Vermont Biodiesel Project

FINAL PROJECT REPORT

Laboratory and Field Testing of Biodiesel in Residential Space Heating Equipment

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1.0 ACKNOWLEDGEMENTS

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2.0 EXECUTIVE SUMMARY

The development of bio-based fuels presents an opportunity to utilize a domestically produced, more environmentally benign means of providing space heating in Vermont homes. *Bioheat* is an industry-accepted term for any blend of biodiesel (fuel derived from vegetable oil or animal fat) with conventional high- or low-sulfur petroleum home heating oil. *B20 bioheat* is a common blend of 20% biodiesel and 80% No. 2 fuel oil. This study closely examines the impact of B20 bioheat on residential oil-burning heating system performance characteristics.

Interest in bioheat continues to grow in Vermont. Fuel dealers throughout the state regularly receive inquiries from customers about this fuel and whether it might be used for heating in residential, commercial, municipal and institutional settings. At least 12 Vermont home heating fuel dealers now offer either B5 or B20 blends of bioheat. Increasing numbers of fuel dealers and their customers are exploring this fuel for several reasons, including:

- **Reduced energy dependency**. Because the vast majority of biodiesel is produced domestically, increasing its use can reduce the U.S. dependence on foreign oil sources and extend supplies of conventional (petroleum) fuel.
- **Environmental considerations**. The U.S. Environmental Protection Agency estimates that the use of B20 biodiesel reduces total hydrocarbon emissions (a major contributor to climate change) by up to 30%. In open-flame heating applications, other air emissions are reduced, as well, including NO_x, sulfur, smoke and particulate matter.[1]
- **Price stability**. By consuming more domestically produced biodiesel, Vermonters who use bioheat may be better insulated from the dramatic price fluctuations that have become increasingly common in the global petroleum markets.

Whatever the perceived benefits of bioheat, with increasing usage come several important questions that fall roughly into the categories of (1) fuel and equipment performance, (2) fuel supply reliability, (3) fuel cost, and (4) fuel environmental characteristics.

In the fall of 2005, the Vermont Sustainable Jobs Fund (VSJF), the Vermont Biofuels Association (VBA), and the Vermont Fuel Dealers Association (VFDA) created the Vermont Bioheat Program (VBHP) to help contribute to the understanding and acceptance of this relatively new product in the home heating fuel market. With the support of the National Oilheat Research Alliance (NORA) and the VFDA, the VBHP was designed to address questions surrounding fuel and equipment performance through a series of pilot projects and laboratory studies designed to help suppliers and users of bioheat to better understand how the fuel will perform once introduced into residential heating systems.

[1] C.R. Krishna, *Biodiesel Blends in Space Heating Equipment,* December 2001, BNL-68852.

The overarching objective of the pilot projects and laboratory studies of the Vermont Bioheat Program was to introduce bioheat as a viable source for home heating applications in Vermont. Specific VBHP research goals include:

1. Demonstrate the operational use of B20 bioheat in residential heating equipment at two laboratory locations in Vermont during the 2005-2006 heating season.
2. Demonstrate the operational use of B20 bioheat in residential settings in partnership with one or more Vermont fuel companies committed to providing B20 bioheat to their heating fuel customers during the 2005-2006 heating season.
3. Provide information to fuel distributors and service personnel on proper handling of biodiesel.
4. Document and distribute the research findings to target audiences with a stake in using bio-based heating products in the state.

Key VBHP research results indicate that there is a decrease in system combustion efficiency of up to 0.5% when B20 bioheat is used as a fuel, as compared to efficiency values when No. 2 fuel oil is used. Several performance indicators support this conclusion, including increases in net stack temperature readings, decreases in CO_2 emission levels, decreases in breech draft, and other factors. However, this finding does not necessarily indicate a limitation of the fuel. Because testing protocol dictated that B20 bioheat be introduced later in the heating season, it's possible that accumulated soot and scale build-up on the system heat exchangers accounts for some or all of the combustion efficiency decrease. It should be noted that most oil-burning heating systems experience a decrease in combustion efficiency over the course of a heating season as the build-up of deposits on the heat exchanger reduce its ability to absorb heat from the combustion flame.

Reduced combustion efficiency values may also be attributable to the fact that the test systems, which had been optimally tuned for the use of No. 2 fuel oil at the beginning of the season, required a re-adjustment of the fuel/air mixture to attain maximum efficiency when B20 bioheat was introduced. These findings suggest areas of further testing. Nonetheless, reduced combustion efficiency values of less than 1% are negligible in practical terms and should not discourage those considering the use of B20 bioheat.

Another key finding indicates that cad cell resistance increases by as much as 40.6% when B20 bioheat is used. This is likely attributable to the lower luminosity and different color spectrum of the B20 bioheat flame when compared to the flame produced by No. 2 fuel oil. Fuel technicians and users of B20 bioheat should be aware that higher cad cell resistances can sometimes lead to "nuisance tripping" of the burner. However, no such behavior was observed in the 26 test units included in this study.

Anecdotally, the two commercial fuel dealers that participated in this study reported no system service calls that were attributed to the use of B20 bioheat. In fact, the two participating fuel dealers had this to say about their experiences with bioheat: "*In* *summary, we would like to say that B20 performed as well as No. 2 fuel oil in a heating application. We will recommend it to any customer currently burning No. 2 fuel oil"* and *"We were pleasantly surprised. We experienced no more problems with the boilers and furnaces at Middlebury College [using B20 bioheat] than we would expect from units running on No. 2 fuel oil."*

While there are several aspects of using B20 bioheat that warrant further research, the preliminary findings of the VBHP indicate that B20 bioheat performs as well, or nearly as well, as traditional No. 2 fuel oil in residential oil heating applications. B20 bioheat's added environmental and economic benefits suggest that this is a fuel that requires serious consideration as an alternative to traditional petroleum heating fuels.

3.0 INTRODUCTION

Twenty-eight million Americans rely on oil-based fuel to heat their homes. Residents of the Northeastern U.S. are especially dependent on distillate fuel oils for heating, more so than any other area of the country. In Vermont, for example, more than 112 million gallons of No. 2 home heating fuel oil were used during 2004[2], accounting for more than 58% of total home heating energy use followed by propane with a 14% share.[3]

Such heavy dependence on heating oil leaves Vermonters and others in the Northeast particularly vulnerable to fluctuations in oil prices and supplies, but also allows for relative ease of introducing bio-based fuels to Vermont homes and businesses. The recent introduction of bio-based fuels presents an opportunity to utilize a domestically produced, more environmentally benign means of heating Vermont homes.[4]

Though the collective oilheat industry may ultimately focus its marketing efforts on a fuel blend that is something other than a B20 bioheat blend, the VBHP research team decided to study B20 bioheat as a means of testing the upper limit of what is today considered marketable to mainstream oil heat consumers. It should also be noted that biofuels are not approved by the Underwriters Lab Inc. (UL) for use in any oil-fired appliance or component – and approval is not expected until early in 2007. When it occurs, UL approval of bioheat will be a critical component of a robust and sustainable bioheat industry.

With the support of the National Oilheat Research Alliance, a partnership of the VSJF, the VBA, and the VFDA created the VBHP to increase the understanding of the performance characteristics of B20 bioheat. Through a series of pilot projects and laboratory studies, the VBHP was specifically designed to help suppliers and users of bioheat to better understand how the fuel will perform once introduced into their heating systems. Pilot projects are divided into the following categories:

Bioheat laboratory testing – Laboratory testing of B20 bioheat was conducted at two Vermont research facilities using five separate heating systems. Testing included combustion efficiency testing and emissions testing on a wide variety of boilers, furnaces, and burners, as well as the first phase of fuel stability testing.

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[2] Source: EIA, http://tonto.eia.doe.gov/dnav/pet/pet_cons_821use_a_EPD2_VRS_Mgal_a.htm.
[3] Source: EIA, http://tonto.eia.doe.gov/oog/info/state/vt.html.
[4] For the purpose of this study, the term *bioheat* is used to generally describe biodiesel that is used as a home heating fuel and *B20 bioheat* is used to describe a blend of 20% biodiesel and 80% No. 2 home heating fuel oil. *BioHeat*™ is a new industry-accepted, branded term for any blend of pure biodiesel with conventional high- or low-sulfur petroleum home heating oil. To qualify as *BioHeat*™, the petroleum portion of the biodiesel blend must meet the specification according to ASTM D396, and the biodiesel portion must meet the specification according ASTM D6751, prior to blending. In May of 2006, NORA signed a subleasing trademark agreement and became industry partners with the National Biodiesel Board. As a result of this agreement, NORA and its dealers may now use the *BioHeat*™ trademark.

Bioheat field testing – Field testing of bioheat was conducted in 26 residences throughout Vermont using 26 separate heating systems. Field testing included the selection of two Vermont fuel dealers that agreed to provide B20 bioheat to a sample group of their customers for an entire heating season, in conjunction with a pre-season, mid-season, and post-season analysis of each customer's heating system.

3.1 Background

In 2003, the Vermont Sustainable Jobs Fund convened a group of Vermont organizations and businesses interested in growing the demand and supply for biodiesel in the state. This meeting's outcome became the core of the three-point Vermont Biofuels Initiative comprising market conditioning, industry capacity building, and infrastructure development components. In September 2004, VSJF worked with the VBA and the Vermont Department of Public Service to secure funding from the U.S. Department of Energy for the Vermont Biodiesel Project market conditioning phase. Additional partners in the Vermont Biodiesel Project include the Vermont Fuel Dealers Association, the Vermont Agency of Natural Resources, Vermont Department of Buildings and General Services and several private businesses and institutions.

The current market building efforts taking place as part of the Vermont Biodiesel Project entail commercial-scale pilot projects that are already increasing demand for biodiesel within the state. This effort includes workshops and trainings for fuel providers and users, outreach activities and educational materials, pilot projects for space heating and off-road vehicles, and emissions testing. Collectively, these activities are designed to stimulate the use of five million gallons of biodiesel in the state by 2007.

The VBHP was designed to provide the Vermont Biodiesel Project, whose focus is primarily on commercial applications, with an opportunity to learn more about another important market sector: the residential home heating market. With more than 112 million gallons of No. 2 oil used in residential heating applications in Vermont in 2004, this is a market critical to building a robust biodiesel industry.[5] By comparison, Vermont commercial and industrial distillate fuel oil usage (No.2 and kerosene combined) accounted for only 53 million gallons in 2004.[6]

The residential heating industry's acceptance of bioheat is critical to the fuel's success in the home heating marketplace. Concerns among pump and burner manufacturers include technical and liability issues related to equipment performance, combustion emissions, fuel stability, and fuel solvency. Addressing these concerns is a matter of effectively communicating the results of the testing that has already been completed, conducting new tests that address remaining questions, and seeking certification for bioheat from industry compliance organizations.

With funding provided by NORA through the VFDA, the VSJF selected the VBA to design and implement the research during the 2005-2006 heating season. This report

[5] Source: EIA, http://tonto.eia.doe.gov/dnav/pet/pet_cons_821use_a_EPD2_VRS_Mgal_a.htm.

