Fuel from the Field to the Flue: Grass fueled heating equipment combustion optimization project.

By Christopher W. Davis

VERMONT NRCS CONSERVATION INNOVATION GRANT

Final Project Report – March 24, 2017

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Grantee Entity Name: Meach Cove Real Estate Trust	
Project Title: Fuel from the Field to the Flue: Grass pellet heating equipment combustion optimization project.	
Agreement Number: 69-1644-11-08	
Project Director: Christopher W. Davis	
Contact Information	Phone Number: (802) 985-9218 E-Mail: cdavis@meachcovefarms.org
Period Covered by this Report: October 11, 2011 – December 31, 2015	
Project End Date: 9/20/2015	

Deliverables

1. Publish a final report available in printed, electronic and video formats which will summarize the information collected as a result of this project.

   The report will contain the operational data for one hot water boiler and one hot air furnace both capable of burning pelletized grass fuel.

   The report will contain published results of the combustion testing of several promising species of pelletized grass fuel in this heating equipment.

   Provide a detailed summary and diagrams of any modifications or adjustments made to the two types of heating equipment to optimize the combustion of up to four types of pelletized grass fuel in this heating equipment.

2. Hold open houses, field days and tours by appointment to showcase the work being done in this project.

3. The heating units being evaluated as part of this project will be improved to optimize their operation when using more than one species of pelletized grass. The modifications will be detailed and included in the project report.

4. Collaborate with the manufacturers of the two heating units to incorporate modifications that resulted in improved performance into their production designs.

5. Evaluate, analyze and report on the composition, combustion and ash production of up to four species of grass fuels. This information will be useful to farmers who wish to grow grass for use as pelletized fuel for Vermont and the region. The information will also be useful to anyone wishing to make grass pellet fuel.

6. Conduct continued evaluation and provide updates on the heating equipment after the completion of this project. Provide access to the equipment by appointment.

Table of Contents

Table of Figures

Executive Summary

This project identified and evaluated production heating equipment in the 100,000 – 500,000 BTU output range that had features that would support burning grass biomass fuels in a 1/4" pellet or a 2" diameter "puck" size. We learned that the cost to produce a larger format puck was significantly less to produce than a 1/4" diameter pellet (Wilson, 2014) so we searched for boilers that could handle both fuel sizes which would make the boiler more versatile for facility operators.

Our project took longer than anticipated due to the difficulty locating a production boiler in the < 500,000 BTU/Hour size with the features we identified as necessary to effectively handle grass biomass fuel. We requested an extension to the original September, 2013 grant deadline until September, 2014. We experienced additional delays getting the boiler we purchased certified for operation and we were granted an additional extension of the project end date until September, 2015.

The pricing for two biomass heating units (one hot water boiler and one forced hot air furnace) exceeded the available grant funding so we opted to proceed with just one U.S. made hot water boiler rated at 350,000 BTU/Hour. An Evoworld HC 100 Eco wood chip boiler was purchased and installed in a 4,500 square foot building at Meach Cove in January, 2014.

We met all of the goals and objectives for this project by successfully demonstrating that locally grown grass biomass could be burned efficiently, cleanly and cost effectively in a small commercial U.S. built production boiler. We were surprised that even poor quality mulch hay or agricultural crop residue performed as well or better in the Evoworld boiler than some of the perennial grass species that were grown for their potential as a heating fuel. Other farm operators, small commercial business owners or institutions would benefit from the findings in this report should they wish to use a renewable grass biomass fuel to heat their buildings. We also posted this information on the website created for the project, hosted tours, student visits, open houses, and recorded TV and video reports.

State or Federal programs that incentivize maintaining grass cover crops to reduce nutrient run off and promote converting outdated wood or petroleum fuel heating equipment for farm and small industrial operators would benefit from the findings from this project. This project demonstrated that the technology exists to burn grass biomass cleanly and efficiently in a small commercial boiler which had not been the case previously.

We recommend the continued evaluation of grass, biomass and agricultural field residue fuel sources in a variety of forms and sizes in this and similar boilers.

Introduction

This project began in 2011 at Meach Cove by first selecting the most promising grass species and agricultural biomass/field residue sources for fuel, then by growing, harvesting and densifying them, and finally burning them in a small commercial production boiler rated at 350,000 BTU/Hour output. We recorded the emission data while optimizing the boiler's performance on a variety of grass biomass samples.

- Christopher W. Davis, the manager of Meach Cove Farms in Shelburne, Vermont had experience operating biomass heating equipment and was the Project Director. The Project Director assisted with establishing and maintaining the 2008-13 warm season grasses for biomass study plots on the Meach Cove property that were managed by the University of Vermont Extension Service (Bosworth, Kelly 2015). Mr. Davis also assisted with the 2010-11 assessment of grass pellets as boiler fuel that was completed by BERC at the All Souls Interfaith Gathering church in Shelburne, VT (Sherman, 2011).

- Sid Bosworth, a University of Vermont Extension Service Agronomist, was responsible for the grass species test plots research that began in 2008. Meach Cove hosted one of the test plots where a variety of perennial grass species were grown and evaluated for their potential as fuel (Bosworth, Kelly, 2015).

- Christopher W. Callahan, a University of Vermont Extension Service Agricultural Engineer, assisted with the grass and biomass combustion testing and optimization conducted during this project in 2015. The conclusions he reached are summarized in his report (Callahan, 2016) and referenced throughout this report.

- Adam Dantzscher, of South Burlington, Vt., a former partner in Renewable Energy Resources, Inc., represented RER, Inc. in 2013 when they sold the Evoworld HC 100 Eco boiler to Meach Cove. Mr. Dantzscher was contracted to densify the grass and biomass into 2" diameter pucks that were tested in this project. Mr. Dantzscher also assisted with operational issues with the Evoworld boiler throughout this project.

- Dr. Jerry H. Cherney, Cornell University, Department of Crop and Soil Sciences, and Michael J. Newtown, PE, Associate Professor and Dean, Casino School of Engineering Technology, State University of New York, Canton, were consulted throughout this project and their input shaped the focus of the project.

- Louis Okonski, President, Troy Boiler Works, Inc. and Evoworld USA, located in Troy, N.Y., built, installed and supported the Evoworld boiler. Mr. Okonski and his Troy Boiler Works and Evoworld USA team were a critical resource throughout the project.

- Gus Swanson and Jim Trussler of LST Energy, Nova Scotia, Canada, developed a proof of concept boiler that they operated on grass pellets in 2010-11. Their boiler prototype was evaluated by the Nova Scotia Department of Agriculture, Truro, Nova Scotia (Dutta, 2010). Their early success with burning grass pellets in a small commercial boiler provided the inspiration for Meach Cove to seek a USDA-NRCS Conservation Innovation grant to proceed with this project.

- Bob Miller, founder of Enviro Energy in Unadilla, N.Y. (Metz, 2015), densified the Meach Cove harvested biomass into the 1/4" diameter pellets in 2011 that were tested in this project. Without Mr. Miller's production facility we would have been required to develop an alternative method to produce the grass pellets in smaller quantities or only test the 2" diameter puck form.

The goals of this project were to:

1. Identify and evaluate production biomass heating equipment in the 100,000 – 500,000 BTU output range that had features which could handle burning grass biomass fuels in 1/4" diameter pellets and 2" diameter "pucks".

2. Purchase and install a small (< 500,000 BTU/Hour) commercial production biomass boiler with ASME and UL certifications that would handle the unique issues with grass fuel combustion in a 4,500 square foot building at Meach Cove.

3. Operate and adjust the boiler to optimize the combustion process and ash handling for grass biomass fuels in 1/4" diameter pellets and 2" diameter pucks.

4. Collect and analyze emission data obtained from the grass fuel burned in the boiler. Make necessary adjustments to optimize the combustion performance when burning grass biomass and agricultural field residue in two different sizes. Suggest modifications to the boiler to improve performance with these grass biomass fuels.

5. Report on the results and recommendations from this project in a report and by posting them on our website, hosting open houses, tours, student classes, and live and taped segments for the local TV media.

6. Continue to operate, evaluate, and report on a variety of grass biomass fuels and their performance using the boiler after this project is completed.

The project scope included:

- Identifying, harvesting and densifying three different grass species, three diverse examples of local cool season perennial grass blends, and four samples of these grass species blended with wood chips. Testing two different wood pellet blends as a comparison to the grass samples.

- Selecting the Evoworld HC 100 Eco wood chip boiler from over a dozen commercial boilers and installing it in a building at the Meach Cove.

- Developing a testing method that would accurately evaluate the combustion performance, stack emissions, and the ash residue resulting from burning the grasses and biomass blends in the Evoworld boiler.

- Create a website to display the information gathered by this project. Plan and host a series of open houses, presentations, media reports, student classes, and tours to disseminate the information learned from this project.

- Produce a report to summarize our findings and recommendations for follow up research.

- After completing this project, continue to operate the Evoworld boiler on wood and other biomass blends, monitor and report on its performance. Host tours by appointment.

We have already listed the business and academic relationships that facilitated this project. Most significant among them were Sid Bosworth and Christopher Callahan of the University of Vermont Extension Service, and Bob Kort, CIG Program Manager, Energy Coordinator, USDA NRCS. In addition we must acknowledge the support and contributions of the Meach Cove Directors, the Meach Cove staff members Barbara Mercure who was the project Accounting Manager, Gary Marshall, Jack McGuire, Jesse Addis, Richard Lawrence and Denny DeCoff. We are grateful to Gerry and Betty Guillemette who mowed and baled most of the biomass used in this project. Without the hard work and assistance from these individuals and their institutions this project could not have been completed.

The project was funded by Meach Cove and the USDA NRCS CIG grant. Meach Cove contributed 63.6 %, or $ 128,341.82 in expenditures or in-kind contributions. The USDA NRCS CIG grant provided 36.4 % or $ 73,400.00 to cover testing, materials and a portion of the installation of the Evoworld HC 100 Eco boiler (Project Budget, page 84).

Project Background

The directors of Meach Cove have been interested in exploring ways to make better use of the natural resources available locally to offset petroleum that is being used on the property for space heating. Being able to economically and dependably burn grass fuel that is raised on this, or other Vermont farms, represents a major step towards identifying another viable renewable biomass fuel source for space heating applications. Data collected in this project demonstrated that grass can be harvested and densified into a 2" diameter puck at a cost that is competitive with the cost of wood pellets and #2 fuel oil (Callahan, 2016).

Research by others showed that grass fuel is a true renewable fuel source containing 90% of the energy content of wood and 70% less greenhouse gas emissions than fossil fuels. This report and previous studies have documented some of the issues and challenges encountered when burning grass fuels in commercially available smaller (<500,000 BTU/Hour) wood heating equipment (Kiraly, 2014, Sherman, 2011; Callahan, 2016).

This project drew from and added to the grass fuel combustion research performed recently by a number of individuals, groups and institutions such as Sherman, 2011, Kiraly, 2014, Wilson, 2014, and Callahan, 2016. When this project began there were many unanswered questions and issues to be resolved from the production of densified grass fuel and how to burn it in small commercial boilers (< 500,000 BTU/Hour). Attempts to burn grass in various forms in these smaller boilers resulted in issues such as clinker formation, high particulate emissions, high ash content and generally poor combustion efficiency (Sherman, 2011, Kiraly, 2014). For these reasons facility operators typically select one of the more reliable and mainstream petroleum fuel heating systems for their space heating needs. Individuals or institutions seeking a more renewable alternative to petroleum fuel have previously only considered selecting wood chip or wood pellet boilers to meet their heating needs.

Prior to learning of the Evoworld HC 100 Eco boiler, we had not identified a small commercial production boiler that had the design features or the combustion control capabilities to effectively deal with the challenges already mentioned when burning grass biomass or agricultural crop residue as a heating fuel.

These essential boiler features include:

1. The ability to store and convey an industry standard 1/4" diameter pellet or a larger size "puck".

2. Having sufficient combustion control capability to maintain the temperature ranges necessary for successful grass combustion. When the combustion temperatures are too hot it can cause ash fusion which results in clinker and slag formation which typically requires manual removal from the combustion chamber. Combustion temperatures that are too cool can result in unburned residue and inefficient

combustion resulting in higher emission gasses, particulates and unburned residue.

3. The ability to automatically remove the high volume of ash (up to 8% of the input volume) that is typical with grass and biomass fuel sources. Because wood pellets or wood chips typically produce ash volumes from 0.3 – 6%, boilers designed to burn wood typically perform poorly on grass and biomass fuel.

