. Thus, the Connecticut policy would only be implemented when adjacent states pass into law similar requirements.

Tax Incentives

In addition to requirements, incentivizing the use of biodiesel with tax advantages is also common. New York State has enacted a personal tax credit for biodiesel. Under this system, a household will receive $.01 per gallon for each percentage of biodiesel in the fuel. For a blend of 20 percent for a household using 800 gallons, this could result in receipt of a tax credit in the amount of $160 per annum

State Efforts to Lower GHGs

How Biodiesel could work

Biodiesel is now produced in the U.S. in quantities significant enough to have a clear impact on the home heating oil market. However, other alternative fuels can be considered for displacement of diesel (Smagala, Christensen, Mohler, Gjersing, & and McCormick, 2012) and heating oil and have received attention. This includes:

- Hydrotreated vegetable oils
- Unconverted vegetable oil (straight vegetable oil or SVO)
- Esters of levulinic acid
- Free fatty acid fuels from hydrolysis of waste greases (FFA)

- Raw pyrolysis oil
- Upgraded pyrolysis oil

All of these fuels have been evaluated for use in home heating systems to different degrees at BNL. Generally, for any alternative fuel to be considered for widespread use as a blend stock to displace petroleum fuels it needs to meet all of the requirements for storage, handling, materials compatibility, combustion and air pollutant emissions as discussed in Section V above. Experience to date has shown that fuel stability and compatibility with legacy materials is likely to be more of a concern than combustion performance. In this regard, there is a strong contrast between diesel engine applications and the stationary burners. Burners involve a simple, steady atmospheric combustion process and are relatively tolerant to fuel quality. Stationary burners for this reason can be considered a preferred market entry point for alternative fuels. While more tolerant than diesel engines to fuel quality it is still critical that any alternative fuel be able to be used in the stationary market safely and reliably.

Some of the fuels in the above list can be considered as specialty fuels which will require hardware conversion for reliable use and may not be miscible with No. 2 fuel oil at all. This might include for example special seal materials or fuel heating provisions. Raw pyrolysis oil, SVO, and FFA fuels are in this category. These fuels have potential for displacement of petroleum fuels but are practically limited to larger applications where investment cost associated with conversion are justified and, potentially, there is a unique local fuel supply opportunity.

Figure 14) FFA fuel (processed trap grease) firing in a residential oil burner in tests at Brookhaven National Lab. Fuel temperature is 230 F.

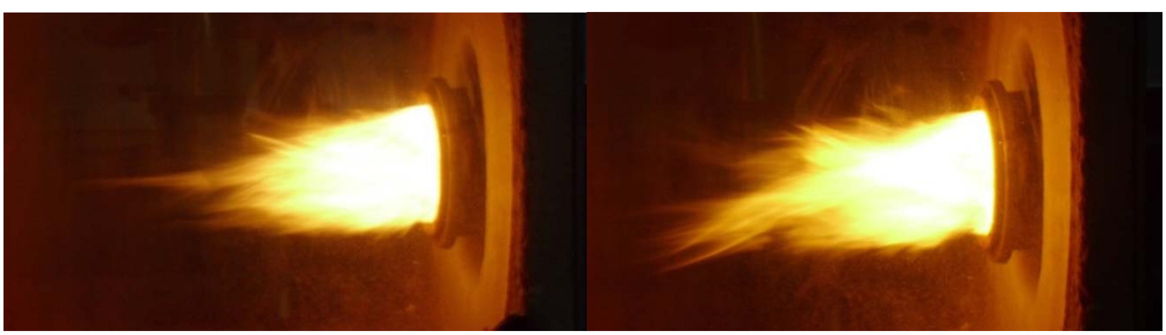
Some of the fuels in the above list are high quality but low aromatics fuels and this includes the hydrotreated vegetable oils, GTL and CTL. These fuels are considered very strong candidates, technically, for the displacement of petroleum in stationary burner applications and the primary limitation to their deployment is availability and cost. If used at high blend levels or without blending, elastomer swell and lubricity may be a concern requiring additives. Overall, however, these fuels can be considered technically ready for use in this market, assuming that the properties of ASTM D396 for No. 2 heating oil are met.