[6] Source: EIA, http://tonto.eia.doe.gov/dnav/pet/pet_cons_821use_a_EPD0_VCS_Mgal_a.htm and http://tonto.eia.doe.gov/dnav/pet/pet_cons_821use_a_EPD0_vin_Mgal_a.htm.

represents the final outcome of that research. It is the hope of the research team and sponsoring organizations that the findings of this study will provide equipment manufacturers, fuel suppliers, certifying bodies, and the heating oil consumers with information necessary to expand the use of this renewable, domestically produced fuel.

3.2 Benefits of Biodiesel[7]

Reduced CO_2 Emissions

A 1998 biodiesel lifecycle study, sponsored by the US Department of Energy and the US Department of Agriculture, concluded that B100 biodiesel reduces net CO_2 emissions by 78% compared to petroleum diesel. B100 biodiesel is said to have a "closed carbon cycle" due to the fact that most of the CO_2 released when it is burned is reabsorbed by plants grown for further fuel production. In a 2003 British study, researchers found that biodiesel and other biofuels used for electricity, heating, and transportation fuel emitted less CO_2 per unit of energy generated than a comparable quantity of fossil fuels.[8] In 2000, biodiesel became the only alternative fuel in the country to have successfully completed the EPA-required Tier I and Tier II health effects testing under the Clean Air Act.

In addition, biodiesel has a positive energy balance. For every unit of fossil energy needed to produce a gallon of B100 biodiesel (100% biodiesel with no petroleum component), 3.24 units of energy are gained. By contrast, petroleum diesel has a negative energy balance of 0.83.[9]

Energy security

With many agricultural commodity prices approaching record lows, and petroleum prices approaching record highs, utilizing domestic sources of vegetable oils for biodiesel production can reinvigorate the U.S. farm economy and enhance U.S. energy security. Because biodiesel can be manufactured using existing domestic industrial production capacity, and used with conventional equipment, it provides substantial opportunity for reducing U.S. reliance on foreign energy sources.

A Boost to U.S. Farm Economy

A study completed in 2001 by the U.S. Department of Agriculture found that an average annual increase of the equivalent of 200 million gallons of soy-based biodiesel demand would boost total crop cash receipts by $5.2 billion cumulatively by 2010, resulting in an average net farm income increase of $300 million per year. The price for a bushel of soybeans would increase by an average of 17 cents annually during the ten-year period.

Fuel Performance

Biodiesel has positive performance attributes such as increased cetane, high fuel lubricity, and high oxygen content, which may make it a preferred blending stock

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[7] Source: Adapted from *Benefits of Biodiesel*, National Biodiesel Board, http://www.biodiesel.org/pdf_files/fuelfactsheets/Benefits%20of%20Biodiesel.Pdf.

[8] Elsayed et al., *Carbon and Energy Balances for a Range of Biofuels Options*, March 2003, Resources Research Unit, Sheffield Hallam University.

[9] Source: USDA and US Dept of Energy, "Lifecycle Inventory of Biodiesel and Petroleum Diesel…" http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19980501_gen-339.pdf.

with ultra-low sulfur diesel. The energy content of B100 (about 133,000 BTU per gallon) is slightly lower than No.2 fuel oil (about 140,000 BTU per gallon). It also has a slightly higher density and higher cloud and pour point temperatures than traditional home heating oil. Biodiesel is completely miscible and when properly blended with petroleum, even though they have different densities, the fuels will not stratify.[10]

3.3 Market Barriers

Storage and Supply Infrastructure

Even with growing acceptance and demand for bioheat, a lack of sufficient storage, blending, and supply infrastructure (within and outside of Vermont) will continue to exert pressure on market development. Though the situation is improving, Vermont fuel dealers have limited options when it comes to picking up fuel at distribution points outside Vermont. At the time of this report, only the Albany, New York terminal provides year round, state-of-the-art blending. There are sites in Vermont, however, where tanker loads of No. 2 fuel oil can be splash blended with biodiesel. Whether the dealer trucks in pre-blended bioheat from the terminal, splash blends from a bulk plant or purchases B100 to later splash blend on their premises, they must possess (or add) additional fuel storage if they are to offer their customers a choice between No. 2 fuel oil and bioheat. As yet, no Vermont fuel dealer has switched to only carrying bioheat, although this is happening in Massachusetts, Pennsylvania and New York.

Experience and Education

On the supply side, the storage, blending and use of bioheat are a new undertaking in an otherwise mature industry. Dealers and oilheat service technicians will need to educate themselves on the characteristics of bioheat and to gain experience with its use. The VFDA and VBA hold seminars and trainings throughout the year, some of which are eligible for NORA accreditation. On the demand side, on-going outreach and education efforts are leading to a more informed base of oil-heat consumers who understand the benefits (and limitations) of using bioheat.

Lack of UL and ASTM approval

UL currently requires that residential oil burners and all related components be approved to burn No. 2 fuel oil that adheres to ASTM specification D396. While biodiesel meets a separate ASTM specification (ASTM D6751), it is unlikely that heating equipment manufacturers will fully embrace bioheat until UL approval for their products is obtained. At the same time, equipment manufacturers recognize that bioheat represents a growing market and business opportunity. As a result, many are eager to see an ASTM specification for a bioheat blend and UL approval of the use of bioheat or the *BioHeat* ™ trademark.

3.4 Technical Barriers

Cold weather issues

The cold flow characteristics of bioheat are similar to those of No. 2 fuel oil. However, B20 bioheat blends may increase the cold flow properties approximately 2-5 degrees

[10] C.R. Krishna, *Biodiesel Blends in Space Heating Equipment,* December 2001, BNL-68852.

Fahrenheit from the base heating oil with which it is blended.[11] The same solutions that the oilheat industry has used to solve cold weather problems related to No. 2 fuel oil should be used with biodiesel blends to assure satisfactory cold weather performance (i.e., blend the fuel with kerosene, use pour point depressants, or store the fuel utilizing inside protection or tank heating elements).

Mechanical issues (seals, filter clogging)
Bioheat blends of 20% or less are compatible with all known oil tanks and systems, gaskets, seals, hoses and O-rings according to the National Biodiesel Board. For bioheat blends higher than B20, only steel, mild steel, stainless steel, aluminum, fluorinated polyethylene, fluorinated polypropylene, fiberglass, Teflon and Teflon lined, or Viton components (or vessels) are recommended. Also, for blends higher than B20, lines made of brass, bronze, copper, lead, tin, or zinc (i.e. galvanized) may cause high sediment formation and filter clogging and are not recommended.

3.5 Past Bioheat Research Findings

***Combustion Testing of a Bio-diesel Fuel Oil Blend in Residential Oil Burning Equipment*, 2003[12]**

This study evaluated the combustion performance of a blend of 20% soy-based biodiesel fuel combined with 80% low sulfur (0.05%) highway diesel compared to conventional home heating oil. Tests were conducted at the New England Fuel Institute Training facility using a range of conventional oil-powered boilers and furnaces over a range of fuel firing rates and excess combustion air settings.

Key observations and findings included:

- **Nitrogen Oxide emissions are frequently reduced** by about 20% by using the biodiesel/low sulfur blend.
- **Combustion stability with the biodiesel blend is very good** as indicated by low levels of carbon monoxide that are similar to the conventional fuel oil.
- **Sulfur Oxide emissions are reduced by 83%** by using the biodiesel blend with low-sulfur fuel.
- **Smoke numbers are lower with the biodiesel blend than the home heating oil** when the same burner air setting is used.
- **Fuel oil and combustion odors are improved by using the biodiesel /low sulfur oil blend** compared to home heating oil based on these preliminary tests.

This combustion test project demonstrated that very good combustion performance is produced by the biodiesel fuel blend in the conventional residential oil heating equipment that was tested. No significant changes in carbon monoxide levels (incomplete

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[11] *Bioheat Fact Sheet*, National Biodiesel Board.
[12] John E. Batey, *Combustion Testing of a Bio-diesel Fuel Oil Blend in Residential Oil Burning Equipment*, Energy Research Center, Inc., prepared for Massachusetts Oilheat Council and National Oilheat Research Alliance, 2003.

combustion) were observed. The reduction of air emissions with the biodiesel blend is substantial, producing much lower environmental impacts. This includes reductions in sulfur oxides (83%), nitrogen oxide (20%), carbon dioxide (20%), and particulate matter. Most of the sulfur oxide reduction is produced by using the low sulfur highway fuel. Preliminary analyses indicate that the 20% soy-based biodiesel/low sulfur diesel blend has an environmental cost that is better than natural gas when gas leakage during transmission, storage, and distribution are included. This transforms home heating oil into a premium fuel with very favorable environmental impacts. Other benefits include improved odor characteristics, and production of part of the fuel derived from agricultural sources within the U.S.

***Biodiesel Blends in Space Heating Equipment*, 2001**[13]

The executive summary from this study states: "A number of blends of varying amounts of biodiesel in home heating fuel were tested in both a residential heating system and a commercial size boiler. The results demonstrated that blends of biodiesel and heating oil can be used with few or no modifications to the equipment or operating practices in space heating. The results also showed that there were environmental benefits from the biodiesel addition in terms of reductions in smoke and in Nitrogen Oxides (NO_x). Residential size combustion equipment is presently not subject to NO_x regulation. If reductions in NO_x similar to those observed here hold up in larger size (commercial and industrial) boilers, a significant increase in the use of biodiesel-like fuel blends could become possible."

Abbott & Mills Bioheat Field Study[14]

In the heating seasons of 2001 through 2005, the Abbott & Mills Oil Company of Newburgh, New York, conducted a field study of 100 homes in the Hudson River valley, just north of New York City, which are using B20 bioheat for home heating. The project was funded jointly by the New York State Energy Research Authority (NYSERDA), Brookhaven National Laboratory, and the Northeast Regional Biomass Program, through its grant to NYSERDA.

Though a final report has not yet been produced, a conversation with the project manager at NYSERDA, Ray Albrecht, revealed some preliminary findings[15]:

- Test equipment was composed of standard, commercially available heating systems.
- Test equipment ranged widely in age and condition.
- Approximately 300,000 gallons of B20 bioheat was delivered to 100 homes over the course of four heating seasons.
- Study purchased B100 biodiesel and splash blended with No. 2 fuel oil.
- No service calls based on the fuel switch were recorded.

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[13] C.R. Krishna, *Biodiesel Blends in Space Heating Equipment,* December 2001, BNL-68852.
[14] Source: http://www.nyserda.org/programs/transportation/AFV/pdfs/Albrecht-NYSERDAKrishBrookhavenLab.pdf.
[15] Conversation with Ray Albrecht, 5/10/06.

- No cadmium sulfide flame detector (i.e., cad cell) issues (such as nuisance tripping) were recorded.
- Fuel storage tanks were located underground or in basements, so no cold weather issues were recorded.
- Test equipment was subjected to standard clean and service calls.
- Fewer heat exchanger deposits found after burning.
- Oil burners technicians noted that burners should be in reasonable tune for most efficient operation while using B20 bioheat.

Worley and Obetz, Inc. Bioheat Field Application[16]

Beginning in the fall of 2004, Worley & Obetz, Inc. became the first energy company in Pennsylvania to provide bioheat blends of up to 20% to all of its heating oil customers. Since the 2005 heating season, Worley & Obetz has used bioheat to heat 10,000 homes in central Pennsylvania.

Worley & Obetz indicates that their customers have not experienced any increase in maintenance while using bio-heating oil and that their bioheat products, marketed under the AmeriGreen™ BioHeating Oil brand, can be used in any heating system that currently uses heating oil with no modifications.