4. Designed with the capability to automatically clear clinkers, slag and any residue that may form during combustion.

5. Having stainless steel boiler and flue components where there is contact with the combustion gasses to limit the chance of corrosion of these components due to the high mineral content in some biomass fuels.

6. A boiler manufacturer that is willing to approve the burning of grass biomass in a boiler designed for wood fuel.

This project demonstrated that the technology exists to allow a farm operator, a municipal or government facility, an industrial complex owner, or a facility with a central heating plant to utilize locally sourced grass, biomass or crop residue to efficiently and cost effectively provide space heat. This project could be especially beneficial to farm operators who have the capability to harvest grass or biomass from their own land. These operators could arrange to have this biomass densified for their own use, or they could sell it to others who wish to use biomass for their space heating needs.

This project also demonstrated that grass biomass of a wide variety and quality could perform acceptably as a fuel source in a small size commercial boiler. It was noteworthy that even grass of a quality too poor for animal feed, which is typically found in abandoned pastures and field buffer areas, could be burned cleanly and economically in this boiler. The use of grass biomass harvested from fallow or non-prime crop land represents an additional resource for a farm operator to use for themselves or to sell to others. Having a market for biomass harvested from these buffer strip areas could help to incentivize the practice of establishing grass buffer strips adjacent to drainage ditches or waterways to help with water quality issues. The value of using marginal agricultural lands and buffer strips to reduce nutrient loss and help improve water quality has been well documented (Stutter, 2012, Helmers, 2006). Harvesting a seasonal grass crop for its fuel potential from marginal agricultural lands is an established concept (Bosworth, 2014, Wilson, 2014) but finding production ready heating equipment in a small commercial size that could handle it was an obstacle. This project demonstrates that this practice can provide a source of heating fuel or a marketable commodity for the farm operator.

Based on the combustion data obtained from the locally sourced grass biomass fuels tested in this project there is no negative side to using grass fuel in a properly equipped, adjusted and maintained boiler with the design features described in this report.

Review of Methods

This project was innovative because prior to our identifying the Evoworld HC 100 Eco wood chip boiler, there were few commercial production boilers under 500,000 BTU/Hour that could effectively handle grass biomass fuel and conform to the current U.S. and EPA standards. The Evoworld boilers are manufactured in the U.S., have UL and ASME certification, and they have features that are essential for grass fuel combustion. The Meach Cove insurance underwriter and the State Fire Marshal would not allow any boiler to be operated in a commercial building without those certifications. This project was a unique success because previous attempts to burn grass in wood chip or wood pellet heating equipment had marginal success, while the Evoworld boiler's performance with challenging biomass fuels produced favorable results. The data obtained also indicated that the weedy Agricultural Biomass samples burned more efficiently and cleaner than most of the other 100% grass samples and were comparable to the wood pellets.

Our original CIG application proposed testing both a hot water boiler and a forced hot air furnace. As part of this project we researched small commercial production boilers that might work for grass it became clear that the grant funding would not be enough to purchase more than one heating unit. We decided to purchase just the hot water boiler because the boiler could handle either typical 1/4" diameter pellets or larger 2" diameter "pucks", and the building at Meach Cove where it would be installed was already configured with baseboard hydronic radiation.

The Evoworld HC 100 Eco boiler we chose was unique because the control processor and software allowed us to pre-set ranges for critical operation functions such as fuel feed, air flow, oxygen levels and temperature of the boiler water or flue gas (Figures 3-7, pages 43-46). Because of these innovative and unique features of the Evoworld HC 100 Eco boiler we were able to set ranges which allowed the boiler to operate with all of the biomass fuels we tested. There was a steep learning curve for us while we experimented with the settings typical for wood chips or wood pellets. To meet the goals of this project the project director worked with Christopher Callahan, an agricultural engineer with the University of Vermont Extension Service, and Adam Dantzscher, to identify boiler settings that optimized the combustion of the grasses and biomass blends we tested.

Grass and Biomass Types Tested

Meach Cove has been an active participant in the Grass Energy Partnership since 2008. Meach Cove worked with the University of Vermont Extension Service to establish a perennial energy grass species replicated test plot on the Meach Cove property along with some larger plots of Switchgrass and Reed Canarygrass (Figures 1-2, pages 41-42). Based on the earlier research by Sid Bosworth and Tim Kelly (Bosworth, Kelly, 2015) we selected three perennial energy grass species to test in this project (Cave-N-Rock variety of Switchgrass, Reed Canarygrass, and Giant Miscanthus). We also tested typical "mulch" hay, agricultural crop residue salvaged from abandoned pasture land, and "grass" pellets produced by Enviro Energy, LLC in Wells Bridge, N.Y. We thought it would be useful to retest nine wood and grass blend pellet samples that were originally tested in

2010 by BERC (Sherman, 2011). For comparison we tested one brand of 1/4” diameter 100% softwood pine pellets (Vermont Wood Pellets) and one brand of 50% hardwood / 50% softwood pellets (Energex, Canada).

We grew and harvested the Cave-N-Rock variety of Switchgrass, a native perennial warm season grass that shows promise as a grass energy choice because once it is established it can thrive in a range of soil types and climatic zones and previous research indicated it had a low ash content compared to other perennial grasses (Figure 12, page 49).

We tested Reed Canarygrass because it is a common grass species in the U.S. and it is well adapted to wetter and marginal soils. Reed Canarygrass has a low value for animal feed but it has shown promise as a fuel grass (Bosworth, Kelly 2015).

Giant Miscanthus (miscanthus giganteus) is a warm climate grass that was planted as rhizomes rather than seed in 2010 as part of the UVM Warm Season grass evaluation project (Bosworth, Kelly, 2015). Once we realized that Giant Miscanthus could survive the Vermont climate we felt it was worth testing it along with the other biomass fuel samples because of the limited emission data available on it, and because it is being planted as a land reclamation crop in many parts of the U.S. (Figure 12, page 49).

We felt it was important to test the typical “mulch” quality hay and the coarser and weedier hay harvested from abandoned pasture land that we called “Ag Biomass” because they represent a crop that is not suitable for livestock feed that is widely available throughout the U.S. (Figure 14-15, page 50). Ag Biomass hay is known to cause difficulty when burned in smaller (< 500,000 BTU/Hour) heating equipment due to its higher ash content, and its potential to form clinkers or slag (Kiraly, 2014). Because poor quality Ag Biomass hay is widely available and adapts to all soil conditions we thought it was worth testing in comparison to the cultivated biomass fuel grass species of Switchgrass, Reed Canarygrass, Giant Miscanthus, and the wood pellets.

Sources of the Grass Biomass Tested

The 100% “mulch” hay 1/4” diameter pellets we tested were purchased from Enviro Energy, LLC in Wells Bridge, N.Y. This was mulch quality hay that had been harvested in a late season cut from open land near the Enviro Energy facility. The Enviro Energy facility used a diesel power unit to provide the electricity to run a wood pellet mill and air dryers and their typical production rate was one ton of grass pellets per hour (Figures Figure 22- 24, pages 54-55).

The 100% Reed Canarygrass and Switchgrass pellets that we tested were grown on the Meach Cove property and trucked in 45-65 pound square bales to Enviro Energy where they were pelletized into 50 pound bags (Figure 2, page 42). The blended grass and wood 1/4” diameter pellets were left over samples from the 2010 testing performed by BERC and reported by Adam Sherman in 2011. These pellets were produced from mulch hay grown at Meach Cove and Switchgrass and Reed Canarygrass harvested on the

Borderview Farm in Alburgh, Vermont, and processed into 1/4” diameter pellets at the Vermont Wood Pellet facility in North Clarendon, VT. We thought it would be informative to test these same previously tested samples in the Evoworld HC 100 Eco boiler which we believed was better equipped to handle the combustion issues detailed in the BERC report (Sherman, 2011).

Because the Evoworld HC 100 Eco boiler could handle both a typical 1/4” diameter pellet as well as a larger fuel form, we tested most of these same biomass grass species densified into a 2” diameter puck.

The Switchgrass and Reed Canarygrass used to make these 2” pucks was harvested from the test plot at Meach Cove in 500-700 pound round bales (Figure 2, page 42 and Figure 13, page 49).

The mulch hay and Ag Biomass crop residue was also harvested from areas on the Meach Cove property in 50-70 pound square bales (Figure 2, page 42, Figure 14-15, page 50).

The Giant Miscanthus was harvested in Arkansas and supplied by Adam Dantzscher who manufactured the 2” diameter pucks with a modified BHS “Slugger” machine (Figure 16, page 51). Adam Dantzscher chopped the round and square bales in a tub grinder powered by a tractor PTO, fed the chopped hay into an electric hammer mill and then into the BHS Slugger machine which was also powered by a tractor PTO. The BHS Slugger production of 2” diameter air dried pucks varied from 400-700 pounds per hour depending on the biomass feed source and the moisture content of the materials being densified. These pucks were made in batches weighing 600-700 pounds and they dropped directly from the BHS Slugger drying racks into 48” x 48”x 48” bulk bags which could be moved by forklift or bucket equipped tractor and were stacked three bags high until needed for testing (Figure 18, page 52).

Biomass sample analysis

Once the biomass fuel samples were densified into either the 1/4” pellet or 2” diameter pucks, random samples were obtained from the batches, packaged in 1 gallon Ziploc bags and sent to Twin Ports Testing, Inc. in Superior, Wisconsin for analysis. Twin Ports performed a proximate analysis of the samples to determine their composition by measuring the:

- Moisture Content
- Ash Content
- Volatile Matter
- Fixed Carbon
- Calorific Energy (heating) Value
- Ash Fusion Temperature

Twin Ports also performed an ultimate analysis of the samples to determine the elements in the samples by percentage, weight or volumetric unit which were:

- Carbon
- Hydrogen
- Oxygen
- Nitrogen
- Sulphur
- Chlorine

The data from these reports was summarized in the tables and graphs represented in this report. The compounds and the elements within the samples influence how the biomass performs when it is combusted in a boiler and the results can vary widely as you will see in the Findings section of this report that begins on page 20.

The data we collected compared the combustion and emission data for the grasses and biomass blends we tested with wood pellets, a common and proven biomass fuel source.

The samples tested were:

- 100% Switchgrass (Cane-N-Rock) in 1/4" pellet and 2" puck
- 50% Switchgrass / 50% wood chips in 2" puck
- 100% Giant miscanthus (Miscanthus giganteus) in 2" puck
- 50% Giant miscanthus / 50% wood chips in 2" puck
- 100% Reed Canarygrass in 1/4" pellet and 2" puck
- 100% Enviro Energy mulch hay in 1/4" pellet
- 100% Meach Cove mulch hay in 2" puck
- 50% Meach Cove mulch hay / 50% wood chips in 2" puck
- 100% Ag. Biomass Field Residue in 2" puck
- 100% Reed Canarygrass in1/4" pellet and 2" puck
- 50% Reed Canarygrass / 50% wood chips in 2" puck
- 25%/12%/6% Switchgrass, Reed Canarygrass and Mulch hay in 1/4" pellet
- 100% softwood (pine) Vermont Wood Pellet in 1/4" pellet
- 50% softwood / 50% hardwood (Energex, Canada) in 1/4" pellet

The test samples were weighed into 5 gallon buckets and fed into the chip feed auger on the Evoworld HC 100 Eco boiler (Figure 5, page 45 and Figure 20, page 53). Upper and lower level temperatures in the 550 gallon hot water storage tank and the temperature of the boiler water were recorded before, during and after each test run (Figure 8, page 47). We began each test with a low hot water storage tank temperature to allow the boiler to operate at full load throughout the 60-90 minute duration of the test burn.

Christopher Callahan calculated the gross efficiency of the Evoworld boiler by measuring the temperature change of the boiler water, the storage tank water volume, and the amount of fuel fed into the boiler, measured over a period of time (Callahan, 2016).

To document what was occurring during the combustion of these fuels and to be able to draw comparisons with the data obtained in previous combustion studies with similar grass species we needed to find an easy to use and accurate portable emission analyzers. The minimum combustion parameters we needed to obtain to make adequate comparisons were:

- Combustion input air temperature (F)
- Stack temperature (F)
- Oxygen (O_2)
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Nitrogen Oxide (NO)
- Sulphur Dioxide (SO_2)
- Combustion efficiency
- Percent of exhaust air
- Particulate emissions (Smoke number)

We purchased a Wohler A500 digital combustion analyzer which proved to be durable and accurate during the days of biomass sample testing (Figure 26, page 56). The Wohler analyzer was designed to test petroleum heating equipment. The grass and biomass samples often exceeded the typical operating ranges of the sensors in the Wohler analyzer but it still performed well throughout the testing.

