

Department of Buildings and General Services
Vermont Biodiesel Pilot Project:
Emissions Testing of Biodiesel Blends With #6 Fuel Oil
At the
Waterbury State Office Complex



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October 2005 through April 2006

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Executive Summary:

Both Governor Jim Douglas and Lt. Governor Brian Dubie support the use of renewable energy resources including biodiesel. The Governor has actively pursued the reduction of greenhouse gases within state government via Climate Change Action Plan. To help meet this mandate, BGS began exploring the use of biodiesel, by using it blended with #2 fuel oil in the Brattleboro State Office Building, and blended with diesel fuel in a diesel tractor in Montpelier.

The State of Vermont uses significant amounts of heating fuel. For example, in FY03 the state consumed 170,000 gallons of #2 heating oil statewide. In addition, the state used 250,000 gallons of #6 heating oil Montpelier and 300,000 gallons of #6 heating oil in Waterbury at the central heat plants.

Logistically if the State wished to expand its use of biodiesel, it seems simpler to use biodiesel blends in either Montpelier or Waterbury rather than try to coordinate up to 17 different fuel vendors in over 300 buildings statewide. So BGS examined the possibility of blending biodiesel with #6 fuel oil, and burning it in large institutional boilers. Unfortunately while there is a large amount of published data on the use of biodiesel in #2 fuel oil for use in oil fired equipment, there was no known data on blending biodiesel with #6 fuel oil.

BGS embarked on a test to see if biodiesel would blend with #6 fuel oil, if the blended oils could be burned in large institutional boilers, and if the emissions levels of the products of combustion changed. The tests examined the base case of straight #6 fuel oil, compared to blends of 5%, 10% and 20% biodiesel in #6 fuel oil. The testing took place in February 2006.

The results indicate that:

- Biodiesel mixes readily with #6 fuel oil. At room temperature it blends, by itself, in a matter of days. Heated and agitated it blends in hours. There was no evidence of product separation after blending.
- Blends of biodiesel and #6 fuel oil burn without modification to either boiler or burner.
- Blends of biodiesel and #6 fuel oil have lower SO_x, NO_x and CO emissions rates than straight #6 fuel oil.

The Vermont Biodiesel Pilot Project conducted by the BGS demonstrated the viability of using biodiesel mixed with #6 fuel oil in institutional boilers. The equipment showed no operational issues and functioned without any noticeable problems that could be attributed to biodiesel. The benefits of using biodiesel mixed with #6 fuel oil include easier measurement of fuel in tanks, easier routine cleaning of the burners and strainers, lower emissions, lower demand for imported oil, and reduction of fossil CO₂ emitted.

The downside to burning biodiesel blended with #6 fuel oil is the current cost of the biodiesel, which is approximately twice the price of #6 fuel oil per gallon. As a result the annual fuel cost would increase by 5% to 20% as the blend goes from B5 to B20.

Biodiesel is made from renewable resources, and reduces the amount of greenhouse gases being released into the atmosphere.

Gallon for gallon biodiesel currently costs more than #6 oil, but is produced in the US, thus reducing foreign importation of fossil oil. Biodiesel could be made locally, thus increasing jobs and the benefiting the regional economy. Local production could potentially reduce the cost of biodiesel.

Background:

In 2004, the Department of Buildings and General Services (BGS) joined with the Department of Public Service (DPS), Vt. Sustainable Jobs Fund (VSJF), Vermont Biofuels Association, Vermont Fuel Dealers Association, and the Agency of Natural Resources to implement the Vermont Biodiesel Project (VBP). The purpose of the Vermont Biodiesel Project is to help build the market for biodiesel in Vermont through education and pilot projects. With funding granted from the U.S. Department of Energy State Energy Program through DPS, BGS agreed to undertake a pilot project to help the state learn more about the performance and emissions characteristics of biodiesel under controlled conditions.

Both Governor Jim Douglas and Lt. Governor Brian Dubie support the use of renewable energy resources including biodiesel. The Governor has actively pursued the reduction of greenhouse gases within state government via Climate Change Action Plan, which states that the State of Vermont will reduce its production of greenhouse gas emissions 20 percent by 2012 when compared to 1990. He also signed Vermont onto the Regional Greenhouse Gas Initiative by the Northeast Governors and Eastern Canadian Premiers.