[16] Source: http://www.worleyobetz.com/Default.aspx?tabid=71.

3.6 Summarized Vermont Bioheat Program research findings

Summarized results from the VBHP laboratory and field testing studies are shown in Table 1 below.

Table 1 Summarized results of B20 bioheat testing program

Performance Metric	No. 2 Fuel Oil	B20 Bioheat	Percent change
Barre Technical Center			
Combustion Efficiency (%)	84.6	84	**-0.1%**
Start-up Amperage Draw (Amp)	3.0	3.1	**+3.3%**
Full-load Amperage Draw (Amp)	1.4	1.5	**+7.1%**
Cad Cell Resistance at 100 psi (Ohm)	375	468	**+24.8 %**
Cad Cell Resistance at 140 psi (Ohm)	340	478	**+40.6%**
Green Mountain Technology and Career Center			
Start-up Amperage Draw (Amp)	5.8	6.3	**+8.6%**
Full-load Amperage Draw (Amp)	1.0	1.0	**0.0%**
Cad Cell Resistance – Light (kOhm)	1.34	1.74	**+29.9%**
Cad Cell Resistance – Dark (kOhm)	2.49	2.52	**+1.2%**
Patterson Fuels, Inc.			
Combustion Efficiency (%)	84.5	84.4	**-0.1%**
Net Stack Temperature (°F)	350	380	**+8.6%**
Gross Stack Temperature (°F)	400	435	**+8.8%**
CO_2 Emission Level (%)	10.6	10.2	**-3.8%**
Breech Draft (inches of water column)	.056	.052	**-7.1%**
Champlain Valley Plumbing & Heating			
Combustion Efficiency (%)	83.9	83.5	**-0.5%**
Net Stack Temperature (°F)	433	436	**+0.7%**
CO_2 Emission Level (%)	11.2	11.0	**-1.8%**
Breech Draft (inches of water column)	.051	.049	**-4.0%**

Combustion efficiency, a primary measure of system performance, was measured on 30 different heating systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that combustion efficiency dropped by as much as 0.5% when systems were fueled with B20 bioheat. Because B20 bioheat was introduced later in the heating season, the decease in efficiency might be attributable to accumulated build-up on system heat exchangers.

Start-up amperage draw, a measure of energy needed to start the burner motor, was measured on five separate heating systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that start-up amperage draw increased by as much as 8.6% while systems were fueled with B20 bioheat. This may be an indication of the greater density and viscosity of B20 bioheat (i.e., the more viscous the fuel, the greater the amperage draw).

Full-load amperage draw a measure of energy needed to maintain burner motor speed, was measured on five separate heating systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that start-up amperage draw increased by as much as 7.1% while systems were fueled with B20 bioheat. As with start-up amperage draw, this result may be an indication of the greater density and viscosity of B20 bioheat (i.e., the more viscous the fuel, the greater the amperage draw).

Cad cell resistance indicates how effectively the cadmium sulfide flame detector (i.e., the cad cell) senses the flame produced by the burner. The cad cell is a safety device designed to prevent the accumulation of fuel should the burner flame be extinguished. This metric was measured on five separate heating systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that cad cell resistance increased by as much as 40.6% while systems were fueled with B20 bioheat, thereby increasing the likelihood that the burner safety switch will turn the burner off. The higher resistance value may be attributable to the lower luminosity of the B20 bioheat flame.

Net stack temperature is a measure of how effectively combustion heat is being used for system heating. Higher net stack temperatures indicate lower combustion efficiencies. This metric was measured on 26 separate systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that net stack temperature averaged results increased by up to 8.6% while systems were fueled with B20 bioheat. Because B20 bioheat was introduced later in the heating season, the increase in net stack temperature might be attributable to accumulated build-up on system heat exchangers.

Gross stack temperature is a measure of how effectively combustion heat is being used for system heating. Higher gross stack temperatures indicate lower combustion efficiencies. This metric was measured on six separate systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that gross stack temperature averaged results increased by up to 8.8% while systems were fueled with B20 bioheat. As with net stack temperature, because B20 bioheat was introduced later in the heating season, the increase in net stack temperature might be attributable to accumulated build-up on system heat exchangers.

CO_2 emission levels are a direct indicator of combustion efficiency – higher CO_2 emission levels indicate higher combustion efficiency. This metric was measured on 26 separate systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that averaged CO_2 emission results decreased by as much as 3.8% while systems were fueled with B20 bioheat.

Breech draft is an indicator of how effectively a system is drawing combustion air from the atmosphere and how well the chimney or venting system is drawing the combustion products through the heat exchanger. The greater the breech draft value, the more efficient a system's performance. This metric was measured on 26 separate systems using No. 2 fuel oil and B20 bioheat. A comparative analysis of the averaged results indicates that averaged breech draft results decreased by as much as 7.1% while systems were fueled with B20 bioheat. Breech draft is directly related to the heat exchanger design, the chimney, the draft regulator setting, and restrictions or soot and scale build up in the heat exchanger. A decrease in breech draft may be attributable to build-up on the system heat exchangers as the heating season progressed.

3.7 Testimonials

Each participating research laboratory and field-testing fuel supplier was asked to report on their overall experience using B20 bioheat, recommendations for potential users, and plans for future use of bioheat, if any. Following are some of their comments:

Barre Technical Center: "Our recommendation would be that anyone switching to bio have their furnace/boiler cleaned and tuned using the proper testing equipment. Testing would allow the equipment to be set-up for the maximum efficiency for biofuel."

Green Mountain Technology and Career Center: "In short…the only real test results we had of any concern would be light sensing from the cadmium sulfide flame detector, and whether the differences in light magnitude and color would cause nuisance trips of the reset flame safety device on the primary control."

Patterson Fuels, Inc.: "In summary, we would like to say that B20 performed as well as #2 fuel in a heating application. We will recommend it to any customer currently burning #2 fuel. Our future plans are to continue to market B20 in our service area while at the same time working to upgrade our infrastructure to handle the product better."

Champlain Valley Plumbing & Heating: "We had heard that there would be increased service issues [when using B20 bioheat in heating systems] – the biodiesel would act as a cleaning agent plugging filters, strainers, and burner nozzles. We were pleasantly surprised. We experienced no more problems with the boilers and furnaces at Middlebury College [using B20 bioheat] than we would expect from units running on No. 2 fuel oil…Champlain Valley Plumbing & Heating is going to offer B5 to all of our customers this year as part of our pre-buy program in hopes of curbing some of our country's dependency on foreign oil and increasing markets for our farmers in this country."

4.0 LABORATORY TESTING METHODOLOGY AND FINDINGS

Vermont Bioheat Program laboratory testing was conducted at two oilheat maintenance vocational training centers, one at the Barre Technical Center (BTC) in Barre, Vermont, and a second at the Green Mountain Technology and Career Center (GMTCC) in Hyde Park, Vermont. At both of these centers, secondary-level students train to operate and maintain various heating, ventilation, and air conditioning systems under the supervision of NORA-certified instructors. In some cases, the students themselves are NORA- and/or NEFI- certified. The instructors coordinating this research study at the above facilities were Joel Parmelee at BTC and Mark Wright at GMTCC.

4.1 Test Plan

In late 2005, the two selected heating laboratories received a fuel delivery of B20 bioheat from a single load and fuel supplier (to ensure fuel quality consistency) and developed a plan to evaluate the performance of the lab equipment according to the following tests:[17]

- Live-fire equipment testing
- Individual unit testing
- Parallel or simultaneous testing
- Individual component testing
- Fuel stability testing

Test parameters included:

- Start up amperage
- Running amperage
- Operating voltage
- Efficiency test measurements, preferably 80% or better
- Running oil pressure
- Running oil vacuum
- Resistance reading on cad cell with fire at 100psi pump pressure
- Resistance reading on cad cell with fire at 140psi pump pressure
- Pump cut-off pressure setting check at 100 psi pump pressure

[17] See Appendix A for full laboratory testing and field testing specifications.

4.2 Facilities and Equipment

Test equipment used at BTC and GMTCC is detailed in Table 2 below.

Table 2 Test equipment specifications at BTC and GMTCC lab facilities

Appliance Type	Appliance Brand	Burner Brand	Burner Model	Nozzle Brand	Nozzle Size	Spray Angle	Spray Pattern	Oil Pump Brand, Model
Test Unit - Green Mountain Technology and Career Center Lab								
Furnace	Thermopride	Beckett	AF	N/A	.75	80	Hollow	Suntec, AZVA-7116
Test Units - Barre Technical Center Lab								
Boiler	Burnham	Beckett	AFG	Hago	0.8	60	Solid	Beckett, Cleancut
Furnace	Laars MAX	Beckett	AF2	N/A	0.85	60	N/A	Beckett, Cleancut
Steam boiler	Peerless	Beckett	AFG	Danfoss	N/A	80	N/A	Beckett, Cleancut
Furnace	AIRCO	Beckett	AFG	Hago	0.85	60	Solid	Beckett, Cleancut

4.3 Procedures

In live-fire equipment testing, units were tested in live-fire conditions. Labs were requested to provide each unit with new oil filters, nozzles and pump strainers and to take fuel samples for later evaluation.

In individual unit testing, identical heating units were tested first with No. 2 fuel oil and then with B20 bioheat. Testing parameters listed in section 4.1 were documented in each case.

In parallel or simultaneous testing, units of similar style and construction with identical burners were tested simultaneously with No. 2 fuel oil and B20 bioheat.

Labs were also requested to perform individual component testing in which various oil pump brands could be tested individually to determine the long-term effects of operating on B20 bioheat. However, time and resource restrictions prevented this testing from occurring.

In fuel stability testing, five-gallon vented steel fuel storage cans, one half-full with No. 2 fuel oil and the other half-full with B20 bioheat were placed outside during the duration of the 2005-2006 heating season. Samples were prepared but time and resource restrictions prevented fuel analysis from taking place.

4.4 Findings

Green Mountain Technology and Career Center

Figure 1 GMTCC student Mike McNally conducting B20 bioheat testing

GMTCC used a total of 35 gallons of B20 bioheat and a similar amount of No. 2 fuel oil during its research. GMTCC focused on two aspects of equipment performance with regard to No. 2 fuel oil and B20: (1) appliance amperage draw at start-up and full-load, and (2) electrical resistance of the cadmium sulfide flame detector (i.e., cad cell). Ten testing samples were taken for each test parameter and readings were averaged. Results are illustrated in Figures 2 and 3 below.