To measure the particulate emissions we used a Wohler RP 72 hand operated Smoke Test Pump. The hand operated Smoke Test Pump draws flue gas through a piece of filter paper which leaves a particulate stain on the paper that is removed from the test wand and compared to a color gradient chart numbered from 0 to 9 (Figure 27, page 56). A smoke level number of “0” represents no smoke detected and a smoke level number of “9” represents a solid black sample, or the maximum visible stain on the filter paper. This simple visual method of estimating the level of particulates that represent the stain on the sample filter paper is commonly used by heating equipment service technicians when tuning oil and gas appliances, so we felt it could provide useful data for this project. More refined particulate analysis of flue gasses requires specialized portable laboratory equipment to collect micro weight data such as that recorded in the BERC testing in 2010 (Sherman, 2011). These emission samples were collected from a 1” flue port installed in flue section 20” from the boiler induced draft fan outlet (Figure 28, page 57).

Project Schedule of Events

October through December, 2011: We reviewed the previous research on species of grass used as fuel and small commercial boilers under 500,000 BTU/Hour that had features well suited to burning grass and biomass in 1/4" pellet and a 2" diameter "puck" sizes.

October, 2011: Meach Cove harvested grass from the Meach Cove test plots and delivered it to Enviro Energy, LLC in Wells Bridge, N.Y. where it was densified into 1/4" pellets.

January, 2012: Pellet samples were sent to Twin Ports Testing, Inc. for calorific, chemical and ash testing.

April 2013: Meach Cove collaborated with Renewable Energy Resources, Inc. to identify a boiler that could handle grass and biomass in a 1/4" pellet or a 2" diameter puck form.

September 23, 2013: Original project end date, extended until September 20, 2014.

September 2013: Meach Cove places an order with RER, Inc. for an Evoworld HC 100 Eco wood chip boiler.

December 2013: Meach Cove employees installed the Evoworld wood pellet and wood chip conveyors in the fuel bins that they constructed.

January 29, 2014: Evoworld HC 100 Eco boiler and a 550 gallon hot water buffer tank are delivered and placed in the Meach Cove boiler room.

April 11, 2014: The boiler room installation is completed and the Evoworld boiler is test run. We are still waiting for UL certification and final inspections of the boiler.

August 2014: Project end date extended to September 2015.

September 22, 2014: UL certification received for the Evoworld USA HC 100 Eco boiler.

September 26, 2014: The boiler passes inspection by Hartford Insurance Co. inspector.

October 6, 2014: State Fire Marshal approved operation of the boiler.

October 17, 2014: The Evoworld boiler begins heating the Meach Cove building burning wood pellets.

March 6, 2015: The first round of grass and biomass fuel combustion testing begins.

September 20, 2015: Project end date.

October - November 2015: Christopher Callahan assists the Project Director in the second round of grass and biomass testing which includes 2” dimeter pucks.

October 23 and 24, 2015: Open houses held at Meach Cove Farms.

October 26, 2015: Fox Channel 22/44 reporter on site for six live broadcast segments highlighting the project.

November 4, 2015: WCAX Channel 3 UVM Extension Service show Across the Fence report on Grass to Energy describing this project airs.

October 2015 – April 2016: Evoworld boiler operated on wood pellets. Periods of 3-7 days the boiler was operated on grass biomass 2” pucks or blends of grass and wood pellets.

Project Location & Map showing where the samples were grown and tested

Project location and Natural Resources Inventory maps are provided on pages 41 and 42 showing the Meach Cove Farm, the Warm Season Grass test plots, the building where the Evoworld boiler was installed, and the areas where the mulch hay and Ag Biomass samples were harvested.

Summary of what worked and what did not

The Evoworld HC 100 Eco boiler we installed performed better than we could have anticipated given the range of biomass material we tested for this project. Once we learned how the boiler control software operated, we were able to program operational ranges that allowed the boiler to adjust to variations in the fuel performance during the test burns. We used the combustion data collected with a Wohler A500 emission analyzer to adjust the fuel feed rates and air settings to optimize the boiler’s performance with each fuel sample.

The set up for this project took longer than anticipated for a number of reasons.

- It was a challenge to identify a production boiler that had the features necessary to handle the known issues others had experienced when burning grass and other forms of biomass in a small (< 500,000 BTU/Hour) rated commercial boiler.

- Once the Evoworld HC 100 Eco boiler was ordered there were delays while the boiler was built and another seven months to obtain the UL certification for this boiler model.

- We learned that ASME and UL certifications were required by the Meach Cove insurance company and the State Fire Marshal in order to operate a boiler in a commercial building in Vermont. We experienced months of delays resolving boiler room and fuel storage design issues to the satisfaction of both of these authorities.

- During the initial boiler test operation it was discovered that modifications were needed to the way the boiler was plumbed into the building's heat distribution manifold.

- It took time to learn how the Evoworld boiler control software operated. The Evoworld USA construction team in Troy, N.Y. only had experience burning wood in the boilers so the Project Director, with assistance from Adam Dantzscher and Christopher Callahan worked out the settings necessary to optimize the combustion of the grass and biomass fuel blends.

What would be done differently

If we started this project today we would have the design for biomass fuel storage bins and the boiler room layout that the Vermont Fire Marshal and the insurance company inspector would approve. All of the Evoworld boiler models are now ASME and UL certified. We have learned how to configure the Evoworld operating system to optimize its performance on a variety of biomass fuels sizes and types. During this project we learned that adding a scraper bar to the combustion shelf in the firebox should allow the boiler to operate with minimal primary air restriction when burning grass pellets or 2" diameter pucks. Activating this scraper bar before each firing should clear any clinkers and residue if they form off the combustion shelf and this should permit repetitive burn cycles with the grass biomass fuels.

One significant limitation to anyone considering burning grass biomass fuels today is locating someone to process the harvested grass biomass into a densified puck or pellet form. Without a demand for grass biomass fuel, there is no incentive for a business to invest in the equipment to densify grass into boiler sized fuel. Without a source of densified grass, potential adopters would have to invest in densifying equipment or seek other wood based biomass fuel. Based on historical evidence, a significant rise in the cost of petroleum fuels should spur renewed interest in grass (and wood) biomass as a space heat fuel source (Kotrba, 2015).

Discussion of Quality Assurance

The Meach Cove property is 1000 acres that is comprised of roughly one-third managed forestland, one-third productive agricultural land, and one-third pasture, riparian buffer areas, wetlands or ponds. In 2008 Meach Cove collaborated with the University of Vermont Extension Service to establish a replicated grass species study plot on a five acre parcel on the Meach Cove property (Figure 1, page 41). The grass study plot provided the Switchgrass and Reed Canarygrass that was densified and tested for this project. Other areas of the Meach Cove property provided the mulch quality hay and the agricultural residue samples that were tested (Figure 2, page 42).

The grass plot study site was selected because it was separate from the certified organic acres that are in active crop production. This location permitted the UVM study to incorporate fertilizer rate trials and test the effect of chemical weed control methods on some of the grass plots without impacting the adjacent certified organic fields. The samples of mulch quality hay and agricultural crop residue were harvested from other areas on the Meach Cove property because they represented abandoned pastureland or buffer areas near drainage ways (Figure 2, page 42). We selected these areas because they are similar to non-prime agricultural land on almost every farm in this region.

We selected Twin Ports Testing, Inc. in Superior, Wisconsin to perform the analysis on the densified grasses we evaluated because they are a lab that specializes in biomass testing with an excellent reputation. Twin Ports Testing, Inc. was the lab used in the 2010-11 testing that is described in the BERC "Technical Assessment of Grass Pellets as Boiler Fuel in Vermont" authored by Adam Sherman (Sherman, 2011) so we wanted to use them so that we could make comparisons with our samples.

1/4" pellet and 2" puck samples were randomly drawn from the bags of the densified grass species and placed in one gallon Ziploc sample bags and mailed to Twin Ports Testing. Twin Ports performed Ultimate and Proximate Analysis, as well as tested the chlorine level of the samples. The Twin Ports Testing website listed on page 39 of the References provides a detailed summary of how they manage the chain of custody of the samples they test.

A Wohler A500 hand held digital combustion analyzer was used to measure and record nine qualities of the combustion emissions of the EVO HC 100 Eco wood chip boiler while burning the wood pellets and the biomass blends. The Wohler A500 analyzer had new sample modules installed and it was calibrated at the Wohler U.S. service center prior to beginning this project. The Wohler unit runs a self-calibrating sequence every time it is turned on. Prior to each test run the sample tubing on the Wohler analyzer was blown out with compressed air to remove any moisture or particulates and the various filters in the Wohler instrument were changed (Figure 26, page 56).Emission samples were collected in a 1" flue port installed in the flue section 20" from the boiler induced draft fan outlet (Figure 28, page 57 and Figure 9, page 47).

Prior to commencing the combustion testing for this project the Evoworld boiler fuel bin and the fuel feed auger were vacuumed clean, the boiler tubes were cleaned, and the firebox was scraped down and vacuumed to minimize residual ash from prior fuel tests.

Every effort was made to perform the combustion testing by following the same series of steps and, if possible, by the same individual. We isolated the heat distribution system so that the boiler was only heating the 550 gallon buffer tank. The temperature of the buffer tank was noted before and after each test burn which allowed estimates of the thermal efficiency of the test burns to be calculated (Callahan, 2016). The boiler was started and allowed to run through the typical self-cleaning cycle prior to start up, it then begins a 5 minute start up and ignition sequence. Once the boiler reached the “full load” combustion stage indicated on the boiler control panel the tester would begin to take emission and smoke samples with the Wohler equipment. Samples were taken at 10-15 minute intervals over the course of 60 to 90 minutes with the boiler operating at “full load”. The data was captured by the Wohler instrument and printed using the Wohler wireless printer as each sample was taken. The Wohler RP72 smoke test pump was used to take flue gas samples from the 1” flue port as each emission sample was recorded. The smoke test filters were labeled and stapled to the Wohler printouts. We made adjustments to the air flow and fuel feed rates for the boiler during the test runs to minimize the CO levels and maximize the combustion efficiency and noted these changes on the work sheets used for each test.

Emission measurements with the Wohler A500 and the smoke tests were performed following the same process and as close to the same time interval for each test run by the same person for consistency. The raw data was transferred from the Wohler emission print outs and smoke test paper disks into an Excel spreadsheet. Both the Project Administrator and the Project Director reviewed the data for accuracy after it was entered in the Excel spreadsheet and after it was graphically displayed.

Summaries of the data were used to create the bar graphs visually illustrate and compare the data.

Findings

The initial round of testing performed from March through June of 2015 focused on 1/4" diameter pellet samples of mulch hay, Switchgrass, Reed Canarygrass, and testing the pellet samples of these same perennial grasses mixed at 6%, 12%, and 25% with pine sawdust making up the balance. These were the same samples tested in 2010-11 (Sherman, 2011) in a SolaGen 500,000 BTU/Hour boiler designed to burn wood pellets. We wanted to see how a boiler with the features of the Evoworld HC 100 Eco wood chip boiler performed when burning these same fuel samples.

Following production of 2" diameter pucks by Adam Dantzscher using many of the same grass species, and blends of grass samples with wood chips, we conducted combustion tests in October and November, 2015 with the assistance of Christopher Callahan. The analysis of that round of testing was provided by Christopher Callahan in his report titled "Solid Grass Biomass Fuels in Vermont: An Update" (Callahan, 2016). The experience gained in running the Evoworld boiler March through June, 2015 testing, and Christopher Callahan's expertise in tuning the Evoworld boiler during the October and November 2015 testing yielded sufficient data to draw a number of important conclusions about the variety of biomass types and blends we tested.

Optimization of the Boiler Settings

As previously described, the Evoworld HC 100 Eco wood chip boiler has a number of design features that made it well suited to burning other types and form sizes of biomass fuel. The Evoworld control software allowed us to make changes to the performance ranges for the fuel and air delivery rates before and during the boiler's heating cycle. Once we established the upper and lower range for the fuel feed rates, the level of fuel in the combustion chamber, the volume of air being supplied (from below the combustion shelf, mid height in the combustion chamber, and in the upper portion of the combustion chamber), and the draft pressure being applied by the Induced Draft (ID) fan in the flue, the Evoworld software would make instantaneous adjustments as the boiler operated through the ignition, full load, and "after venting" stages of the boiler's programmed combustion cycle (Figure 6, page 46).

We began our testing by using settings for wood chips and wood pellets as recommended in the Evoworld manual. We applied the tuning suggestions for fuel and air adjustments as described in the manual and noted the changes in the performance with the type of fuel we were burning. Through trial and error we arrived at settings that gave us the best range of emission data during the test burns. We got better at making these range adjustments over the period of time we spent with each biomass sample we tested.