Esters of levulinic acid are under active commercial development as a blend stock at low levels for No. 2 heating oil and No. 2 heating oil/biodiesel blends. These fuels offer potential as a low cost, biomass-derived alternative fuel. However, the properties, qualities, and blend formulation are still under development. NORA is interested in this area and is considering projects focused on this fuel.

Currently BNL is working on a Department of Energy sponsored project to evaluate the use of upgraded pyrolysis oils ("bio-oil") as a direct displacement fuel for petroleum in home heating oil (Mante, Butcher, Wei, Trojanowski, & and Sanchez) (U.S. Department of Energy, Bioenergy Technologies Office, 2012). The target is a 20% blend ratio in heating oil with a product fuel that is fully compatible with the supply and end use infrastructure. Several other national labs and the Alliance are also involved in this program. Raw pyrolysis oil is acidic, unstable, and not miscible with No. 2 oil. Through catalytic hydroprocessing this fuel can be converted into a very suitable fuel. Full conversion to a synthetic hydrocarbon, however, is expensive and a key technical challenge in this program is finding an economical compromise between upgrade cost and technical quality of the product. Results to date indicate very strong potential for the use of highly upgraded bio-oil as a direct replacement fuel. Again cost and availability are key current barriers.

For partially upgraded bio-oil, fuel storage stability and elastomer compatibility are seen as the primary technical concerns. Equipment manufacturers in this industry are beginning to introduce pumps and other components which have different elastomers (viton vs nitrile) which are more compatible with biofuels. This transition may provide an opportunity for expanded use of partially upgraded fuels. The transition period however, may be long. Typically residential marketers deliver to thousands of customers and the need to deliver different fuels to different customers would be a significant market barrier for any new fuel.

Figure 15) Comparison of the flame of No. 2 heating oil (left) and 100% upgraded bio-oil (right). Tests at Brookhaven National Laboratory



VII. Conclusion

The biodiesel fuel and the move to renewable fuels present exciting opportunities for the heating oil industry and its consumers. First, such a transition to renewable fuels will be made with minimal capital costs by consumers. Thus, a significant barrier to the use of renewables will be avoided, as the industry transitions its customers to renewable fuel with no required or minimal upfront costs by consumers. Second, it provides an exciting opportunity for the local oilheat retailers to continue to serve their customers into the future, which will allow these companies to provide employment for individuals in service, marketing, and management in local communities.

This transition to a renewable fuel also provides an opportunity to examine the relationship to competing fuels. As noted in the report, heating oil has continued to take steps to reduce its emissions profile and the recent reduction in sulfur in fuel is a significant step forward, and puts emissions of criteria pollutants on par with natural gas. Second, as the report noted, a close examination of greenhouse gases indicates in the short term, a transition to low levels of biodiesel in heating oil may be the most effective method to reduce greenhouse gas emissions, and a movement to natural gas may be far less effective.

The short term goal of the industry is to move to higher levels (more than 20%) may require some technological changes in heating equipment. To that end, the Alliance and NBB are continuing to work to develop a 100 percent biodiesel fuel that will be suitable for heating oil applications, and a burner that can be used to burn 100 percent biodiesel. The Alliance has initiated contracts with vendors to develop such equipment and is excited by the opportunity that developing this equipment in the near term will provide for the long term future of the industry and the environment.

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Appendix A – Congressional Report Requirement Language

Subtitle D-Oilheat Efficiency, Renewable Fuel Research and Jobs Training

(D) REPORT. –

CONTENTS.-The report required under clause (i)
shall-

(I) PROVIDE information on the environmental benefits, economic benefits, and any technical limitations on the use of biofuels in oilheat fuel utilization equipment; and

(II) Describe market acceptance of' the fuel, and information on State and local governments that are encouraging the use of biofuels in oilheat fuel utilization equipment.

(ii) COPIES.- The Alliance shall submit a copy of the report required under clause (i) to-

(I) Congress;

(II) The Governor of each State, other appropriate State leaders, in which the Alliance is operating; and

(III) The Administrator of the Environmental Protection Agency.