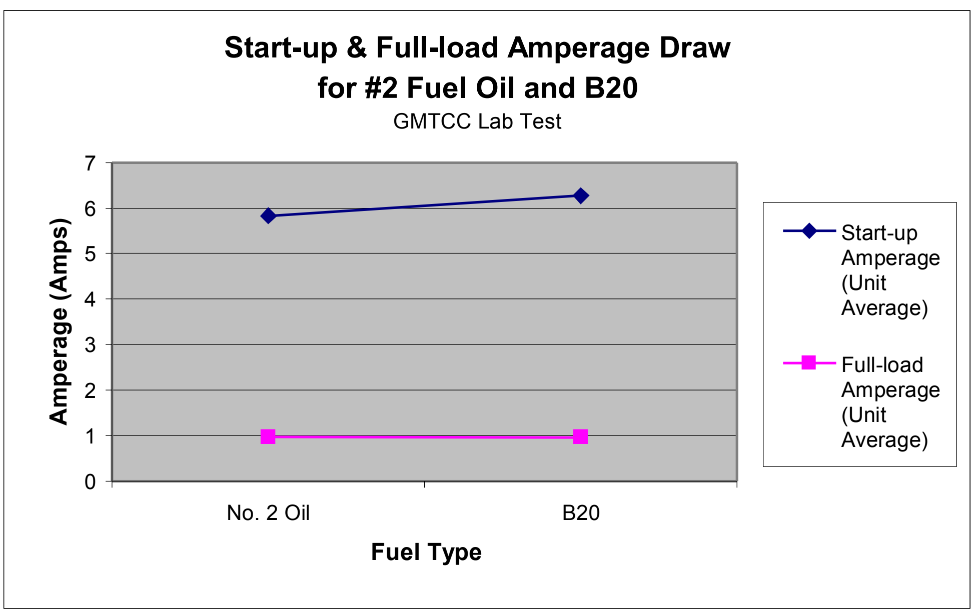

Figure 2 Start-up and full-load amperage draw for No. 2 fuel oil and B20 (GMTCC lab test)

As Figure 2 indicates, motor start-up amperages increased slightly when B20 was used – from 5.8 to 6.3 amps – an 8.8% increase. This is possibly due to the slightly higher viscosity and slightly higher density of B20. Full-load amperage remained unchanged at 0.96 amps for No. 2 fuel oil and B20. The Beckett AF motor used in the test was rated at 115 volts and 1.7 amps.

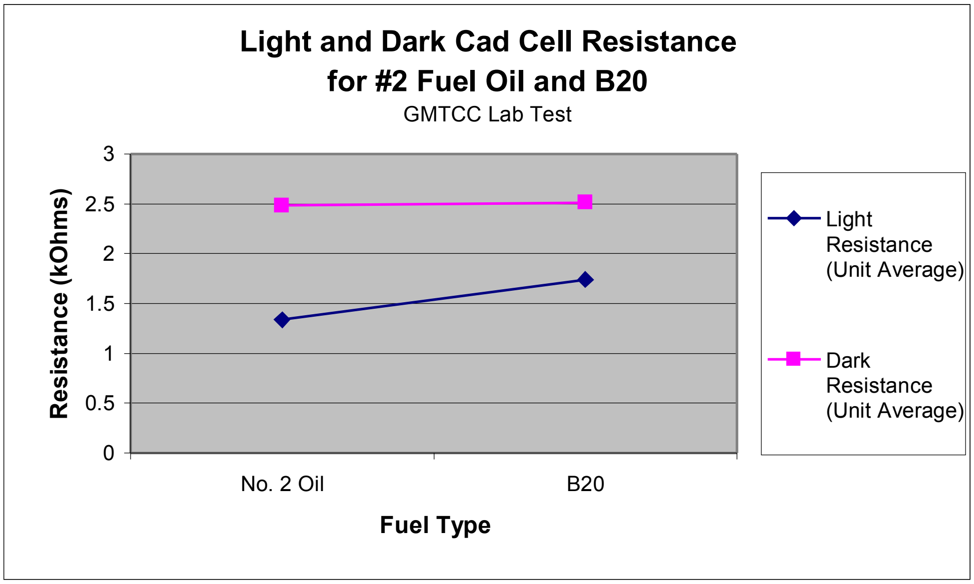

Figure 3 Light and dark cad cell resistance for No. 2 fuel oil and B20 (GMTCC lab test)

Figure 3 illustrates that cad cell light resistance increased from 1.3 kOhms to 1.7 kOhms and dark resistance increased from 2.4 kOhms to 2.5 kOhms when B20 bioheat was used. C.R. Kirshna et al. found a similar effect when using B100 bioheat in their 2001 bioheat study[18]:

> One difficulty was noticed and reported on in these preliminary tests: when firing neat [B100] biodiesel at high excess air levels, the flame proving control displayed a tendency to shut off the system even though the flame was lit and operation seemed normal. This was attributed to the "less bright flame" seen when compared with [No. 2] fuel oil and the consequent response of the cad cell used to sense it. The photosensitive cell's dark resistance is higher and the control is set to shut off if it gets above a certain level.

These increased cad cell resistances could potentially result in nuisance control "reset tripping" in which the heating unit switches off because the flame is no longer detectable. However, no reset tripping was experienced during GMTCC testing and no control difficulties were experienced by Krishna in later testing of bioheat blends up to B100.[19] The resistance data suggests that a thorough inspection and tuning of the burner and

[18] C.R.Krishna et al., *Lab Tests of Biodiesel Blends in Residential Heating Equipment*, Proceedings of the 2001 National Oilheat Research Alliance Technology Conference, BNL-52625, 2001.
[19] C.R. Krishna, *Biodiesel Blends in Space Heating Equipment*, National Renewable Energy Laboratory, 2001, p. 10.

control system is important before the introduction of B20 bioheat, and in particular, a proper adjustment of the fuel/oxygen mixture that results in a flame color appropriate for the cad cell. A specialty cad cell primary control manufactured and "tuned" for various bioheat blends might also be considered by the heating industry as the use of bioheat becomes more widespread.

GMTCC also looked at the combustion efficiency of its test system while using No. 2 fuel oil and B20 bioheat. While no specific data was recorded, lab personnel found that there were "negligible changes in efficiency…between the B20 and No. 2 heating oil. Steady state efficiencies were only single percentage points different from one fuel to the other. Efficiencies [for No. 2 fuel oil and B20 bioheat] were within one to two percentage points up and/or down."

<u>Barre Technical Center</u>

Figure 4 Instructor Joel Parmelee (second from right) and his HVAC students at BTC

BTC lab testing included the analysis and documentation of several performance factors including combustion efficiency, motor start-up and full-load amperage draw, and cad cell resistance at pump pressures of 100 p.s.i. and 140 p.s.i. Results are illustrated in Figures 5, 6, and 7 below.

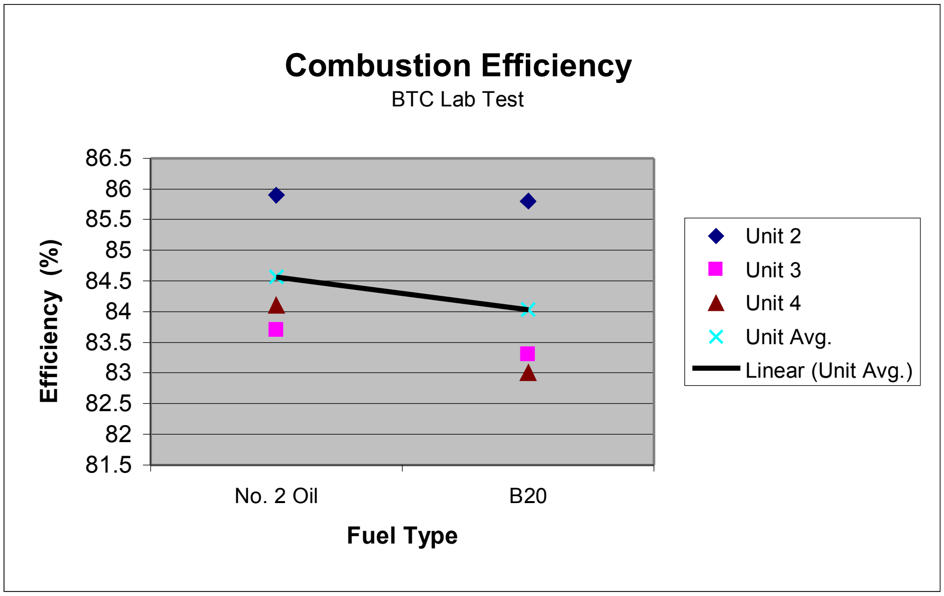

Figure 5 Combustion efficiency for No. 2 fuel oil and B20 (BTC lab test)

A drop in combustion efficiency of approximately 0.5% was found with the use of B20 bioheat, as indicated in Figure 5. This is consistent with the findings at GMTCC, which found a variation of 1-2 efficiency percentage points in its test unit. One-half of a percentage point is well within the expected test cycle "noise" variation. It should also be noted that the data from BTC Unit 1 was not included in the data set for Figure 5 because of equipment operational difficulties during testing. This qualification does not apply to other testing included in this section.

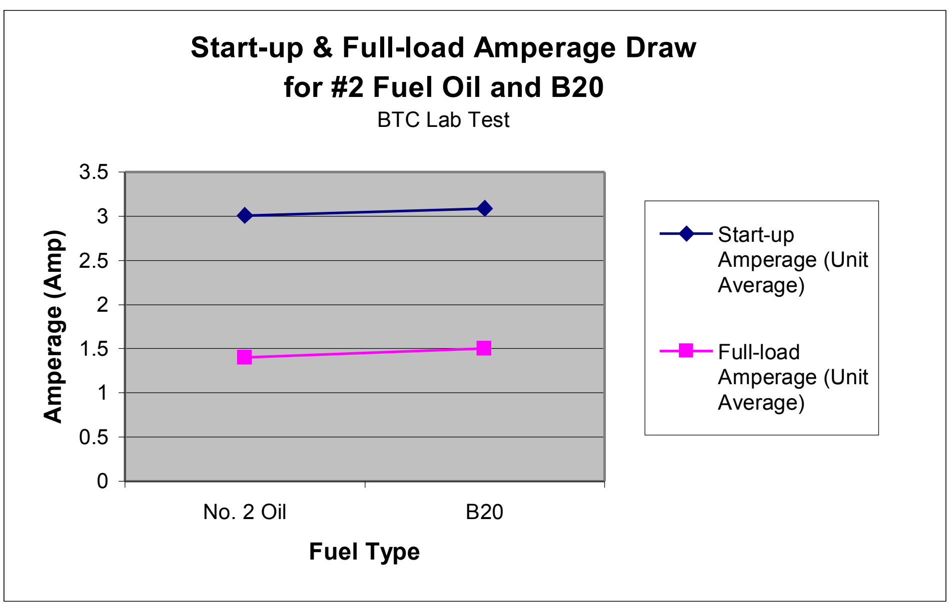

Figure 6 Start-up and full-load amperage draw for No. 2 fuel oil and B20 (BTC lab test)

As illustrated in Figure 6, burner motor amperage draw at start-up increased slightly from 3.0 amps to 3.1 amps, while full-load amperage draw increased from 1.4 amps to 1.5 amps. These findings are consistent with testing at GMTCC and are likely due to the slightly higher viscosity and slightly higher density of B20.