We had an easier time getting better combustion performance from the 2" diameter pucks for all the types of biomass we tested. My initial thought is that this was because of the greater air spacing between the pucks which allowed more primary air flow to the fuel pile. Another factor may have been that the density of the pucks was less than the pellets which resulted in them breaking down more readily during the combustion. The 2" diameter pucks left a lighter weight fluffy ash residue vs. the denser and crusty residue we found after the test burns with the grass pellet samples (Figures 31-32, pages 58-59).

We learned that to get more robust combustion we needed to reduce the rate that grass fuel in either the ¼" pellet or 2" diameter puck forms was fed into the combustion chamber during the ignition phase of the boiler cycle. I believe this was because it took longer to get the grass samples burning hot enough so that new fuel being introduced to the combustion chamber would not smother the fuel pile burning on the combustion shelf.

We found that we needed to increase the amount of air being fed into all levels of the combustion chamber when we were testing the grass samples. With the additional combustion chamber air input we had to increase the draft underpressure range to allow the boiler more latitude to increase or decrease the ID fan speed during the combustion cycle.

We also learned that we needed to run the combustion air fans at higher levels through the entire combustion cycle and the after venting period to provide a more complete combustion of any residual fuel in the combustion chamber.

Because we got better at making adjustments to the boiler settings and ranges we have a higher level of confidence in the later round of test data but we feel both sets of test data contain valuable information.

Summary of Exhaust Gas Measurements March - June 2015

Avg	Stack Temp °F	O2	CO ppm	CO2	EFF	Ex Air	NO ppm	SO2 ppm	Smoke Test
Blend: 100%									
100% VT Wood pine pellets	380	12.23%	518	7.70%	71.38%	144.58%	35	6	>9
100% Egx Wood Blnd pellets	356	11.42%	274	9.25%	80.57%	144.33%	59	2	8
100% Enviro Energy hay pellets	331	13.88%	1724	6.88%	80.21%	323.33%	115	74	>7
100% Switchgrass pellets	302	15.92%	456	5.81%	56.39%	381.10%	89	1	>6
100% Switchgrass pucks (2008)	363	13.58%	423	7.15%	76.92%	199.63%	96	0	7
100% Reed Canary pellets	353	12.70%	892	8.01%	77.84%	180.56%	112	4	7->9
Blend: 25% (Sherman 2011)									
25% Switchgrass/75% pine pellets	360	9.80%	117	10.80%	82.43%	87.67%	94	1	0
25% Reed Canary/75% pine pellets	321	16.50%	254	4.30%	74.10%	367.00%	50	1	0
25% MC Mulch hay/75% pine pellets	339	12.33%	216	8.37%	80.07%	173.67%	104	0	0
Blend: 12% (Sherman 2011)									
12% Switchgrass/88% pine pellets	379	9.27%	123	11.33%	82.00%	79.00%	81	3	0
12% Reed Canary/88% pine pellets	351	12.07%	140	8.63%	81.07%	138.33%	69	0	0
12% MC Mulch hay/88% pine pellets	373	9.80%	169	10.83%	81.83%	89.00%	102	2	0
Blend: 6% (Sherman 2011)									
6% Switchgrass/94% pine pellets	375	9.53%	96	11.07%	82.00%	83.00%	73	1	0
6% Reed Canary/94% pine pellets	380	11.30%	236	9.37%	80.50%	118.33%	61	2	0
6% MC Mulch hay/94% pine pellets	400	10.38%	253	10.28%	80.58%	97.75%	71	1	0

Table 1 - Summary of Exhaust Gas Measurements March-June 2015. Typically, an average of three readings toward the end of a 1 hour test run. Not representative of optimized performance.

Combustion Residual Comparison March - June 2015

	Gross Calorific Value BTU/Lb	Ash Moisture free WT %	Ash Fusion Reducing Atmosphere Temp °F	Chlorine Moisture free mg/kg
Blend: 100%				
100% VT Wood pellets	9043	0.23	2680	27
100% Energex Wood Blend pellets	8670	0.68	2630	
100% Enviro Energy Hay pellets	8290	4.98	2520	3703
100% Switchgrass pellets	8117	6.63	2590	2517
100% Switchgrass pucks (2008)				
100% Reed Canary pellets	8213	4.54	2520	1041
Blend: 25% (Sherman 2011)				
25% Switchgrass/75% pine pellets	8534	2.22	2460	75
25% Reed Canary/75% pine pellets	8430	1.69	2540	90
25% MC Mulch Hay/75% pine pellets	8404	1.63	2210	649
Blend: 12% (Sherman 2011)				
12% Switchgrass/88% pine pellets	8627	1.31	2230	36
12% Reed Canary/88% pine pellets	8559	0.90	2495	81
12% MC Mulch Hay/88% pine pellets	8783	0.90	2360	228
Blend: 6% (Sherman 2011)				
6% Switchgrass/94% pine pellets	8529	0.91	2400	33
6% Reed Canary/94% pine pellets	8526	0.56	2385	33
6% MC Mulch Hay/94% pine pellets	8618	0.56	2240	126

Table 1a - Combustion Residual Comparison for March-June 2015.
SOURCE-Twin Ports Testing Inc. Analytical test reports

Summary of Exhaust Gas Measurements October - November 2015									
Avg	Stack Temp °F	O2	CO ppm	CO2	EFF	Ex Air	NO ppm	SO2 ppm	Smoke Test
Blend: 100%									
100% VT Wood pellets-Not Tested									
100% Energex Wood Blend pellets	365	9.78%	369	10.83%	82.75%	89.17%	68	1	>9
100% Enviro Energy Hay pellets	234	18.83%	849	2.07%	64.07%	844.00%	46	93	7
100% Switchgrass pucks	350	13.80%	325	6.93%	77.48%	207.40%	97	1	6
100% Reed Canary pucks	347	14.60%	184	6.13%	74.93%	246.33%	107	0	7.0
100% Miscanthus pucks	351	13.98%	87	6.77%	77.83%	200.33%	64	0	5
100% MC Mulch Hay pucks	368	13.90%	227	6.83%	75.95%	205.50%	113	0	5
100% Ag. Biomass pucks	307	12.43%	272	8.30%	81.53%	153.00%	138	0	6
Blend: 50%									
50% Switchgrass/50% Wood pucks	253	17.55%	229	3.18%	73.38%	538.75%	57	0	9
50% Reed Canary/50% Wood pucks	348	14.06%	188	6.68%	77.42%	204.20%	164	0	6
50% Miscanthus/50% Wood pucks	322	16.05%	125	4.75%	73.90%	325.50%	70	0	6
50% MC Mulch Hay/50% Wood pucks	308	16.23%	236	4.58%	74.50%	340.75%	86	0	6

Table 2 - Summary of Exhaust Gas Measurements October-November 2015. Typically, an average of three readings toward the end of a 1 hour test run. Not representative of optimized performance.

Combustion Residual Comparison October - November 2015				
	Gross Calorific Value BTU/Lb	Ash Moisture free WT %	Ash Fusion Reducing Atmosphere Temp °F	Chlorine Moisture free mg/kg
Blend: 100%				
100% VT Wood pellets	9043	0.23	2680	27
100% Energex Wood Blend pellets	8670	0.68	2630	102
100% Enviro Energy Hay pellets	8290	4.98	2520	3703
100% Switchgrass pucks	8353	3.90		973
100% Reed Canary pucks	7898	8.06		3312
100% Miscanthus pucks	8105	3.99		352
100% MC Mulch Hay pucks	7952	6.80		2146
100% Ag. Biomass pucks	8123	5.35		227
Blend: 50%				
50% Switchgrass/50% Wood pucks	8344	4.01		899
50% Reed Canary/50% Wood pucks	7900	8.14		2983
50% Miscanthus/50% Wood pucks	8079	6.25		341
50% MC Mulch Hay/50% Wood pucks	8180	6.15		1211

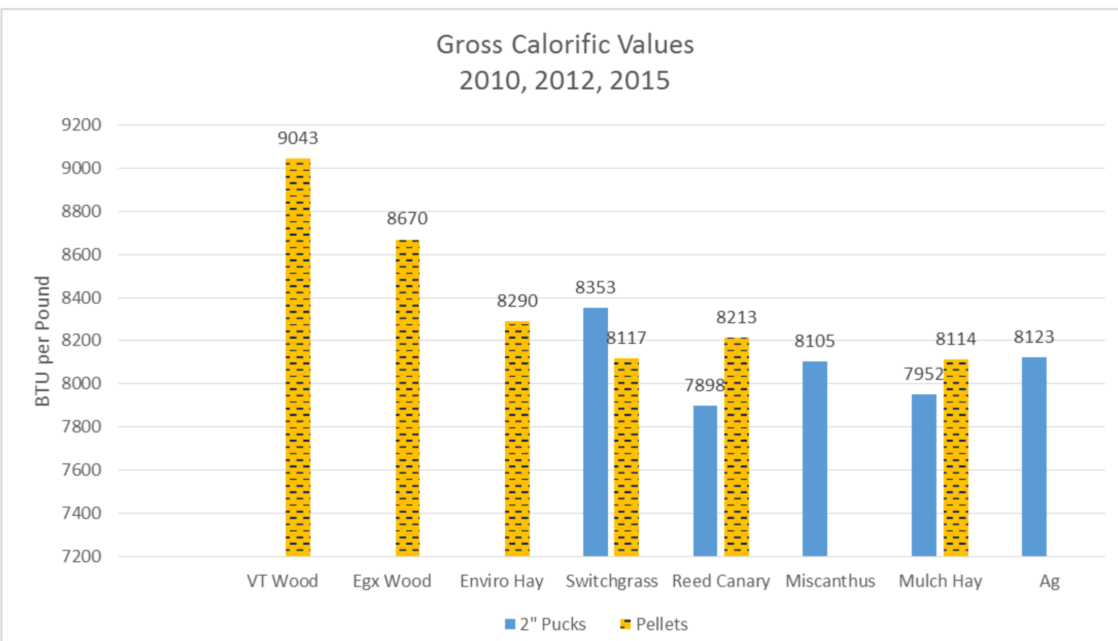
Table 2a - Combustion Residual Comparison for October-November 2015.
SOURCE-Twin Ports Testing Inc. Analytical test reports

Findings Summary

1. A small (350,000 BTU/Hour rated) commercial U.S. built, ASME and UL certified, hot water boiler designed to burn wood chips can be adjusted to burn grass fuel and agricultural biomass/field residue in 1/4” pellet and 2” diameter puck forms with emissions and combustion efficiency data comparable to wood pellets. Prior to identifying the Evoworld HC 100 Eco boiler, we were unable to locate a commercial production boiler with ASME and UL certification and the design features that could handle grass or biomass.

2. We discovered during the testing that the Evoworld processor and programming was capable of automatically adjusting the air and fuel delivery rates to optimize the combustion performance while burning different species of grass in 1/4” pellets and 2” diameter pucks (Figure 17, page 51). We had to work out the upper and lower ranges for these settings for each phase of the boiler’s combustion cycle (start up, ignition, full load, after venting) to get optimal emission performance from the boiler.

3. The mulch quality hay harvested from abandoned pasture land we described as “Agricultural Biomass/field residue” in this study, was densified into a 2” diameter pucks and had an energy content and combustion emission properties compared favorably to the perennial fuel grasses (Switchgrass, Reed Canarygrass, Giant Miscanthus) and the two types of wood pellets tested.



Moisture Free GCV data taken from Twin Ports Testing Analytic test reports; arrival dates 2/22/2010 (VT Wood & Mulch pellets), 1/31/2012 (rest of pellets) & 11/30/2015 (2” pucks)

4. Some clinker formation and unburned residue occurred when burning the perennial fuel grass and mulch hay in the 1/4” pellet form (Figures 32-33, page 59). We were able to adjust the boiler to minimize clinker formation with the 2” diameter pucks.