Combustion of fossil fuels causes an increase in the amount of CO₂ which is present in the atmosphere. CO₂ in the atmosphere appears to cause a rise in the overall temperature of the planet. This is because the CO₂ allows the radiation of the sun to enter, but not escape, much as a greenhouse does, that is why it is referred to as a “Greenhouse Gas”. Each gallon of #2 fuel oil that is burned releases 21.95 pounds of CO₂, and each gallon of #6 fuel oil that is burned releases 25.22 pounds of CO₂.

Combustion of renewable fuels also release CO₂, however this carbon has been drawn from the atmosphere during the growing of plants. Biodiesel is made from a combination of vegetable oil and methanol. The predominate sources of vegetable oil are currently soy beans and canola. The plants absorb CO₂, and release oxygen, while they grow. When burning biodiesel, the carbon in the fuel recombines with the oxygen in the atmosphere, and CO₂ is released. The same CO₂ that caused the plants to grow in the first place, thus a closed cycle where there is no net increase in the amount of CO₂ in the atmosphere. In actuality, there is still a small net increase in CO₂ (4.39 pounds of CO₂ per gallon) because the methanol, which is used in the production of biodiesel is made from methane. And the predominant sources of methane are currently coal and natural gas, but there is still an 80% reduction in fossil CO₂ compared to #2 fuel oil.

To help meet this mandate, and gain familiarity with the use of biodiesel, BGS has been using a B20 blend (20% biodiesel, 80% fossil fuel) of biodiesel in #2 fuel oil in the Brattleboro State Office Building for the past two heating seasons. BGS has also been using B20 in a small diesel tractor at the Montpelier State Office Complex. Among other state institutions using biodiesel, the Agency of Transportation has experimented with B20 in their diesel truck fleet. These activities provided initial levels of experience with the fuel in state facilities and equipment.

The State of Vermont uses significant amounts of heating fuel. In FY03 the State used 170,000 gallons of #2 heating oil statewide in some 300 buildings. 250,000 gallons of #6 fuel oil were used in Montpelier and 300,000 gallons of #6 fuel oil were used in Waterbury. The average fuel use over the past 11 years has been 276,993 gallons of #6 fuel oil in Montpelier and 261,993 gallons of #6 fuel oil in Waterbury.

Expanding the use of biodiesel in the state requires a well crafted, efficient strategy. At the beginning of the project, few fuel dealers supplied biodiesel to their customers. Since BGS manages facilities for the state, a decision to introduce biodiesel product in blends with #2 heating oil would require delivery of small batches at some of the 300 buildings statewide and coordination with up to 17 fuel vendors. The alternative would entail more significant biodiesel use at either the Montpelier complex, Waterbury complex, or both. Logistically, BGS determined that it would be easier to obtain fewer deliveries at one or two sites compared to multiple sites throughout the state. Under the direction of facilities engineer and project manager Teigh Southworth, BGS decided to conduct its initial larger scale tests at the Waterbury complex.

While there much published data about biodiesel blends with diesel and #2 oil, there is little published data on biodiesel blends using #6 fuel oil. The popular consensus is that it should work in large institutional boilers, but the state could find no evidence of anyone having tested it before.

For each gallon of #6 fuel oil that is replaced with biodiesel there is a reduction of 20.83 pounds of CO₂ being released to the atmosphere from fossil deposits. So if a 10% blend of biodiesel were used at the Waterbury State Office Complex alone there would be a 273 ton reduction in annual fossil CO₂ emissions.

Site Selection: The Waterbury State Office Complex:

The powerhouse at the Waterbury State Office Complex provides steam for approximately 600,000 SF of buildings at the complex. The steam is used for space heating, domestic hot water production, in autoclaves in the laboratories, and in the kitchen for cooking.

The powerhouse contains four boilers: Two #6 fuel oil fired B&W, 600 BHP, watertube boilers; a 400 BHP, woodchip fired, IBC, firetube boiler; and a 125 BHP, #2 oil fired, Hurst scotch marine summer boiler. There are two 20,000 underground fuel tanks with a redundant fuel delivery system to the two B&W boilers.