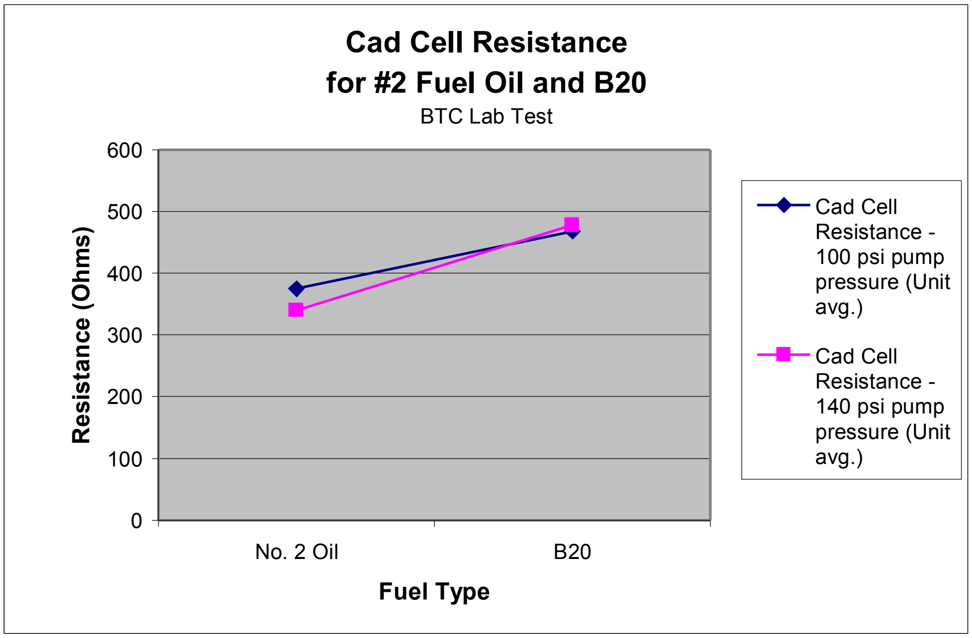

Figure 7 Cad cell resistance for No. 2 fuel oil and B20 (BTC lab test)

Figure 7 indicates that cad cell resistance increased slightly with B20 usage at pump pressures of 100 p.s.i. and 140 p.s.i. As described in relation to GMTCC lab testing, because the B20 flame burns with less luminosity, cad cell resistance is expected to increase. If the effect is extensive enough, it could potentially cause nuisance tripping of the control system. However, no such tripping behavior was observed during BTC lab testing. The fact that cad cell resistance increased similarly for the two different pump pressures indicates that there is only a minor relationship between cad cell resistance and force of the fuel stream, regardless of the fuel used.

5.0 FIELD TESTING METHODOLOGY AND FINDINGS

Field testing was conducted at 26 separate residential units using the services of two Vermont fuel dealers: Patterson Fuels, Inc. of Richmond, Vermont and Champlain Valley Plumbing & Heating of Bristol, Vermont. In each field test case, NORA- and/or NEFI-certified oilheat technicians conducted a visual inspection and performance test of the test heating units prior to introducing B20 bioheat. Following this initial performance test, B20 bioheat was introduced and an identical visual inspection and performance test was conducted after B20 bioheat had been in use for the remainder of the 2005-2006 heating season. In some cases, mid-season inspections and performance tests were also conducted.

5.1 Test Plan

The two selected heating fuel suppliers developed a plan to supply B20 bioheat to a sample group of their heating fuel customers and then to monitor, evaluate and describe the thermal and physical performance of B20 bioheat in the customer's heating system.

The plans included a full system inspection (as described below) before the B20 was introduced, a mid-season visual inspection of the system, a follow-up full inspection at the end of the heating season, and the documentation of any service calls or unusual incidents reported by the bioheat customers during the test period.

Following is list of procedures and required information collected prior to the introduction of B20 bioheat:

- Perform combustion efficiency test
- Inspect and clean heat exchanger, flue pipe, burner chassis, electrodes, and flame retention head
- Replace fuel filter, pump strainer, and burner nozzle
- Document all field data on a system-by-system basis
- List condition and location of fuel storage tank (if available)

5.2 Facilities and Equipment

Table 3 indicates equipment on which B20 bioheat was field tested by participating fuel suppliers.

Table 3 Equipment specifications for CVPH and Patterson Fuels field tests

Appliance Type	Appliance Brand	Burner Brand	Burner Model	Nozzle Size	Spray Angle
Test Units – Patterson Fuels, Inc.					
Boiler	Energy Kinetics EK1	Beckett	AFG	0.85	70A
Boiler (2)	Energy Kinetics EK1	Beckett	AFG	0.75	70A
Boiler	Sears Homart	Beckett	AFG	1.00	80A
Furnace	Bard	Beckett	AFG	1.00	80A
Furnace	Williamson	Beckett	AFG	1.00	80A
Test Units – Champlain Valley Plumbing & Heating					
Boiler	HB Smith 2500A/2500L	N/A	N/A	1.50	60B
Boiler	Burnham V-77	N/A	N/A	1.35	80B
Boiler	Buderus G115/4	N/A	N/A	0.65	.80B
Boiler	HB Smith S/W4	N/A	N/A	1.35	60B
Furnace	Williamson 1164-15-5158	N/A	N/A	0.65	70A
Boiler	Peerless WB-15-WPCT	N/A	N/A	1.10	80A
Boiler	Utica 500 ST	N/A	N/A	1.00	80B
Boiler	Buderus G115/5	N/A	N/A	0.85	60B
Boiler	Buderus 205/5	N/A	N/A	0.85	60B
Boiler	Buderus G215/5	N/A	N/A	1.50	80B
Boiler	Buderus G305/5	N/A	N/A	1.75	70B
Boiler	New Yorker FR-232-W	N/A	N/A	1.65	80A
Boiler	Buderus G115/5	N/A	N/A	0.85	60B
Boiler	N/A	N/A	N/A	N/A	N/A

Appliance Type	Appliance Brand	Burner Brand	Burner Model	Nozzle Size	Spray Angle
Boiler	Utica 500 ST	N/A	N/A	1.00	80B
Boiler	N/A	N/A	N/A	N/A	N/A
Boiler	Ducane ULBB085A3BK	N/A	N/A	.60	70A
Boiler	Buderus G115/28	Riello	N/A	0.65	70B
Furnace	Williamson 116415-3	N/A	N/A	1.00	80A
Furnace	EFM LBO-12AR	N/A	N/A	1.00	80B

5.3 Findings

Patterson Fuels, Inc.

Figure 8 Jason Harvey of Patterson Fuels in front of B20 bioheat storage tanks

Patterson Fuels selected a sample group of six units and conducted an initial round of system performance tests to establish baseline data using conventional No.2 fuel oil. B20 bioheat was then introduced to the sample group and records were kept on each system as the season progressed. Mid-term tests and visual inspections were conducted in December and March of 2006. A final inspection and combustion test was performed in May of 2006 and a report of the results was produced. Results from Patterson Fuels testing are illustrated in Figures 9, 10, and 11 below.

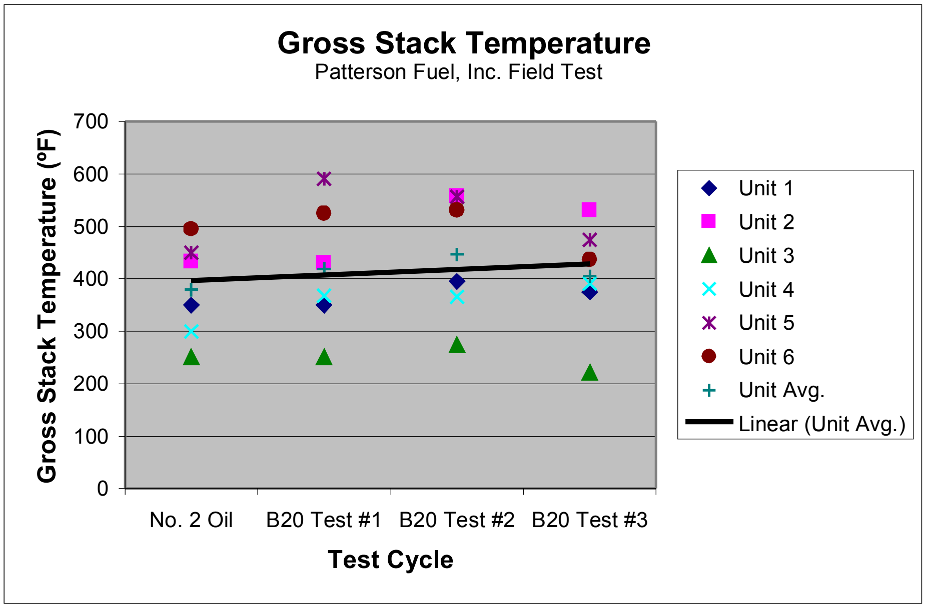

Figure 9 Gross stack temperature for No. 2 fuel oil and B20 (Patterson field test)

Figure 9 indicates that the gross stack temperature as averaged across the six test units trends upward from 400°F to 435°F – an 8.8% increase. Gross stack temperature is a measure of the temperature of gasses in the flue downstream of the combustion chamber. Higher stack temperatures generally indicate lower combustion efficiency, as more heat is lost to the atmosphere.

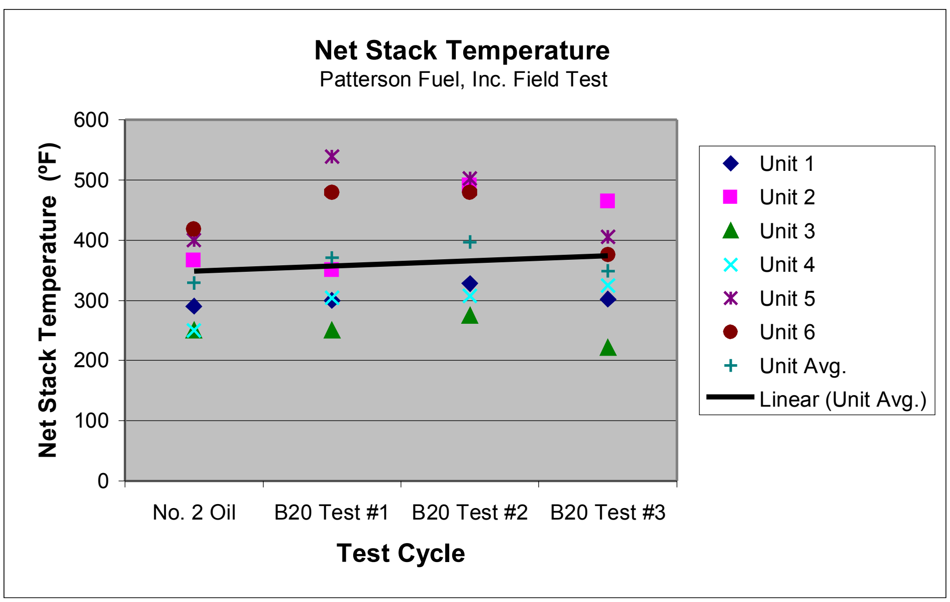

Figure 10 Net stack temperature for No. 2 fuel oil and B20 (Patterson field test)

Figure 10 indicates that the net stack temperature as averaged across the six test units trends upward from 350°F to 380°F – an 8.6% increase. Net stack temperature is calculated from the gross stack temperature less the temperature of air entering the burner. Higher net stack temperatures generally indicate lower combustion efficiency, as more heat is lost to the atmosphere. Other parameters used in determining combustion efficiency include carbon dioxide emission levels, carbon monoxide emission levels, oxygen content of the exhaust gasses, exhaust gas temperature, and air combustion temperature.