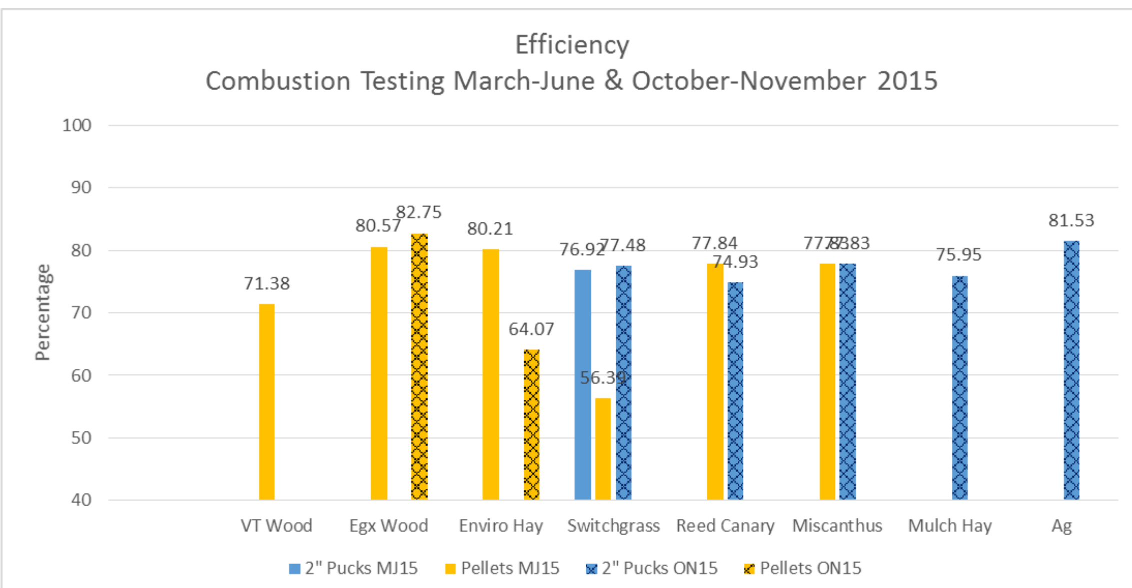
5. Analysis of the Twin Ports Testing data revealed that the 100% Switchgrass in a 2” puck had the highest Gross Calorific value of the grasses tested (8,353 BTU/Lb.) and it was 7.6% less than the 100% softwood (Vermont Wood Pellet) pellets and only 3.7% lower than the 50% softwood / 50% hardwood (Energex) wood pellets.

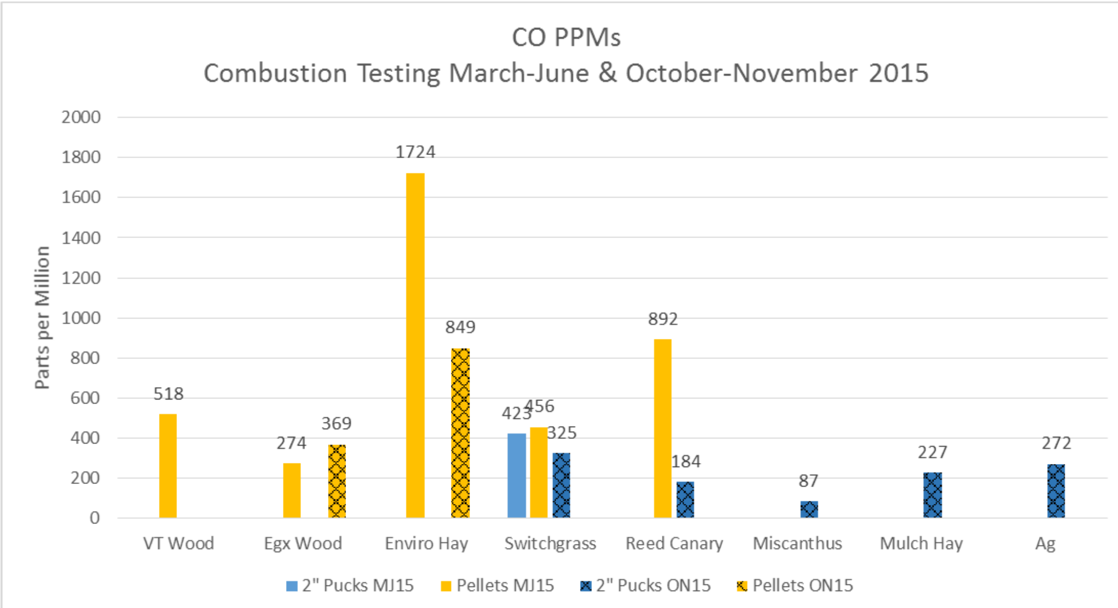
6. The Evoworld HC 100 Eco boiler is able to efficiently burn the range of 100% grass species and grass/wood blends we tested with combustion efficiency that ranged from 56.3 – 81.5% as compared with wood pellets with a range of 71-82%. Only a 50% softwood / 50% hardwood (Energex) pellets burned with higher efficiency (82.75 %) than the 100% Enviro Energy mulch hay pellets (80.2%) and Agricultural Biomass/field residue 2” diameter pucks (81.5%).

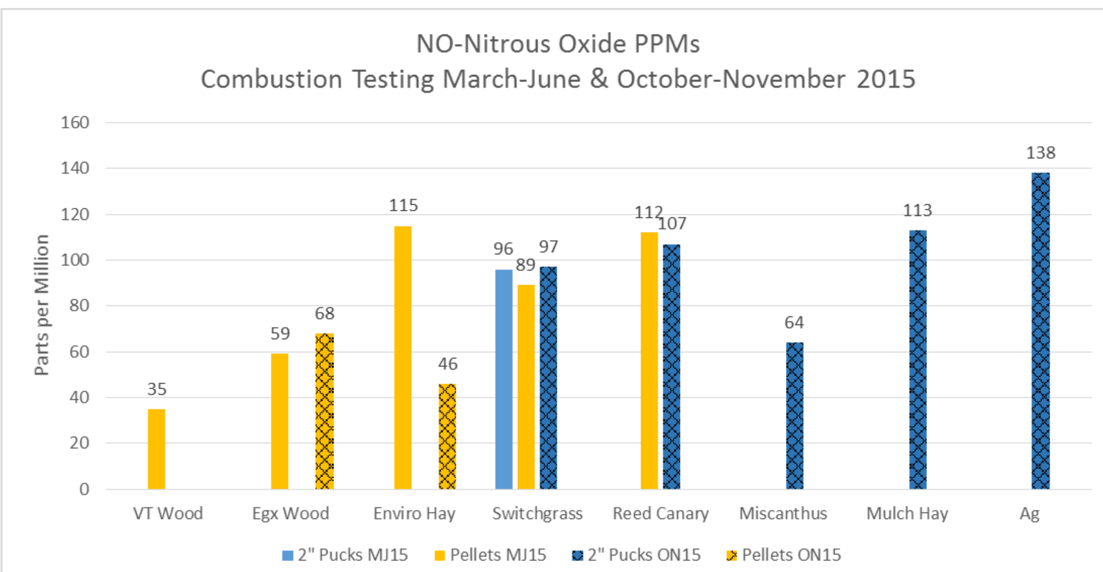
7. The Agricultural Biomass/field residue that was harvested from an abandoned pasture on the Meach Cove property (Figure 2, page 42) burned with the highest efficiency of the other grass and biomass types tested at 81.5%, and had lower CO and a lower smoke test number than the wood pellets we tested.

8. Giant Miscanthus grass in 2” diameter pucks and pellets burned easily with similar efficiency (77.8%), and had the lowest CO (87 ppm) of any of the grasses, wood, or blends we tested.

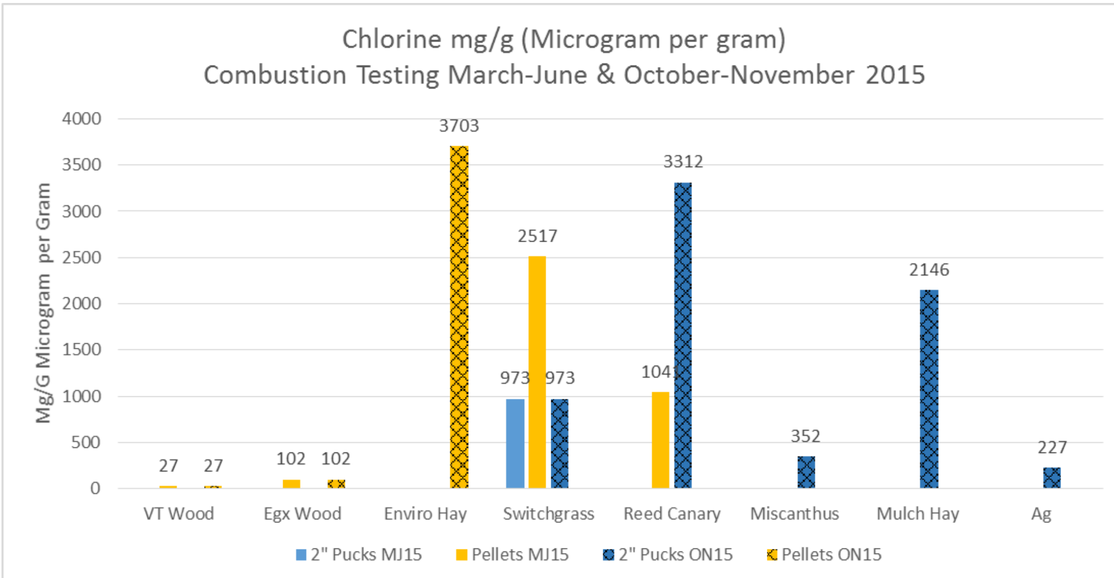
9. The system thermal efficiency ranged from 38 – 83% (Callahan, 2016).




CO PPMs
Combustion Testing March-June & October-November 2015
Parts per Million
2000
1800
1600
1400
1200
1000
800
600
400
200
0
518
274
369
1724
849
423
456
325
892
184
87
227
272
VT Wood
Egx Wood
Enviro Hay
Switchgrass
Reed Canary
Miscanthus
Mulch Hay
Ag
2" Pucks MJ15
Pellets MJ15
2" Pucks ON15
Pellets ON15


NO-Nitrous Oxide PPMs
Combustion Testing March-June & October-November 2015
Parts per Million
160
140
120
100
80
60
40
20
0
35
59
68
115
46
96
89
97
112
107
64
113
138
VT Wood
Egx Wood
Enviro Hay
Switchgrass
Reed Canary
Miscanthus
Mulch Hay
Ag
2" Pucks MJ15
Pellets MJ15
2" Pucks ON15
Pellets ON15

10. Chlorine levels varied drastically between samples ranging from a low of 27 mg/g for the 100% softwood pellets to a high of 3,703 mg/g for the Enviro Energy mulch hay pellets. The agricultural biomass/field residue (227 mg/g) and the Giant Miscanthus (352 mg/g) were the lowest of the 100% grasses and grass biomass we tested.



Chlorine data taken from Twin Ports Testing Analytical test report 1/31/2012
Did not test VT Wood pellets in Oct-Nov 2015 Combustion test

11. There were some issues with grass in both the 1/4" pellet and 2" diameter puck form blocking the primary combustion air after a burn cycle (Figure 30, page 58). Between burn cycles all of the grasses in the 1/4" pellet form cooled and formed a crust of clinker on the fuel pile. This clinker formation required us to manually clear the accumulated clinker and ash between test runs. I believe that these issues could be eliminated with the addition of a mechanical sweeper arm that would push the remaining fuel off the combustion shelf onto the slated floor of the firebox where the normal cleaning cycle at the beginning of each burn cycle would convey it to the ash container. (Figure 7, page 46).

12. Following the conclusion of the grass and biomass testing in November 2015, we continued to heat the building with wood pellets and shut the boiler down for the spring in April, 2016. We intended to clean the boiler tubes, turbulators and firebox after the spring shut down but did not get to the cleaning until the fall of 2016. We discovered at that time that the carbon steel turbulators in the second pass of boiler tubes had become rusted to the tube walls (Figures 10-11, page 48). When the boiler was activated it initiated a cleaning cycle where the turbulators would normally move up and down to clean the tube walls. Because of the rust the turbulators did not move and the cleaning motor continued to run, melting the

motor windings and damaging the control board. After consulting with the Evoworld manufacturer in Troy, N.Y. about this condition, we cannot be sure that the corrosion and rust on the carbon steel turbulators was caused by any byproducts of grass combustion, or because of moisture in the air being drawn through the boiler during the summer and fall months. An additional circuit breaker has been added to these boilers to protect the cleaning motor and the circuit board if this ever occurs again.

13. In Christopher Callahan's 2016 report on the combustion of the 2" diameter grass puck samples, he provided calculations showing that the cost to grow, harvest and process grass into a 2" diameter puck is competitive in price with wood pellets at the time of writing this report ($214 - $265 per ton). The cost to produce the 2" diameter pucks should come down if a steady market demand for these pucks existed (Callahan, 2016).