Waterbury State Office Complex

Jar Test:

One concern BGS staff had was how readily biodiesel would mix with #6 fuel oil. To test this: A half gallon of room temperature #6 fuel oil was placed in a one gallon glass mayonnaise jar, and then about 13 oz. of biodiesel (20% by volume) was carefully placed on the top of the fuel oil. The two products

are quite distinguishable at this point, the #6 fuel oil is a viscous black substance, while the biodiesel is a clear liquid with a golden hue. The jar was carefully set on a shelf in the boiler room and left for a period of time to be observed. The next day there was some gray streaking showing down into the #6 fuel oil at the sides of the jar, with a layer of biodiesel still sitting on top of the #6 fuel oil. Within three days the biodiesel layer was completely gone from view. At approximately two weeks, and there was no evidence of a biodiesel layer either on the top surface, or at the bottom of the jar, and the grey streaks were no longer visible. At that point the jar was vigorously shaken and placed back on the shelf for observation. No visible separation ever took place. Even after six months there was no separation of the fuels. It has been concluded that biodiesel and #6 fuel oil will basically blend themselves at room temperature. This provided the assurance that for testing, biodiesel could be added to the #6 fuel oil in the tank, and because fuel is continuously being circulated from the tank to the fuel heaters and back to the tank, the mechanical agitation would assure adequate blending of the fuels.

Testing Methodology:

To determine the viability of using biodiesel blends with #6 fuel oil, BGS embarked on a test this past winter. Staff had originally planned on testing the boiler at full capacity, but the temperature needs to be below 0° F to get enough load for one boiler to fire at full capacity long enough for testing to take place. Unfortunately the 2006 winter did not cooperate. The staff regrouped and tested the boiler at 50% capacity instead, so that all tests could be run at the same firing rate.

All the emission tests were performed on boiler #2, one of the B&W boilers. The testing entailed measuring emissions on straight (100 %) #6 fuel oil to establish the baseline on February 7th, 2006. The #6 fuel oil in the storage tank was then diluted to a 5% blend of biodiesel (B5) on February 10th. The fuel mix was then used in the boilers for three days to ensure thorough mixing had taken place, then the stack emissions from the boiler were tested. BGS increased the biodiesel in the storage tank to a B10 blend on February 15th, and tested the emissions from this blend February 18th. Staff made the final dilution on February 21st, and the final emissions test was performed on February 28th. BGS received deliveries of #6 fuel oil during the testing period, because the boilers were operating to provide steam to the complex. To ensure the correct dilution at all times, staff coordinated the delivery and blending of biodiesel with the deliveries of #6 fuel oil.

BGS sent fuel samples from each of the four dilutions (B0, B5, B10 and B20) to Saybolt Labs for analysis. This baseline data was needed for the final emissions report by Air Quality Testing Services, the contractor selected to conduct the emissions tests.



AQTS Test Trailer in the Powerhouse

Emissions Test Results:

The results of the emissions tests are as follows, and paralleled the published data for blends of #2 oil and biodiesel fired in boilers:

Summary of Test Results on #6 fuel oil and Biodiesel Blends

Saybolt Labs test results:

Test	Method	#6 Oil Result	B5 Result	B10 Result	B20 Result	Units
Gravity °API @ 60°F	ASTM D-4052	12.4	12.4	14	15.6 @ 60 °F	
Sulfur	ASTM D-4294	1.83	1.86	1.64	1.5 Wt%	
Viscosity, Kin @ 122.0°	ASTM D-445	416.6	273.8	164.9	81.23 cSt	
Viscosity, SFS @ 122.0	ASTM D-2161	196.8	129.5	78.5	40.1 Sec	
Nitrogen	ASTM D-5762	3402	3531	2881	2795 ppm	
B.T.U. Value (Gross)	ASTM D-240	18333	18259	18353	18223 Btu/lb	
B.T.U. Value (Gross)	ASTM D-240	150129	149523	148641	145984 Btu/gal	
Ultimate Analysis						
	Carbon ASTM D-5291	86.88	86.28	86.09	85.06 Wt%	
	Hydrogen ASTM D-5291	10.58	10.5	10.31	10.64 Wt%	
	Oxygen calc.	0.36	1.05	1.76	2.47 Wt%	

Air Quality Testing Services Emissions Tests Results:

O2	13.5	10.9	11.8	10.4 %
CO2	5.8	7.7	7.0	8.0 %
NOx	126.9	134.9	122.9	124.5 ppm
Fd Emission Rate	0.403	0.314	0.313	0.274 #/MMBtu
CO	329.6	139.1	160.9	122.8 ppm
Bias Adjusted	304.7	114.2	135.8	97.9 ppm
Fd Emission Rate	0.594	0.163	0.212	0.132 #/MMBtu
SO2	383.1	484.2	472.9	509.4 ppm
Fd Emission Rate	1.691	1.568	1.672	1.557 #/MMBtu

The principle reaction taking place during combustion is the conversion of carbon to carbon dioxide in the presence of oxygen. Incomplete combustion results in the formation of carbon monoxide (CO). With oxygen bound in the fuel composition, biodiesel is an oxygenated fuel. The Saybolt lab results confirm this by showing an increase in the level of oxygen in the fuel blends from 0.36 percent by weight to 2.47 percent as the amount of biodiesel increases from straight #6 fuel oil to B20 (see Oxygen Calculation).