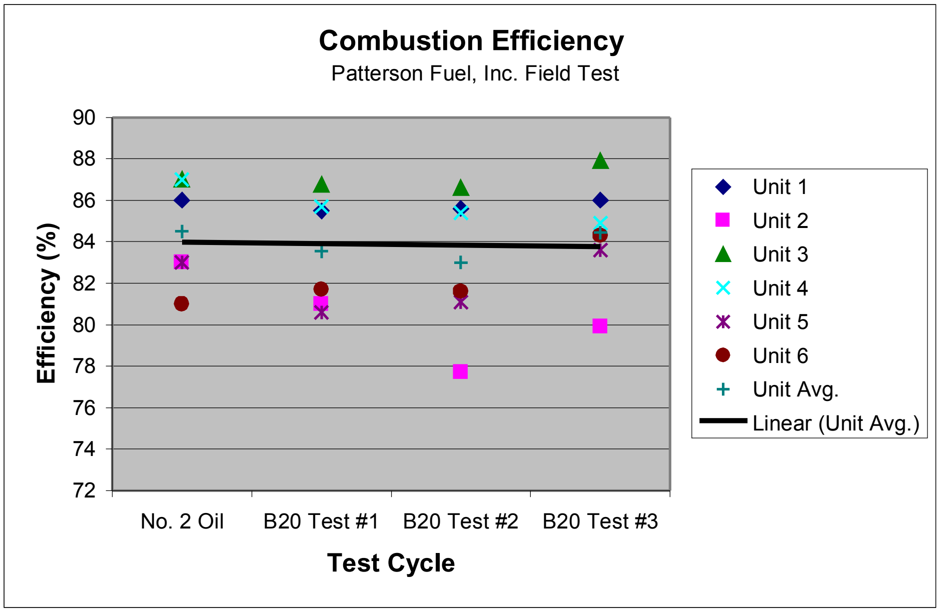

Figure 11 Combustion efficiency for No. 2 fuel oil and B20 (Patterson field test)

Combustion efficiency is a measure of how effectively the heat content of a fuel is transferred into usable heat. The stack temperature and flue gas oxygen (and carbon dioxide) concentrations are primary indicators of combustion efficiency. Figure 11 indicates that the combustion efficiency trends downward slightly with the use of B20 bioheat from 84.5% (using No. 2 fuel oil) to 84.4% (using B20 bioheat). This is likely due to the build up of soot and scale on the system heat exchangers as the heating season progressed.

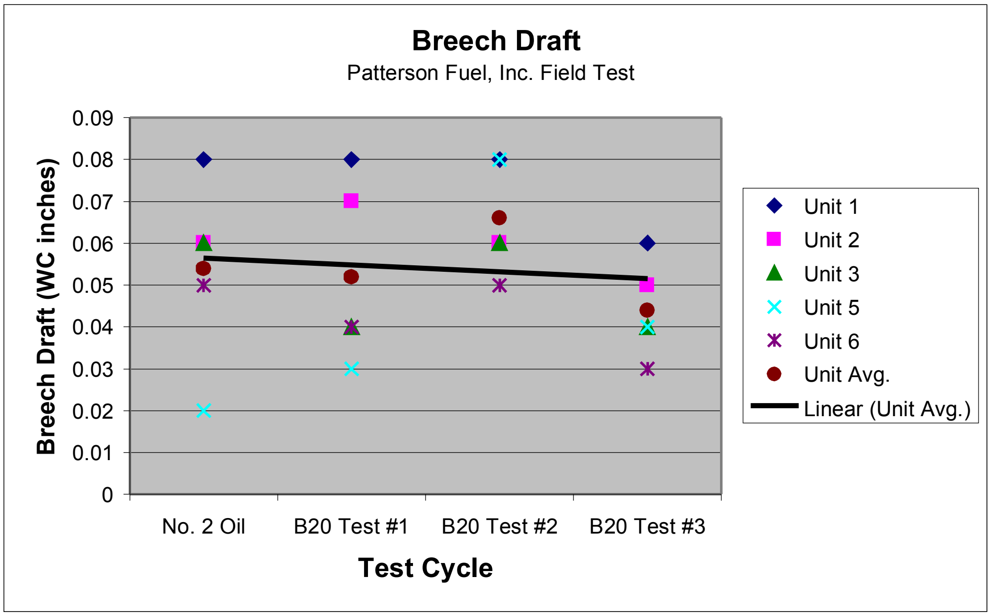

Figure 12 Breech draft for No. 2 fuel oil and B20 (Patterson field test)

Figure 12 indicates a slight decrease in breech draft, possibly indicating a build up of soot and scale on the heat exchanger as the heating season progressed. This diminishing draft level is generally anticipated, and may also account for the modest drop in combustion efficiency. However, it might be also be expected that the heating units would experience less build-up of soot and scale when using B20 bioheat than with No. 2 fuel oil, though this does not appear to be the case.

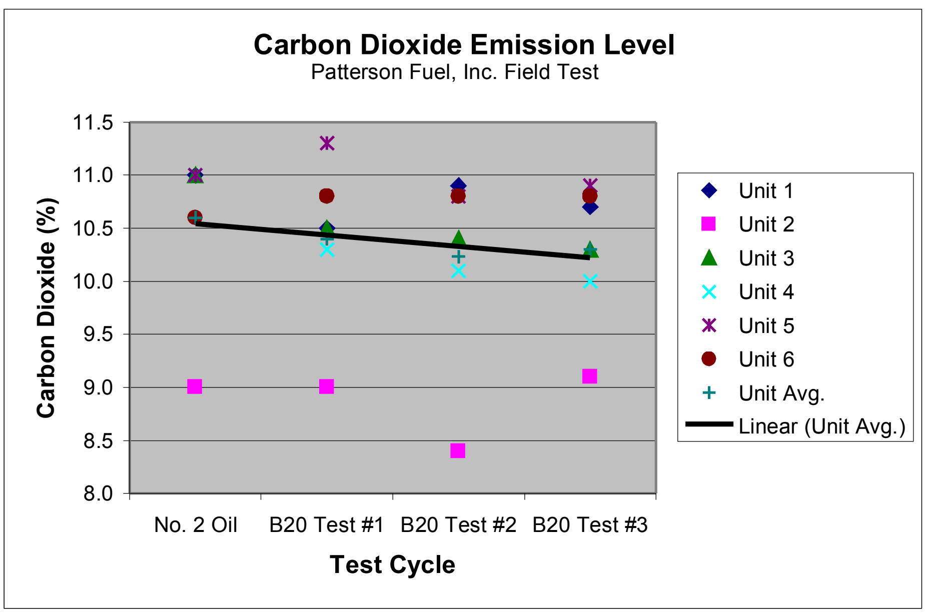

Figure 13 Carbon dioxide emission level for No. 2 fuel oil and B20 (Patterson field test)

Figure 13 indicates that carbon dioxide levels, as averaged across the six test units, trend downward from 10.6% to 10.2% with use of B20 bioheat. The illustrated drop in CO_2 emission level is possibly a function of variation in fuel chemistry. Combustion efficiency is a direct function of CO_2 levels: the higher the CO_2 levels, the higher the combustion efficiency. Since B20 bioheat contains lower hydrocarbon levels than No. 2 fuel oil, CO_2 emissions levels decrease when B20 bioheat is burned, which results in an apparent reduction in combustion efficiency. Specialized combustion test equipment is available to compensate for this fuel variation in carbon emission levels, though this equipment was not used in this testing program.

To obtain maximum combustion efficiency, it is important that a qualified oilheat technician properly tune the burner's fuel/air mixture to a level appropriate to the fuel being used.

Champlain Valley Plumbing & Heating

Figure 14 Champlain Valley Plumbing & Heating staff members

CVPH supplied B20 bioheat to stand-alone heating systems at 20 Middlebury College-owned buildings using residential-scale oil heating equipment over the course of the 2005-2006 heating season. After conducting an initial round of visual inspections and performance tests that established baseline data using conventional No.2 fuel oil, CVPH introduced B20 bioheat to the sample group and documented fuel-related service calls as the heating season progressed. A mid-season round of performance testing was deemed invalid because of faulty test equipment. A final round of visual inspections and performance tests was performed on each unit in May of 2006 and a report of the results was produced. Results from CVPH field tests are illustrated in Figures 15, 16, 17, and 18 below.

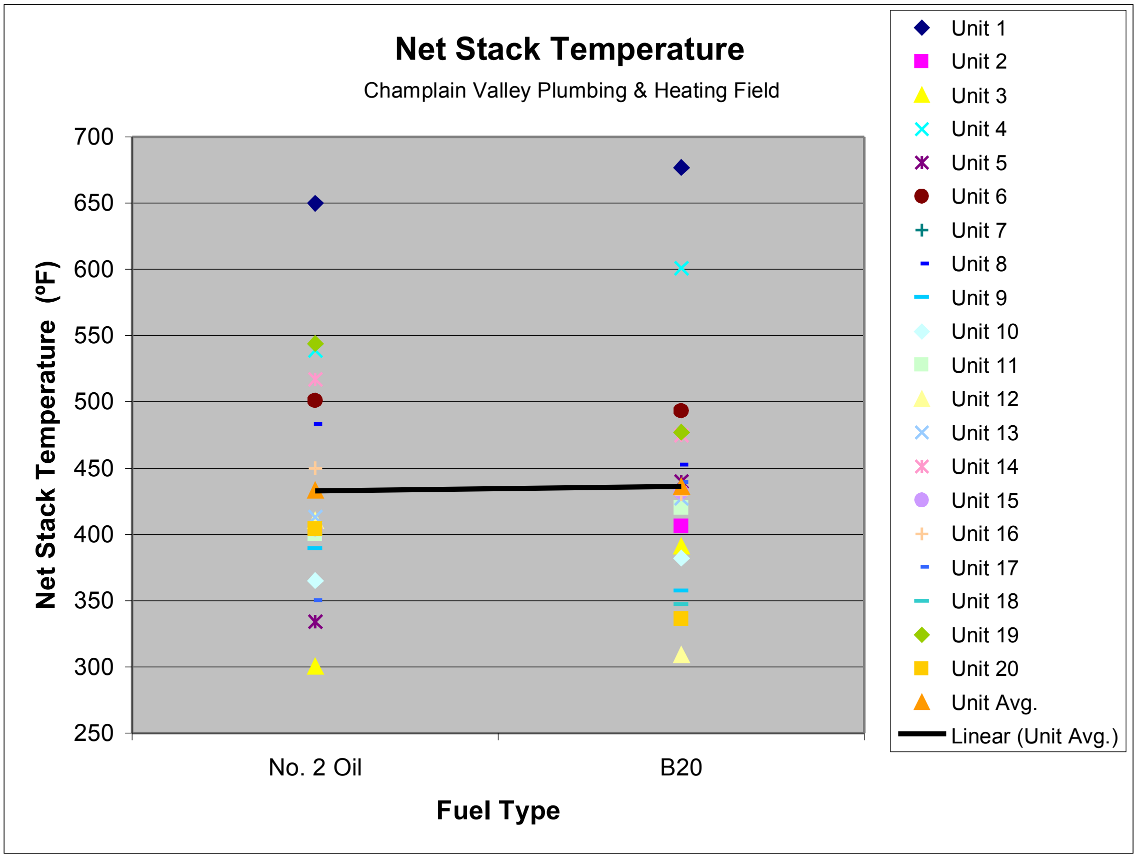

Figure 15 Net stack temperature for No. 2 fuel oil and B20 (CVPH field test)

Figure 15 indicates that the net stack temperature as averaged across the 20 test units trends upward slightly from 433°F to 436°F – a 0.7% increase. This is in-line with test results from Patterson Fuels, which found an 8.6% increase in net stack temperature when B20 bioheat was used. Net stack temperature is calculated from the gross stack temperature less the temperature of air entering the burner. Higher net stack temperatures generally indicate lower combustion efficiency, as more heat is lost to the atmosphere, rather than being converted to usable heat.