14. The cost to produce 2" diameter pucks using portable equipment such as the BHS "Slugger" machine is similar to the cost to operate a small capacity fixed pellet manufacturing facility such as the Enviro Energy plant but the capital cost to purchase and set up a fixed pellet plant is considerably more expensive +/- $100,000 (Callahan, 2016) vs. > $700,000 (Enviro Energy, 2011). From our research we have not identified a portable trailer mounted pelletizing and drying unit that is able to match the output rate, consistent quality or cost of production of a fixed pellet plant to produce standard 1/4" diameter pellets.

15. The table below shows that the cost to heat buildings with the types of biomass fuel sources described in this report using the production costs described in Christopher Callahan's 2016 report are comparable to the present cost of wood pellets or wood chips, and less expensive than petroleum fuels available in this region.

Fuel Cost Comparison

Fuel Cost Comparison

Fuel	Cost	Cost Units	Energy Content	Energy Units	Normalized Fuel Cost $/million BTU
Propane	$2.65	$/gal	92,000	BTU/gal	28.80
#2 Fuel Oil	$2.10	$/gal	129,500	BTU/gal	16.22
Wood Pellets	$277.00	$/ton bulk	8,670	BTU/lb	15.97
Wood Chips	$56.00	$/ton (green)	9.9	mill BTU/Ton	5.70
Ag Biomass	$85-$214	$/ton	8,123	BTU/lb	5.20-13.20
Mulch Hay	$129-$228	$/ton	7,952	BTU/lb	8.11-14.34

Source: Callahan, 2016 with Fuel prices updated for NW Vermont as of 12/1/2016

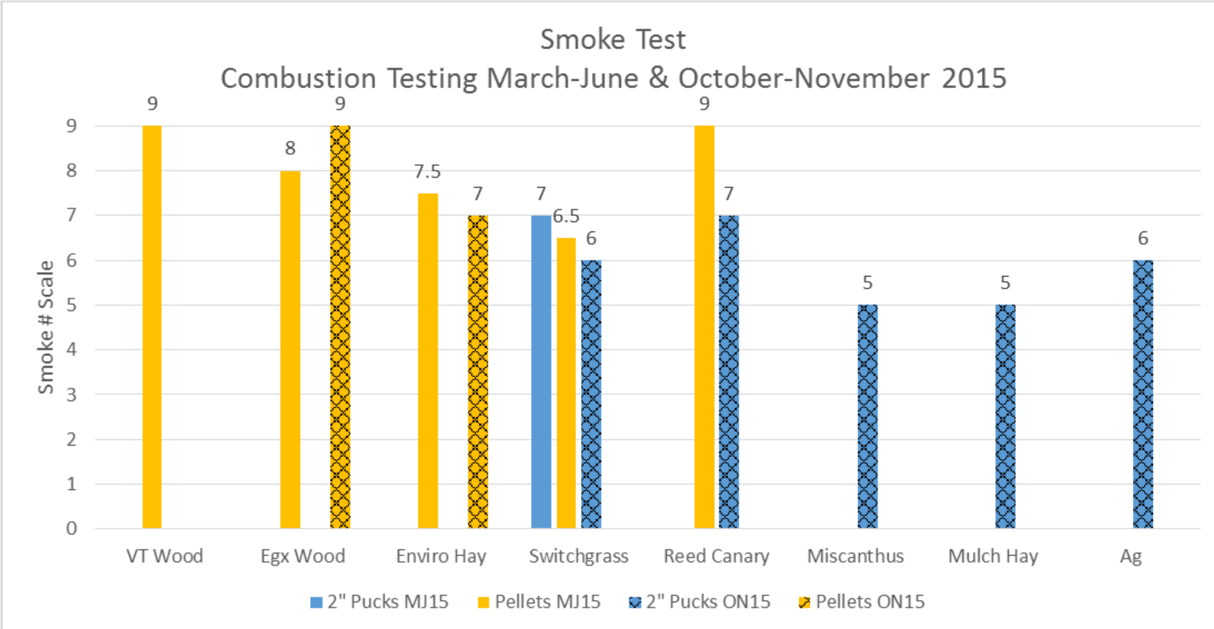
Discussion of the Data

Energy Content

The Gross Calorific Values for the various grass and grass/wood blend samples ranged from 7,898 to 8,353 BTU/lb. for many of the 100% grass species tested and was within 7.6% of the 100% softwood (Vermont Wood Pellet) pellets and 3.66% of the 50% softwood / 50% hardwood (Energex) pellets. Even the Ag. Biomass sample (Figures 14-15, page 50) that was a mix of weeds, orchard grass and oak leaves had only 10.2% less energy value of the 100% softwood (Vermont Wood Pellet) pellets and it was just 6.3% less than the 50% softwood / 50% hardwood (Energex) pellets.

Smoke number comparison

A Wohler RP72 smoke test pump was used to collect and compare the level of staining on a filter paper sample drawn from the flue gases during the test burns. We visually match the stain on the filter paper with the standardized smoke level number scale numbered 0 – 9 with “0” representing no smoke detected and “9” representing a solid black stain. We interpreted the darker stains to represent more particulate matter in the flue gases. All of the 100% grass samples produced smoke test numbers that indicated lower smoke test numbers than either of the two wood pellet samples tested. The Giant Miscanthus and the mulch hay samples had the lowest smoke test numbers (5) compared to the wood pellets at 8 and >9. The 50% grass / 50% wood chip 2” diameter puck samples had smoke test numbers of 6, with only the 50% Switchgrass / 50% wood chip 2” diameter puck sample having a smoke number of 8.



Smoke # Scale : The higher the smoke number, the darker the stain on the filter paper.
(0= no smoke detected; 9=solid black)

Ash

The Twin Ports lab results for the moisture free weight percentage or ash for the 100% grass samples ranged from 3.9% – 8.06% with Switchgrass pucks being the lowest and Reed Canarygrass pucks being the highest. The Mulch hay and Ag Biomass in 2" pucks were 6.8% and 5.35% ash respectively which was not surprising given the findings in previous biomass fuel studies. The 50% grass /50% wood chip 2" diameter puck samples had slightly higher ash percentages than the wood pellets or the 100% grass samples. It is interesting that the higher ash grass samples burned with the lowest smoke test numbers. Further research would be needed to determine the reason for this.

Ash Fusion Temperatures

Twin Ports tested each sample for the ash fusion temperature which is the temperature at which the residual ash becomes fluid. The ash contains minerals that the plants pick up from the soil and these minerals and the concentrations in a particular sample varies with each field and species of grass. The minerals in the ash influence the temperature at which the ash becomes fluid. When fluid ash cools it clumps together and often forms a hard clinker that can coat the components of the boiler in contact with the ash (Figure 32, page 59). Clinker and scale formation results in boiler operation and maintenance issues that can be difficult and time consuming to deal with. Large clinker pieces can restrict the air flow in the combustion chamber and they often jam ash removal augers. In extreme cases this requires the manual chipping of the clinker or slag to remove it from the boiler components which is time consuming. Higher ash fusion temperatures make it less likely that clinkers or scale will form during the combustion process. The wood pellet samples had ash fusion temperatures in excess of 2,630 °F and no clinkers were observed during the testing. The 100% Switchgrass pellets had an ash fusion temperature 90 °F lower than the 100% softwood (Vermont Wood Pellet) pellets and only 40 °F lower for the 50% softwood / 50% hardwood (Energex) pellets. The Enviro Energy mulch hay pellets and the Reed Canarygrass pellets had an ash fusion temperature of 2,520 °F making them more likely to form clinkers which they did when the ash was left to cool between boiler heating cycles (Figure 32, page 59). We did not do ash fusion tests on the 50% grass / 50% wood chip 2" diameter puck samples but based on the findings in the BERC report (Sherman, 2011), we would expect the samples with some wood in them to have lower ash fusion temperatures than the 100% grass samples.

Chlorine

Chlorine is a micronutrient which exists in the soil and it is absorbed by grasses and trees. Grasses typically contain higher levels of chlorine than trees or wood. When chlorine is combusted it can produce a corrosive gas that can attack the interior surfaces of heating equipment and the flue. For this reason the moving step grate (Figure 30, page 58) and the first and half of the second pass turbulators in the Evoworld boiler are constructed of stainless steel (Figures 10-11, page 48). The flue lining was constructed with 316 grade stainless steel with a 304 grade stainless steel outer jacket which have greater resistance to chlorine and sulfur that might be present in the flue gases. The 100% softwood (Vermont Wood Pellet) pellets had only 27 mg/gram of Chlorine, the 50% softwood / 50% hardwood (Energex) pellets had 102 mg/g, the Ag. Biomass (227 mg/g) and the Giant Miscanthus 2" diameter pucks (352 mg/g) had the lowest levels of chlorine among the grass samples, while the Enviro Energy mulch hay pellets (3,703 mg/g) and the Reed Canarygrass 2" diameter pucks (3,312 mg/g) had the highest levels. Not surprisingly the grass samples blended with percentages of wood all had lower chlorine levels than the 100% grass samples.

Sulfur (SO_2)

The presence of high levels of sulfur in a fuel source is an issue when sulfur is combusted it combines with oxygen to form Sulfur Dioxide (SO_2) which is the chemical that causes acid rain. When sulfur dioxide condenses in heating equipment it is corrosive to the steel components. For this reason many boilers and flue liners, including the Evoworld boiler have stainless steel components in the areas that may experience contact with sulfur dioxide. In the Evoworld boiler, the step grate that forms the bottom of the combustion chamber, the first pass turbulators, the lower section of the second pass turbulators, and the flue liner are all constructed with stainless steel as a precaution.

The wood pellets tested had only 1-6 ppm of SO_2, the grass samples tested with the highest levels of SO_2 were the Enviro Energy mulch hay pellets that had average levels between 74 - 93 ppm in the two test periods. The other 100% grass and 50% grass / 50% wood chip 2” diameter puck samples had SO2 levels from 0-4 ppm.

Carbon Monoxide (CO)

Carbon Monoxide (CO) is a byproduct when any carbon containing fuel source is combusted incompletely. The presence of Carbon Monoxide in the environment in high concentrations is dangerous to any living breathing organism because it readily replaces oxygen in the bloodstream and can be fatal in cases of prolonged exposure. Carbon Monoxide as a product of combustion is a concern for air quality regulatory authorities because CO in the combustion gases is typically accompanied by other pollutants and other volatile organic compounds (VOC’s) that form during incomplete combustion. In the U.S. the EPA sets maximum CO performance levels for heating equipment. CO levels were monitored because they help to indicate how well or poorly the various samples were performing as they were combusted in the Evoworld boiler. During the test runs we adjusted the fuel delivery rate and the air feed rate ranges in the Evoworld control software to allow the boiler sensors to automatically adjust these inputs during the combustion cycle. The goal was to have the lowest CO levels while also maintaining a low oxygen level while maximizing the calculated efficiency level. The data indicates that as we got better at adjusting the fuel and combustion air feed rates the CO levels decreased for all the samples while the efficiency increased. The data shows higher CO levels for the earlier testing period (March – June, 2015) and lower levels during the later round of testing when we worked with Christopher Callahan (October – November, 2015). All of the 100% grass samples had CO levels that were lower than the wood pellet samples, with Giant Miscanthus being the lowest. Notably both the 100% Mulch hay and 100% Ag Biomass 2” diameter pucks produced CO levels that were lower than the wood pellets. The 50% grass / 50% wood chip 2” diameter puck samples had CO levels that were similar to the 100% grass 2” diameter puck samples and significantly lower than the 100% grass pellet results.

Nitric Oxide (NO)

Nitric Oxide emissions are a product of combustion of fuels that contain nitrogen and is one of the particulates that contribute to smog and acid rain. Their production is increased with higher temperature combustion. Higher levels of NO are less desirable. In our testing the Enviro Energy mulch hay pellets and the Giant Miscanthus samples had lower levels of NO than the wood pellets. The other grasses tested yielded NO levels that were almost twice that of the wood pellets or the Enviro Energy mulch hay pellets or the Giant Miscanthus pucks. The 50% grass / 50% wood chip 2” diameter puck samples had lower NO levels than the 100% grass samples but slightly higher levels than the wood pellets.

Comparison with the BERC Report Findings (Sherman, 2011)

The design features in the Evoworld HC100 Eco boiler proved to be up to the challenge of handling most of the issues that are typical when grass biomass is burned in a smaller commercial boiler. We thought it would be useful to retest many of the same species of grass and grass blended pellet samples in the Evoworld boiler that were tested in the BERC report authored by Adam Sherman in 2011 (Sherman, 2011). The combustion testing in the BERC report was done in a 500,000 BTU/Hour rated SolaGen wood pellet boiler. The SolaGen boiler larger than the Evoworld unit and it did not have a perforated combustion shelf where primary air is introduced below the fuel pile. The SolaGen boiler introduced primary air from the sides of the combustion chamber. Both boilers relied on the new fuel coming into the combustion chamber to push the burning fuel forward where it would be conveyed out of the boiler by the ash removal auger into a storage container. The SolaGen boiler air and fuel feed rates could be adjusted through the control software but the boiler software could not continuously adjust these inputs during the combustion process the way the Evoworld boiler does.