Because more oxygen is present as the ratio of biodiesel increases, more complete combustion takes place, thus reducing the carbon monoxide levels from 329.6 ppm to 112.8 ppm with a corresponding increase in CO2 from 5.8 percent to 8.0 percent. While both CO and carbon dioxide are “greenhouse

gases” the amount of carbon released from fossil sources decreased as the concentration of biodiesel increased because biodiesel carbon derives from a renewable source. Carbon monoxide is regulated under the Clean Air Act as a criteria air pollutant and thus any decrease in its production is desirable.

Other emissions, generated during combustion, studied in this test include NO_x and SO₂. Nitrogen oxides (NO_x) form as a combustion byproduct in the presence of nitrogen in the air and fuel. Sulfur dioxide (SO₂) forms when sulfur in the fuel combines with oxygen.

The raw emissions levels show that NO_x levels go up and down as the concentration of biodiesel increases, not trending either way. NO_x levels do show a correlation with the amount of nitrogen in the fuel as analyzed by Saybolt Labs. The NO_x emissions rate per Btu shows a consistent decrease as the concentration of biodiesel increases.

The SO₂ levels appear to increase when examining the raw emissions, which is counter intuitive, especially when examining the Saybolt Lab results. These tests clearly show that the sulfur content of the fuel drops as the concentration of biodiesel increases, while the emissions rate per Btu show no clear trend. What could account for this discrepancy? Two possible explanations: Increased fuel consumption, and conversion of sulfur in unburned fuel to SO₂. It is possible that both may be contributing factors.

Increased fuel consumption : The fuel valve is a notched plug valve. As the valve opens, the size of the notch increases. The tests were performed with the fuel valve set at a constant 50 percent open for all tests. The Saybolt Lab results showed that as the concentration of biodiesel increases, the viscosity of the fuel decreases. It is likely that the amount of fuel passing the fuel valve in a given period of time increases as the viscosity drops. The likelihood is

Boiler during test run

quite high since it was observed, but not recorded, that the fuel pressure at the burner nozzle increased as the concentration of biodiesel increased. It is possible that as the concentration of biodiesel increases, the boilers may burn more fuel per test, but this was not measured.

Conversion of Sulfur in unburned fuel to SO₂: During the combustion of #6 fuel oil, smoke emissions are visible exiting the chimney. This is most likely unburned fuel. It was observed, but not measured or documented, that the visible emissions from the chimney appeared to decrease as the concentration of biodiesel increased. It is possible that the less viscous fuel atomizes better at the burner nozzle thereby creating smaller droplets which burn more completely, or that the presence of oxygen in the fuel mixture leads to more complete combustion. Thus more complete combustion causes less sulfur going up the stack as particulates with a resulting increase in SO₂. Further testing would be needed to clarify what is happening.

Either way, there is less sulfur per gallon of blended fuel, which yields less sulfur being released to the atmosphere for every gallon of blended fuel burned.

Procedural response:

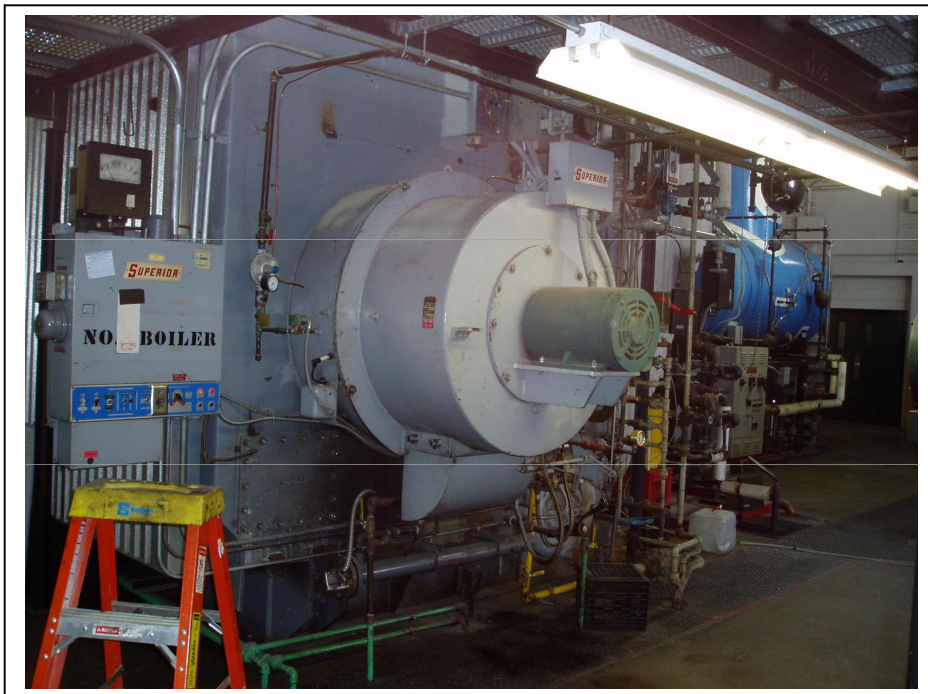
AQTS observed in the initial baseline test (of three test runs) that as the end of the test approached, the results seemed to drift away from the steady readings comprising the majority of the results. It is surmised that because the fuel valve was set at a fixed position and not allowed to modulate, possibly

some paraffin in the fuel oil was building up in the notch of the fuel valve, reducing the amount of oil passing the fuel valve causing the fire to lean out.

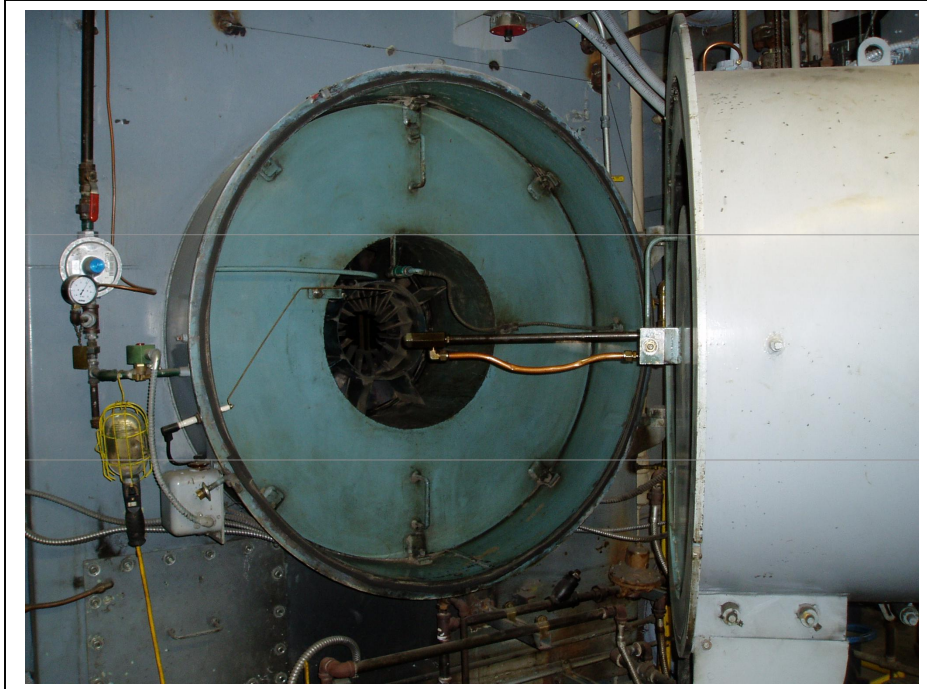
So for each successive test run of all four concentration, as soon as AQTS was ready for a test, the fuel valve was fully opened to allow a full flow of oil to purge the valve, then the valve was closed to halfway and the test conducted.

Observations:

During normal operation the burner needs to be cleaned every 3 to 5 days to remove baked on oil residue. For each day of testing, the condition of the burner and the inside of the boiler was photographed. The burner was then cleaned, and testing commenced.



Boiler, with burner closed



Boiler, burner open,
showing nozzle



Air shutter, in place
inside burner

Air Shutter with Oil Deposits:



Between the 2/3/06 cleaning and the 2/7/06 cleaning, the burner had operated 26.8 hours and burned 720 gallons of straight #6 fuel oil (B0).