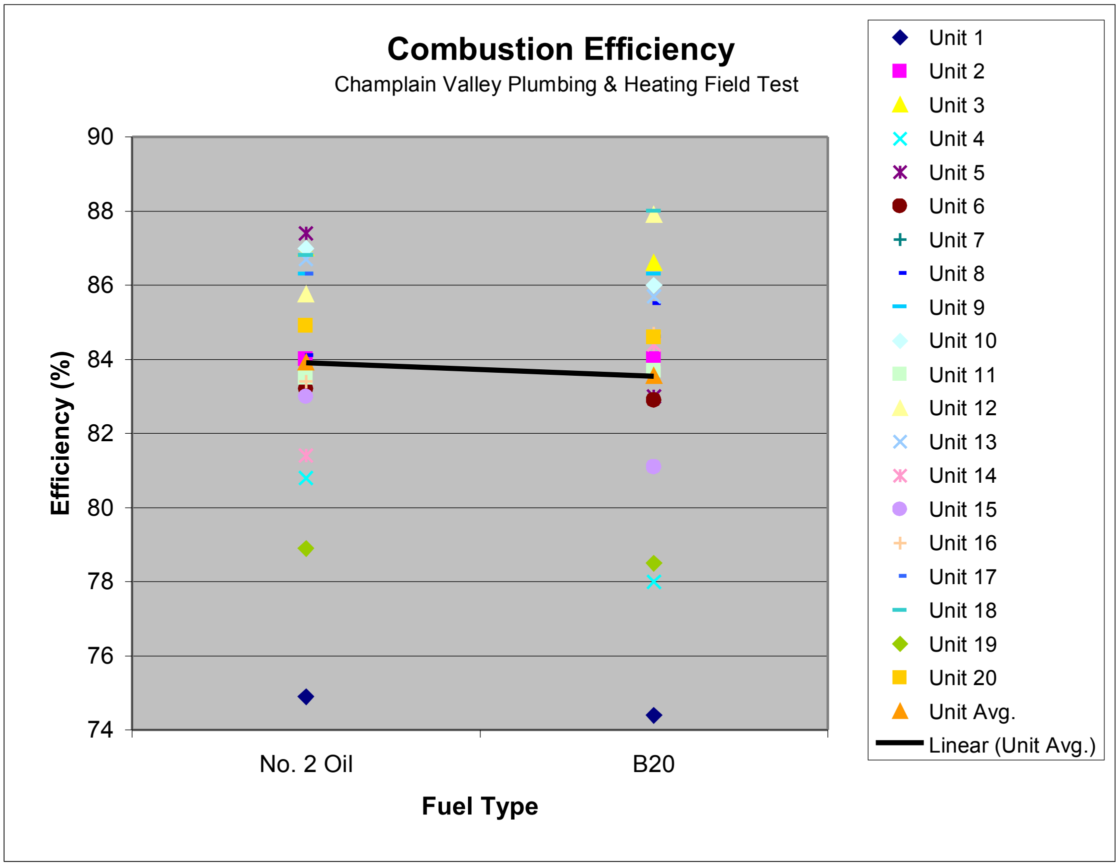

Figure 16 Combustion efficiency for No. 2 fuel oil and B20 (CVPH field test)

Figure 16 indicates that the combustion efficiency, as averaged across the 20 test units, trends slightly downward from 83.9 to 83.5 with the use of B20 bioheat – a 0.5% decrease. Combustion efficiency results from Patterson fuels indicate a similar 0.1% decrease in efficiency. This scale of variation is well within the noise level of measurement variability. Combustion efficiency is a measure of how effectively the heat content of a fuel is transferred into usable heat. Stack temperature and flue gas oxygen (or carbon dioxide) concentrations are primary indicators of combustion efficiency.

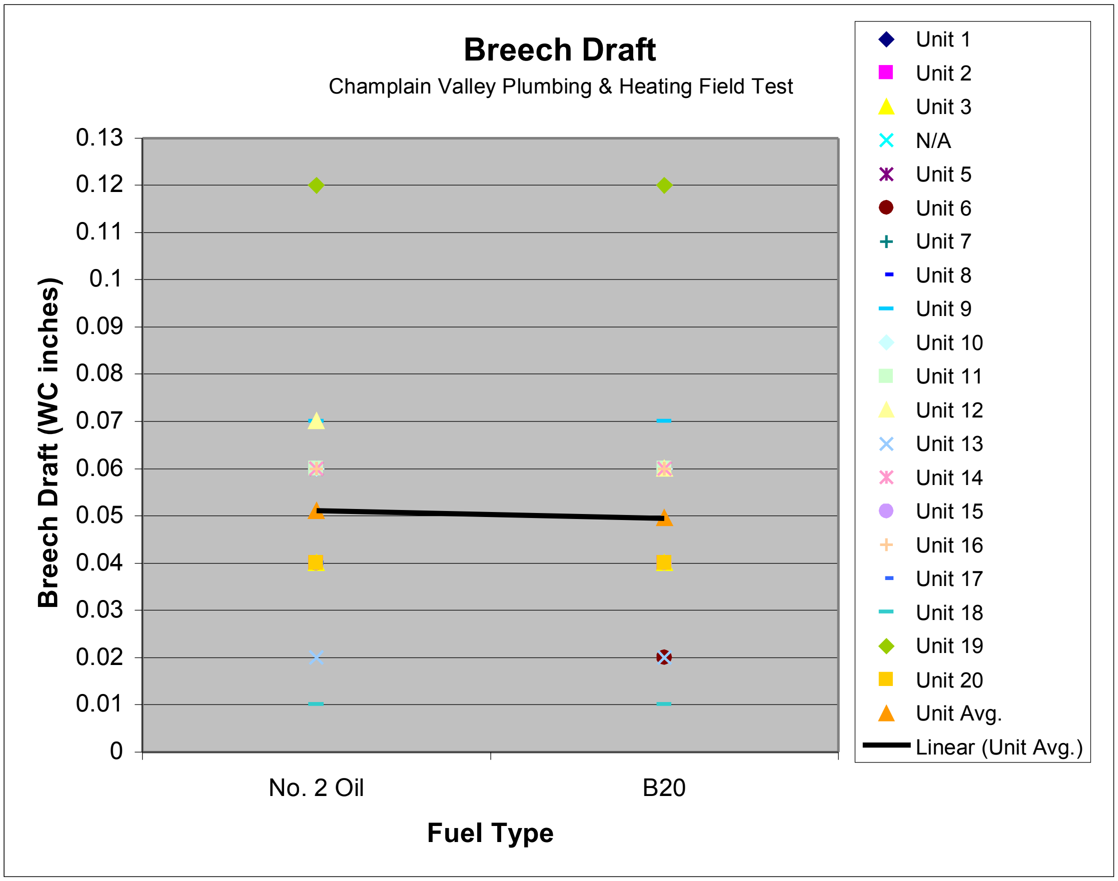

Figure 17 Breech draft for No. 2 fuel oil and B20 (CVPH field test)

Figure 17 indicates a slight decrease in breech draft, from 0.051 inches of water column (using No. 2 fuel oil) to 0.049 inches of water column (using B20 bioheat) – a 4% decrease – possibly indicating a build up of soot and scale on the heat exchanger as the heating season progressed. This finding is similar to that found in Patterson Fuels testing. This diminishing draft level is generally anticipated with all oil-based heating fuels as the heating season progresses, and may also account for the modest drop in combustion efficiency.

It should also be noted that the data from CVPH Unit 4 was not included in the data set for Figure 17 because of equipment operational difficulties during testing. This qualification does not apply to other tests performed in this section.

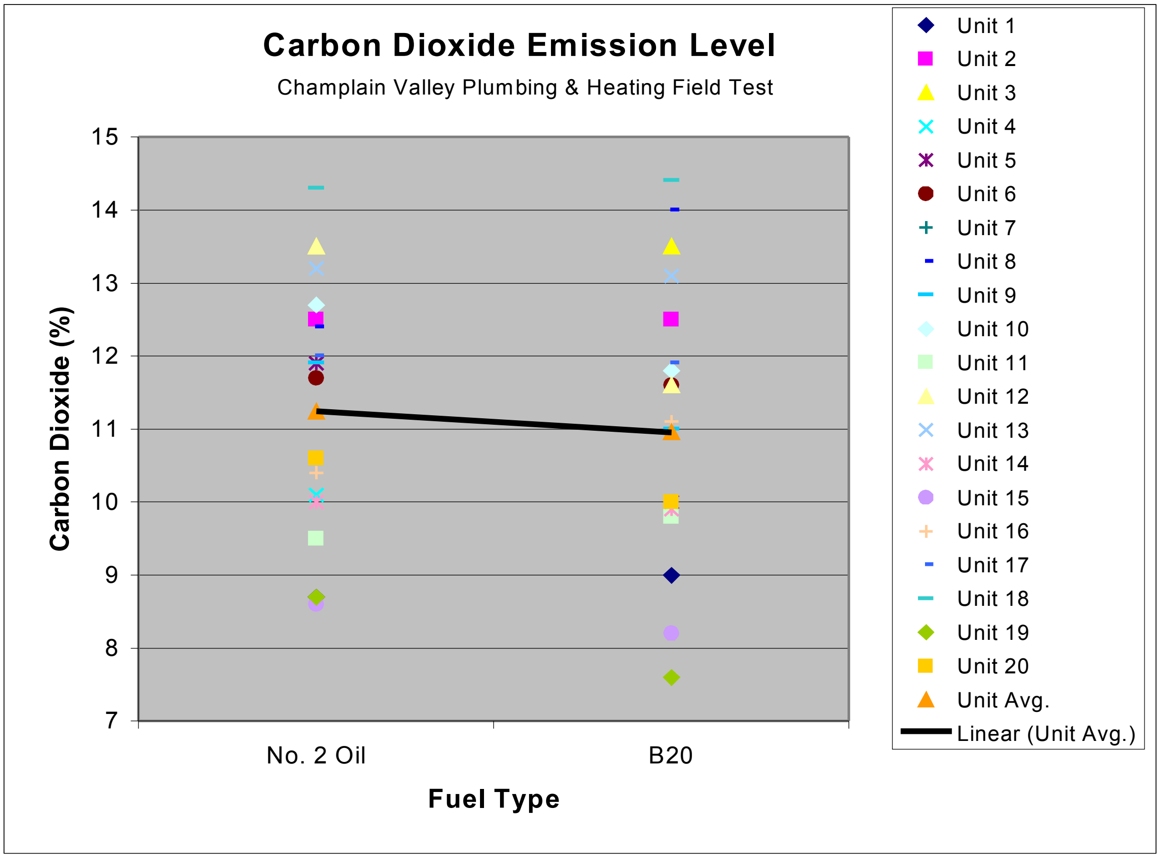

Figure 18 Carbon dioxide emission level for No. 2 fuel oil and B20 (CVPH field test)

Figure 18 indicates that carbon dioxide levels, as averaged across 20 test units, trend downward from 11.2% to 11.0% with use of B20 bioheat. This is consistent with the findings from Patterson Fuels, which decreased from 10.6% to 10.2%, on average. Again, lower levels of hydrocarbons present in B20 bioheat may be responsible for some of all of this effect. Higher levels of carbon dioxide emission levels indicate higher combustion efficiency.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Results from the Vermont Bioheat Program laboratory and field testing programs indicate that the impacts on system performance of switching from No. 2 fuel oil to B20 bioheat in residential heating systems are negligible.