In general the results for the various grass species tested were consistent. In a few cases there were differences. The BERC report only tested 1/4" diameter pellet fuel and they found that some of the 100% grass pellet samples did not hold together as well as the grass/wood blend samples. The 1/4" pellets for this project were manufactured by Bob Miller at Enviro Energy and their process produced a dense, hard pellet that held its shape. The BERC report found that the Switchgrass samples had the lowest ash content of the grasses tested with 4.3%. In this project the Giant Miscanthus 2" diameter pucks yielded 3.9% ash and mulch hay pellets had 4.98% ash. The Switchgrass pellets tested in the BERC report had contained 2% more calorific energy than the 100% softwood pellets. In this project the 100% softwood (Vermont Wood Pellet) pellets had 7.6% more calorific energy than the Switchgrass pucks, and the 50% softwood / 50% hardwood (Energex) pellets had only 3.6% more calorific energy than the Switchgrass 2" diameter pucks.

The BERC report also tested grass/wood blended pellets in 6%, 12%, and 25% percentages of the grass species tested. When we retested these same blended samples in the Evoworld boiler we saw similar trends to the BERC findings. The higher percentages of wood had higher calorific values, higher combustion efficiency, lower CO, SO2 and Chlorine levels than the 100% grass samples. There were fewer distinctions in the ash fusion temperatures and the NO levels.

In both reports, not surprisingly, the wood pellet samples had higher ash fusion temperatures than the grass samples tested with Switchgrass being the closest with an ash fusion temperature within 40° F of the 50% softwood / 50% hardwood (Energex) pellets tested. All of the grasses tested had lower combustion efficiency than the wood pellets, with the Ag Biomass sample being within 1.2% of the 50% softwood / 50% hardwood (Energex) pellets. All of the grasses tested had higher NO and Chlorine amounts, but only the Enviro Energy mulch hay pellets had higher SO_2 levels than the wood pellets sampled.

The BERC study used an EPA certified emission testing service with a portable laboratory to provide particulate emission data that showed the mulch hay sample to have the highest particulates followed by Reed Canarygrass and Switchgrass, with the wood pellets having the lowest particulate levels. We tested particulate emissions for the Evoworld boiler using the Wohler RP72 smoke test pump sample method and the wood pellet samples had higher smoke test numbers than all of the grass samples. The sophistication of the sampling methods and the design differences between the boilers may explain this difference.

The BERC report concluded that grass fuels and the issues associated with them are best suited to the commercial users; and that more research is needed to identify boilers that can handle grass fuel and the economic feasibility of making and distributing grass or grass/wood blended fuel. At the time the BERC project research was done Evoworld boilers were not being imported or built in the U.S. and there were fewer options available to densify grass biomass into a pellet or a puck form.

Conclusions and Recommendations

The data obtained in the project confirmed that the Evoworld HC 100 Eco wood chip boiler could burn a variety of grass species, grass/wood blends, and handle two different fuel size forms efficiently and cleanly. The data obtained confirmed that the goals of this project were met.

This project provides new data on the operational performance and costs of operating a production wood chip boiler made in the U.S. with ASME and U.L. certification that efficiently and cleanly burns a variety of grass grown in Vermont and the U.S.

This project would benefit any farm, light industrial plant, or a facility served by a central heating plant in a location that provides access to grass biomass fuel sources and the space to store and handle them in bulk. This project would be especially beneficial to farm operators who have the capability to harvest grass biomass from non-prime agricultural fields, abandoned pasture land, roadsides, or erosion buffer strips that are typically cut only once a season.

Operating a boiler of this size and type on locally grown mulch quality hay, grass biomass or agricultural crop residue rather than harvesting grown trees for chips or pellets presents numerous benefits. Natural resource protection including reducing soil erosion, runoff, and reducing water contamination from soil minerals are obvious benefits because land can be left in perennial grass cover. Perennial grasses are a crop that grows back each season and can be grown on marginal soils or non-prime agricultural areas. The Evoworld boiler we tested offers a viable alternative to burning wood biomass fuel because it can handle the issues unique to burning grass biomass.

Being able to locally grow, harvest, densify and burn a grass biomass fuel keeps dollars in the local economy which is a major economic benefit (Wilson, 2014).

Analysis by Christopher Callahan in his 2016 report based on data collected during this project demonstrated that harvesting, densifying and burning locally harvested grass or other forms of agricultural biomass can compare favorably with the present price of wood chips, wood pellets, and less than # 2 fuel oil (Callahan, 2016 and the table on page 28). This project demonstrated that when the cost of petroleum fuels increase, agricultural biomass and grass fuel can represent a viable fuel source that every farm has access to.

The cost to purchase and install a wood chip boiler with features similar to the Evoworld model we tested exceeds the cost for a similarly sized # 2 fuel oil boiler by two times for our facility, and it could be higher depending on the application (Budget Estimate, page 85). The fact that the Evoworld boiler was designed to handle wood chips allows it to accept a variety of biomass fuels types and form sizes. The cost per unit for some of these biomass fuels allows the payback period for the installation to be reduced over time (Callahan, 2016).

The limiting factor to using agricultural biomass or grass as a fuel for space heat today remains the lack of sources to densify the biomass into 1/4” pellets or 2” diameter pucks. The data collected as a part of this project and analysis performed by Christopher Callahan indicated that the cost to produce the 2” diameter pucks would come down if a steady market demand for these pucks existed (Callahan, 2016).

Based on our experience during this project we recommend adding a sweeper arm or paddle to the firebox combustion shelf where the primary air is introduced (Figure 7, page 46). Activating this sweeper arm at the beginning of each programmed cleaning cycle would remove the unburned residue and any clinkers between each burn cycle. We believe that a modification to the fire box such as this should allow this boiler to operate continuously on grass fuel in these size forms.

Opportunities for future study

In this project a great deal was learned about how to optimize the combustion of different grasses, blends of biomass, and form sizes. I believe it would be beneficial to continue to work with the 1/4” diameter pellet sized fuel to solve the issues we experienced with clinker formation and decreasing combustion performance.

Given the success we achieved burning 2” diameter pucks it would be interesting to test other form sizes such as commercially available cubes or larger diameter pellets.

We intend to more closely monitor the hours of operation following the complete cleaning of the boiler tubes, sand blasting and brushing the stainless steel turbulators, and the replacement of the carbon steel turbulators in the second pass tubes. It would be useful to know if the rusting we experienced over the summer and fall of 2016 was caused in any part by the by-products of the grass combustion, or simply due to humidity in the air being drawn through the boiler when it was shut down.

Given the success we had with a variety of grasses, blends and wood pellets, I would like to test other types of biomass or crop residue in a densified form. Fuel sources for consideration could include shredded paper, cardboard, invasive plants such as buckthorn and honey suckle, aquatic nuisance weeds, and waste from food industry processing.

Having identified the need to remove partially burned fuel from the boiler’s combustion shelf, it would be useful to work out a solution for that issue, make the necessary modifications, and test the operation of the boiler after making the modification until that problem has been solved. A sketch of what this modification might look like can be found in Figure 7 on page 46.

We were fortunate to have an opportunity to contribute to the research on grass biomass combustion in small sized commercial boilers and we look forward to continuing to work with the Evoworld boiler.

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Appendices & Project Photos

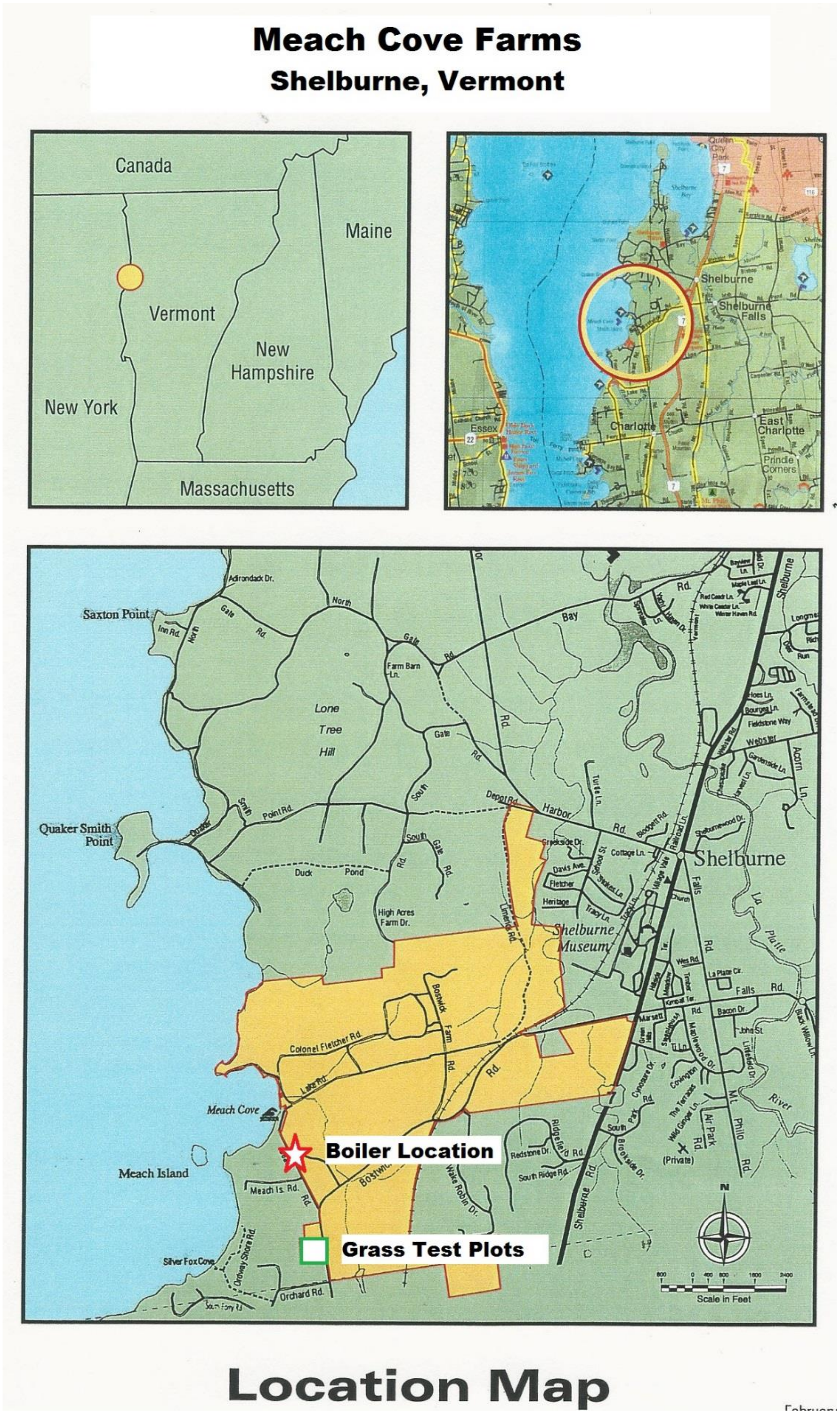
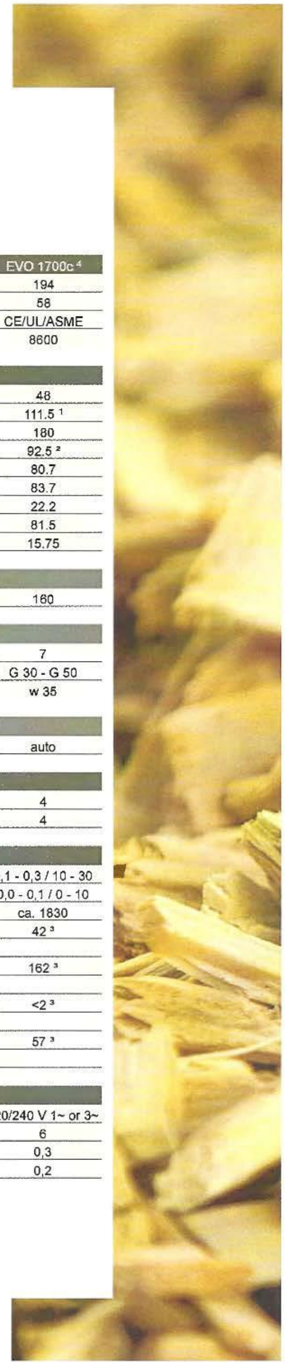