Between the 2/7/06 cleaning and the 2/13/06 cleaning, the burner operated 126 hours and burned 3030 gallons of B5.



Between the 2/13/06 cleaning and the 2/17/06 cleaning, the burner operated 100 hours and burned 4990 gallons of B10.



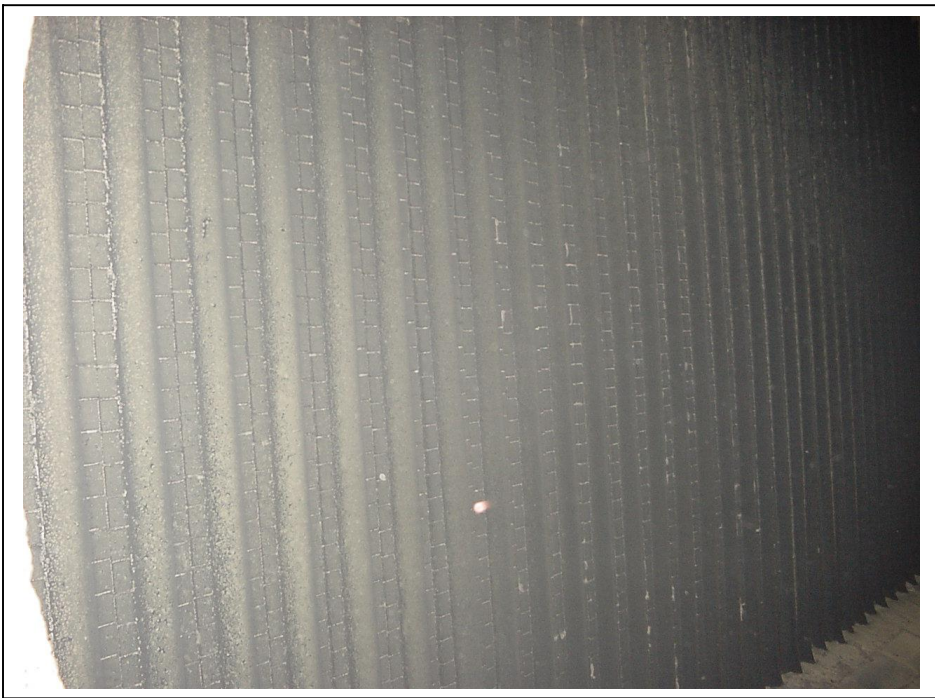
Between the 2/17/06 cleaning and the 2/24/06 cleaning, the burner operated 121 hours and burned 5693 gallons of B20.

Notice as the concentration of biodiesel increases, the amount of deposits decreases even though more oil is burned, and the deposits become drier and less gummy, making it easier to clean them off.

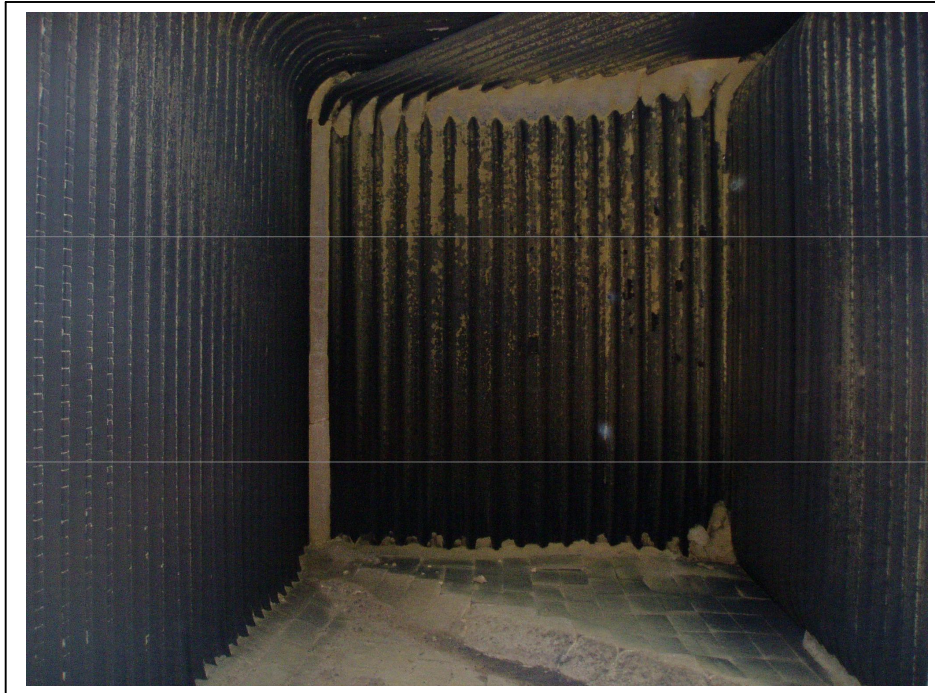
Inside of Boiler:



Prior to the baseline testing on 2/7/06, the boiler had been in operation since October and had burned 49,627 gallons of #6 fuel oil. Notice the grey ash over the baked on oil deposits.

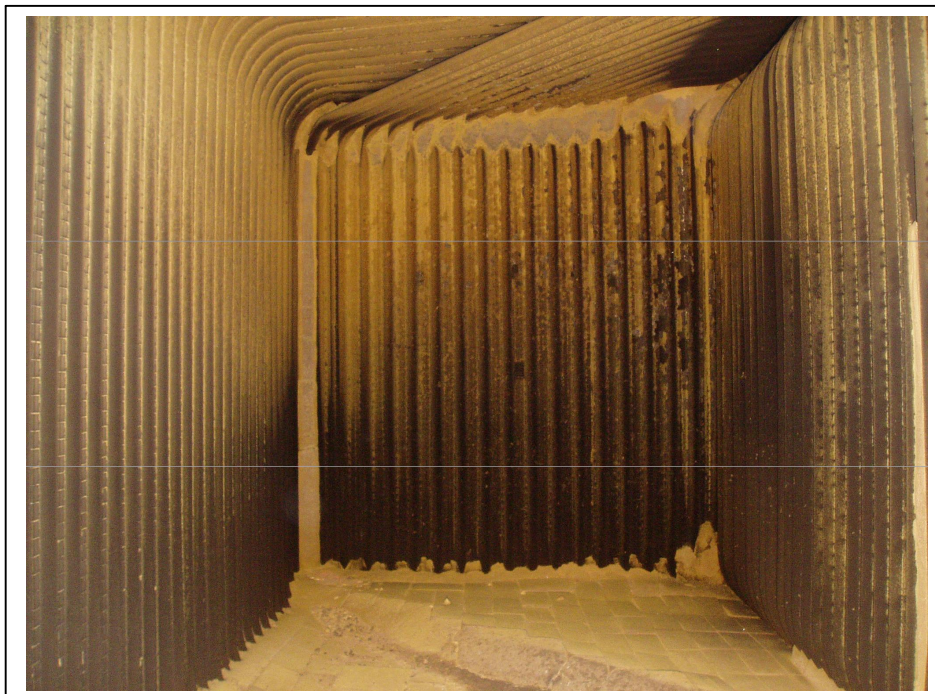


Left wall of boiler after 6 days of operation consuming 3030 gallons of B5.



After 4 days of operation consumed 4990 gallons of B10.

Note that the gray ash and some of the black oil deposits are gone.



After 7 days operation on 5693 gallons of B20. No ash, and much of the black oil deposits are gone as well

Anecdotal observations:

While not a part of the data collected during testing, staff made the following observations during the testing:

- Approximately 2 hours after the first load of biodiesel was added to the underground fuel tank, the suction pressure at the main fuel transfer pump went down noticeably.
- When sticking the underground fuel tank to measure the volume of fuel in the tank, the measuring stick was much easier to push to the bottom of the tank, and the fuel wiped off the stick more easily as the concentration of biodiesel increased.
- Fuel strainers, which normally get cleaned when the burner is cleaned, were much easier to clean. In fact, the basket strainers on the main fuel transfer pumps did not need to be cleaned the entire month of testing. So while the strainers will still need to be cleaned, the addition of biodiesel will make the strainers easier to clean, and may reduce the frequency of cleaning required.
- The visible haze from the stack appeared to decrease as the biodiesel concentration increased.
- Baked on oil deposits on the burner appear drier, less oily, and come off easier as the biodiesel concentration increased. So while the burners still need to be cleaned, the addition of biodiesel will make them easier to clean, and may reduce the frequency of cleaning required.
- Deposits inside the firebox decreased. In fact, much of the winters accumulation of soot and ash were burned off. Fewer residues inside the boiler means there is less insulating material on the heat transfer surfaces, meaning more heat will transfer to the water making the boiler operation more efficient.
- Burner nozzle pressure appears to increase as concentration of biodiesel increases for a given burner setting. This may indicate an increase in fuel consumption, at a given fuel valve setting, caused by lower viscosity of the fuel flowing through the fixed metering port. When a blend is decided upon, the boiler should be “tuned” to the viscosity of the blend to obtain the correct air-to-fuel ratio. It may also indicate that bio blends can be heated to a lower temperature, thus reducing the energy which currently is radiated off the fuel oil piping and from the fuel tank into the ground.
- Fuel in the underground tank appears to heat up faster. This may be because the less viscous oil pumps easier, thus increasing the amount of oil which is passed through the oil heaters per hour. This could translate into lower pumping costs.
- During the baseline testing the filter in the sampling line had to be changed after each one hour test run to prevent clogging the filter. However when testing biodiesel blends, three one hour tests were run per filter with no clogging, and it appeared that the amount of deposits on the filter media decreased as the concentration of biodiesel was increased.