Combustion efficiency is the best overall indicator of system performance and VBHP research findings indicate that there is a decrease in system combustion efficiency of up to 0.7% when B20 bioheat is used as a fuel, as compared to efficiency values when No. 2 fuel oil is used. Several performance indicators support this conclusion, including increases in net stack temperature readings, decreases in CO_2 emission levels, decreases in breech draft, and other factors. However, this finding does not necessarily indicate a limitation of the fuel. Because testing protocol dictated that B20 bioheat be introduced later in the heating season, it's possible that accumulated soot and scale build-up on the system heat exchangers accounts for some or all of the combustion efficiency decrease. It should be noted that most oil-burning heating systems experience a decrease in combustion efficiency over the course of a heating season as the build-up of deposits on the heat exchanger reduce its ability to absorb heat from the combustion flame.

Reduced combustion efficiency values may also be attributable to the fact that the test systems, which had been optimally tuned for the use of No. 2 fuel oil at the beginning of the season, required a re-adjustment of the fuel/air mixture to attain maximum efficiency when B20 bioheat was introduced. These findings suggest areas of further testing. Nonetheless, reduced combustion efficiency values of less than 1% are negligible in practical terms and should not discourage those considering the use of B20 bioheat.

Other key Vermont Bioheat Program findings:

- **Burner motor start-up and full-load amperage** draws increase slightly when B20 bioheat is used, ranging from an 8.6% increase for start-up amperage to a 7.1% increase for full-load amperage. This is likely to the higher density and greater viscosity of B20 bioheat and does not negatively affect system performance.
- **Cadmium sulfide flame detector resistance** increases substantially with B20 bioheat usage, with increased resistance values as high as 40.6%. The flame produced from B20 bioheat is known to have reduced luminosity and is therefore less easily detectable by a conventional cad cell. Typical commercially available cad cell primary controls are designed to detect the flame produced from No. 2 fuel oil. Fuel technicians and users of B20 bioheat should be aware that higher cad cell resistances can sometimes lead to "nuisance tripping" of the burner. However, no such behavior was observed in the 26 test units included in this study.
- **Breech draft** values decrease slightly with the use of B20 bioheat, with draft values decreasing as much as 7.1%. This is likely an indicator of seasonal build-

up of soot and scale on the heat exchanger and is an additional factor in reduced combustion efficiency values.

- **CO_2 emission levels** decrease an average of 3 to 4 percentage points with B20 bioheat usage. This is likely a function of variation in fuel chemistry. Combustion efficiency has a direct relationship with CO_2 emission levels: the higher the CO_2 levels, the higher the combustion efficiency. Since B20 bioheat contains lower hydrocarbon levels than No. 2 fuel oil, CO_2 emissions levels decrease when B20 bioheat is burned, which results in an apparent reduction in combustion efficiency. Specialized combustion test equipment is available to compensate for this variation in fuel chemistry, though this equipment was not used in this testing program.
- **Net stack temperatures** increase as much as 9% when B20 bioheat is used. Again, this effect may be attributed to soot and scale build-up on the heat exchanger as the heating season progressed.

6.2 Recommendations for Use

- **Early-season system inspection and tuning**: In order to ensure that the above parameter changes do not negatively affect impact system performance, it is clear that a *qualified oilheat technician should perform a thorough system inspection, cleaning, and tuning prior to the introduction of B20 bioheat to any residential-scale system. It is especially critical that the burner's fuel/air mixture is adjusted to a level appropriate to the fuel being used.*
- **Fuel solvency**: B20 bioheat is known to have greater detergent characteristics than No. 2 fuel oil. The increased solvency of B20 bioheat can result in residue from storage tanks and fuel lines becoming dislodged and clogging fuel filters in the few weeks following the introduction of B20 bioheat to the system. *Although there were no reports of filter clogging during this study program, it is recommended that system behavior and fuel filters specifically be closely monitored in the six weeks following the introduction of B20 bioheat. Replacement fuel filters should be readily available.*
- **Non-metallic materials**: Krishna's 2001 study outlines another issue associated with the use of B20 bioheat: "One of the concerns in using biodiesel in existing equipment, primarily diesel engines, has been the effect it might have on non-metallic materials that come in contact with it."[20] For instance, questions have been raised about the effect of biodiesel blends on heating system components made from vinyl, vinyl/PVC blends, and neoprene. This study did not address this issue, though it has been raised in other studies. *Again, it is therefore important that a thorough system inspection by a qualified technician (preferably one familiar with bioheat blends) be conducted prior to the introduction of B20 bioheat to any heating system.*

[20] C.R. Krishna, *Biodiesel Blends in Space Heating Equipment,* December 2001, BNL-68852, p. 11.

- **Cold weather storage**: Finally, the addition of 20% biodiesel to No. 2 fuel oil alters the cold flow characteristics of the blended fuel by raising cloud point and pour point.[21] *Users of bioheat blends should be aware of cold weather issues associated with B20 bioheat, particularly as they relate to fuel storage in tanks that are not indoors, underground, or in some other way insulated from cold temperatures.*

6.3 Recommendations for Further Research

The Vermont Bioheat Program findings suggest several areas for further study with regard to B20 bioheat and other bioheat blends in residential oil heating applications:

1. **Multi-season testing**. Only limited conclusions can be derived from one heating season's worth of data. We recommend that a multi-season study of the effects of B20 bioheat be undertaken so as to produce a better understanding of the long-term benefits and challenges of using B20 bioheat in residential heating applications. As part of this multi-season testing, we strongly recommend (1) that the introduction of B20 bioheat into test systems occur early in the heating season, so as to properly isolate the impact of seasonal soot and scale build-up on system heat exchangers; and (2) specialized combustion test equipment able to compensate for lower hydrocarbon levels contained in B20 bioheat be used when measuring CO_2 emission levels and combustion efficiency values.
2. **Cad cell testing**. Results from this study and other sources indicate that flame detection can pose a potential challenge when B20 bioheat is used. To isolate this issue, we recommend a literature search and study be conducted that examines the use of a range of bioheat blends against the performance of cad cells and other flame detection strategies.
3. **Materials testing**. As noted above, some materials traditionally used in oilheat systems have been found to react negatively when exposed to bioheat blends. We recommend a literature search and study that addresses the behavior of all appropriate materials when subjected to short- and long-term exposure to a full range of bioheat blends.
4. **Fuel stability testing**. A 1998 study concluded that biodiesel is less stable than petroleum diesel.[22] An important objective of the Vermont Bioheat Program study was to gain a greater understanding of the stability of B20 bioheat in comparison to No. 2 fuel oil. Samples were prepared and subjected to varying environmental conditions, but due to limited time and resources, chemical analyses of the samples was not possible. Because of the implications of long-term fuel storage in residential home heating, we recommend that the fuel stability study component of this study be completed and results disseminated.

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[21] U.S. Dept. of Energy, *2004 Biodiesel Handling and Use Guidelines*, DOE/GO-102004-1999 (rev. 11/04), p. 31.

[22] Michael S.Graboski and Robert L.McCormick, *Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines*, Prog. Energy Combust. Sci., Vol. 24, pp. 125-164 , 1998.

7.0 APPENDIX A

<u>Vermont Bioheat Program Testing Criteria</u>

<u>Live-fire equipment testing</u>

<u>Testing restrictions:</u> Units to be tested in live fire conditions must start with new oil filters, nozzles and pump strainers. Samples of fuels must be taken and kept in dark storage (in glass Jars) for evaluation by others after testing ends.

Documentation on type of burner tested to include:
1. Burner Brand
2. Model & Serial Numbers
3. Type of heating appliance tested in….Brand & Configuration
4. Furnace Style…lowboy, highboy..etc
5. Boiler style….hot water, steam, dry or wet base
6. Unit model & serial numbers
7. Type of fuel used for Test
8. Nozzle size, pattern and spray angle and Brand
9. Oil pump brand and model

<u>Individual Unit Testing</u>

<u>Test #1:</u> Test unit will be fired with #2 fuel and the following data recorded:
1. Start up amperage
2. Running amperage
3. Operating voltage
4. Efficiency test measurements, preferably 80% or better
5. Running oil pressure
6. Running oil vacuum
7. Resistance reading on cad cell with fire @ 100psi pump pressure
8. Resistance reading on cad cell with fire @ 140psi pump pressure
9. Pump cut-off pressure setting check @ 100 psi pump pressure
10. Remove pump strainer at end of test; clean and reinstall

<u>Test #2:</u> Test unit used for test #1 will be fired with B20 Biofuel and the same data recorded:
1. Start up amperage
2. Running amperage
3. Operating voltage
4. Efficiency test measurements, preferably 80% or better
5. Running oil pressure
6. Running oil suction pressure
7. Resistance reading on cad cell with fire @ 100psi pump pressure
8. Resistance reading on cad cell with fire @ 140psi pump pressure
9. Pump cut-off pressure setting check @ 100 psi pump pressure

10. Inspect inside of pump and pump strainer for unusual deposits and remove and save if there are any (for evaluation by others).

Parallel or Simultaneous Testing

Testing restrictions: units tested must be similar in style and construction. Burners must be identical. Oil pump strainers and system filters must be clean at start of testing. For ease and continuity of testing, suction and pressure gauges will be installed on oil pump ports. All test measurement equipment to be used in testing will be documented and used for both units.

Documentation on type of burner tested to include:

1. Burner Brand
2. Model & Serial Numbers
3. Type of heating appliance tested in….Brand & Configuration
4. Furnace Style…lowboy, highboy..etc
5. Boiler style….hot water, steam, dry or wet base
6. Unit model & serial numbers
7. Type of fuel used for Test
8. Nozzle size, pattern and spray angle and Brand
9. oil pump brand and model

Testing Parameters

1. Start up amperage
2. Running amperage
3. Operating voltage
4. Efficiency test measurements, preferably 80% or better
5. Running oil pressure
6. Running oil suction pressure
7. Resistance reading on cad cell with fire @ 100psi pump pressure
8. Resistance reading on cad cell with fire @ 140psi pump pressure
9. Pump cut-off pressure setting check @ 100 psi pump pressure
10. Remove pump strainer and inspect, if any gumming or sludge; save

Individual Component testing

It would be advantageous if oil pumps could be tested individually for long-term affects of running biofuels. If Suntec, Danfoss and Reillo testing could be afforded it would be of great value. If possible test a unit running on a one-pipe configuration and one running on a two-pipe configuration and compare results

Testing criteria and documentation would be as follow:

Regardless of brand tested:

1. Start testing with a new pump

2. Document whether single or 2 pipe
3. Run steady testing with a closed loop to see if filter/strainers are affected
4. Run at either 100 or 140 psi and document findings
5. Check motor amperages for differences in either start-up or running performance
6. If possible use both ISIR and PSC motor types
7. Note any deviations in pressure weekly or daily

Fuel Testing

Place vented steel storage cans with equal amounts (half full) of 2 different test fuels outdoors (one can with No2 oil and the other can with B20) and leave until mid-April, 2006 for retrieval and stringent chemical analysis to be done by others.