Recommendations For Future Testing:

With a limited budget available for this battery of emissions tests, BGS focused on a core set of pollutants. During the course of the project, several questions emerged pointing to the need for additional testing.

- Repeat the tests, but monitor the quantity of fuel consumed during each test, the amount of steam produced during each test, and the temperature of the stack emissions. It is highly possible that as the viscosity of the fuel blends decreases, there is an actual increase in the amount of fuel burned at the same fuel valve setting. This may explain why emissions levels didn't vary as much as anticipated, because more fuel was consumed as the viscosity decreased. It would also give an indication of the efficiency of the combustion and transfer of heat to the steam.
- Repeat the tests and measure particulate emissions to see if in fact the fuel is more completely combusted, and determine if that is why SO₂ levels do not decrease at the same rate as the sulfur in the fuel.
- Repeat the tests and monitor the opacity of the stack emissions to see if there is a measurable change.
- Conduct a long term test to observe the effects of the blended fuel on fuel system components, and what the long term effects are on firebox cleanliness. Less soot buildup within the boiler should result in higher heat transfer rates because soot acts as an insulator on the walls of the boiler.

Regulatory Issues:

Based upon an initial review of the results of the emissions testing, the Air Pollution Control Division has indicated that they would look favorably on a request to burn blends of up to 20 percent biodiesel and #6 fuel oil in the central heat plants at Waterbury or Montpelier. The existing fuel limits for the facilities would remain the same: the total annual consumption of biodiesel and No. 6 fuel oil combined would need to remain below the existing fuel limit for No. 6 oil.

Conclusion:

The test compared 5%, 10% and 20% blends of biodiesel with straight #6 fuel oil.

Biodiesel mixes readily with #6 fuel oil. At room temperature it blends, by itself, in a matter of days. Heated and agitated it blends in hours.

Blends of biodiesel and #6 fuel oil burned without modifications to either boiler or burner. Although I would recommend fine tuning the burner once a dilution was settled on to maximize efficiency.

Blends of biodiesel and #6 fuel oil have lower SOx, NOx and CO emissions rates than straight #6 fuel oil in institutional boilers.

The Vermont Biodiesel Pilot Project emissions test project conducted by BGS demonstrated the viability of using biodiesel mixed with #6 fuel oil in institutional boilers. The equipment showed no operational issues and functioned without any noticeable problems that could be attributed to biodiesel. The benefits of using biodiesel mixed with #6 fuel oil include easier measurement of fuel in tanks, easier routine cleaning of the burners and strainers, lower emissions, lower demand for imported oil, and reduction of fossil CO₂ emitted.

The downside to burning biodiesel blended with #6 fuel oil is cost of the biodiesel, which is currently approximately twice the price of #6 fuel oil per gallon, delivered. As a result the annual fuel cost would increase by 5% to 20% as the blend goes from B5 to B20.

Gallon for gallon biodiesel currently costs more than 6 oil, but is produced in the US, thus reducing foreign importation, and could be made locally, thus increasing jobs and benefiting the regional economy. Local production would potentially reduce the cost of biodiesel by reducing the cost of transportation of the fuel.

Biodiesel is made from renewable resources, and reduces the amount of greenhouse gases being released into the atmosphere. Commercially available biodiesel is made of a blend of 80% vegetable oil (renewable resource, GHG neutral) and 20% methanol, commercially made from coal or natural gas. So 80% of the oil it displaces is GHG neutral.