Figure 1 Meach Cove Farms Location Map

Figure 2 Meach Cove Farms Natural Resources Map showing sample sites

Evoworld HC 100 (350C) Eco Boiler Specifications

Biomass solutions for a more ecological and economical world



TYPE	EVO 350c	EVO 700c	EVO 1700c[4]
Max. ajustable boiler température (°F)	185	185	194
Permitted operating pressure (psi)	43.5	43.5	58
CE labeling (acc. to low-voltage directive) UL2523, ASME Sec IV	CE/UL/ASME	CE/UL/ASME	CE/UL/ASME
Total weight (lbs.)	2300	3000	8600
DIMENSIONS			
Boiler width (inch)	29.9	35	48
Boiler depth (inch)	53 [1]	59.5[1]	111.5 [1]
Total depth (inch)	65	71.5	180
Boiler height (inch)	69.5 [2]	77 [2]	92.5 [2]
Boiler tube connection height (inch)	51.2	71.3	80.7
Flow height (inch)	61.4	70	83.7
Return height (inch)	16.1	17.3	22.2
Ventilation height (inch)	61.5	70	81.5
Boiler tube connection diameter (inch)	7.87	11.8	15.75
WATER			
Water content (gals.)	40	60	160
FUEL			
Ash box volume (cu ft.)	2.12	7	7
Max. wood chip size	G 30 - G 50	G 30 - G 50	G 30 - G 50
Max. wood chip water content	w 35	w 35	w 35
ASH REMOVAL			
Ash removal	auto	auto	auto
CONNECTIONS			
Flow (inch)	1 ½	2	4
Return (inch)	1 ½	2	4
EMMISION DATA			
Required negative pressure at full load (mbar/Pa)	0,1 - 0,3 / 10 - 30	0,1 - 0,3 / 10 - 30	0,1 - 0,3 / 10 - 30
Required negative pressure at part load (mbar/Pa)	0,0 - 0,1 / 0 - 10	0,0 - 0,1 / 0 - 10	0,0 - 0,1 / 0 - 10
Combustion chamber temperature (°F)	ca. 1830	ca. 1830	ca. 1830
CO at full load (mg/m^3)	212 [3]	53 [3]	42 [3]
CO at part load (mg/m^3)	48 [3]	73 [3]	
NOx at full load (mg/m^3)	110 [3]	127 [3]	162 [3]
NOx at part load (mg/m^3)	108 [3]	107 [3]	
HC at full load (mg/m^3)	4 [3]	1 [3]	<2 [3]
HC at part load (mg/m^3)	1 [3]	1 [3]	
Dust at full load (mg/m^3)	20 [3]	39 [3]	57 [3]
Dust at part load (mg/m^3)	10 [3]	5 [3]	
ELECTRIC POWER CONSUMPTION			
Supply needed	220/240 V 1~ or 3~	220/240 V 1~ or 3~	220/240 V 1~ or 3~
Standby (W)	5	6	6
Power consumption at full load in % of full load	0,4	0,3	0,3
Power consumption at part load in % of part load	0,2	0,1	0,2

1) excl. exhaust fan / stoker 2) excl. chimney box 3) emissions data based on 13 % O2 dry
4) tested with exhaust cyclone

8

Figure 3 Evoworld HC 100 (350C) Eco boiler Specifications

Evoworld HC 100 (350C) Eco Boiler Dimensions in Millimeters

Figure 4 Evoworld HC 100 (350C) Eco Boiler Dimensions

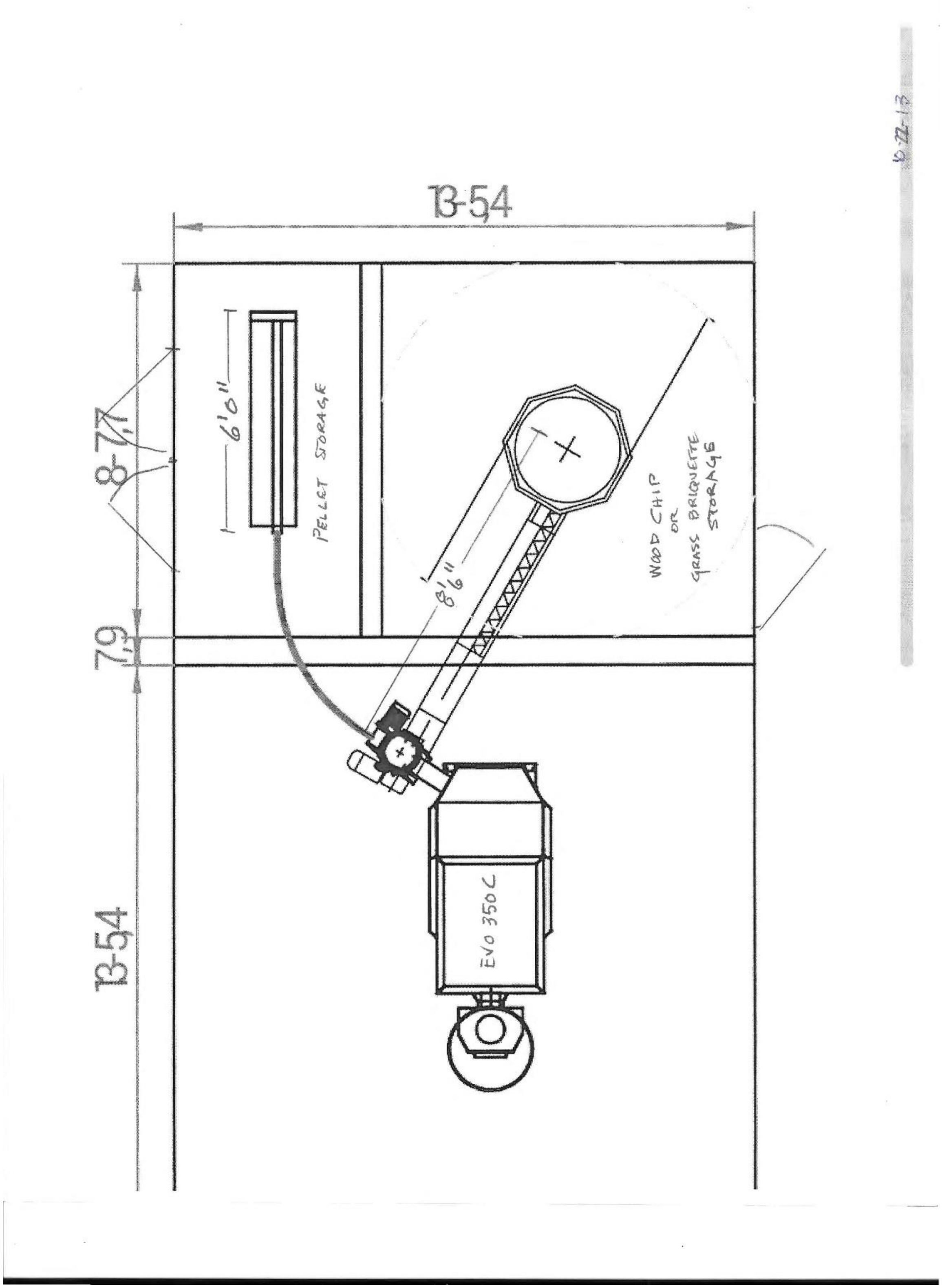


Figure 5 Evoworld boiler fuel system layout, 10-22-2013

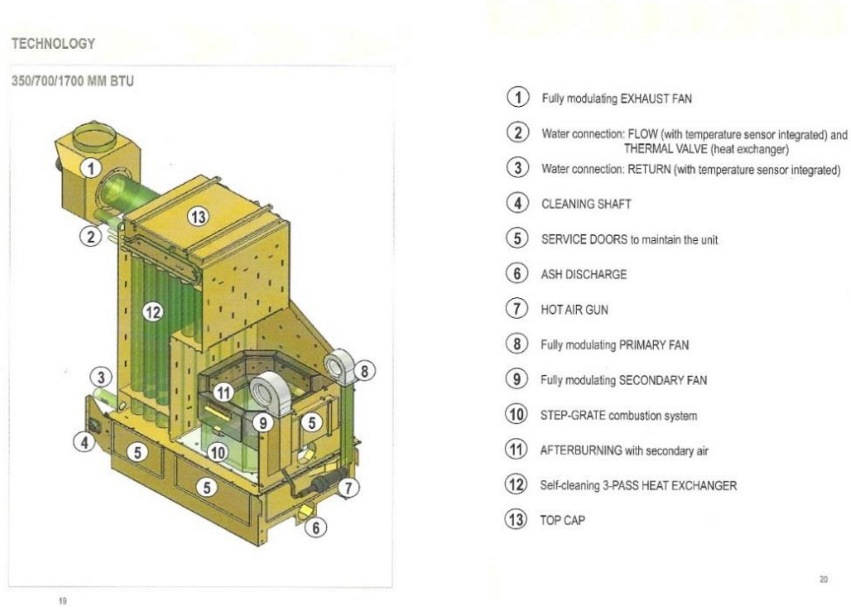


Figure 6 Evoworld boiler parts diagram and key

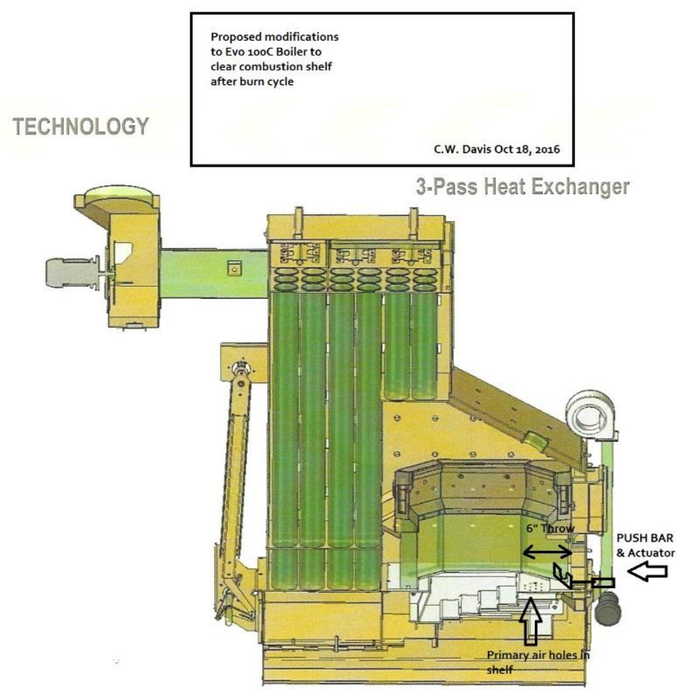


Figure 7 Evoworld boiler with modifications to clear combustion shelf, 10-18-2016

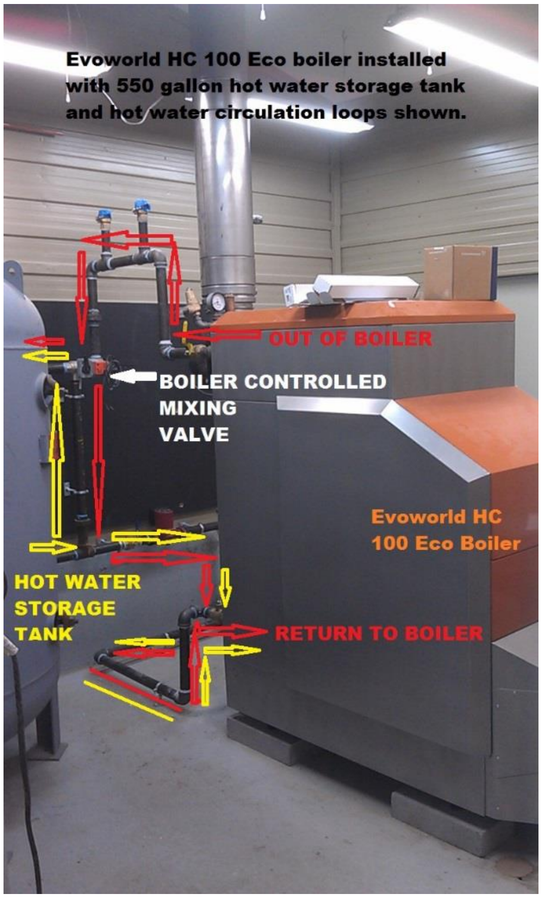


Figure 8 Evoworld boiler and buffer tank loop, 2-22-2017

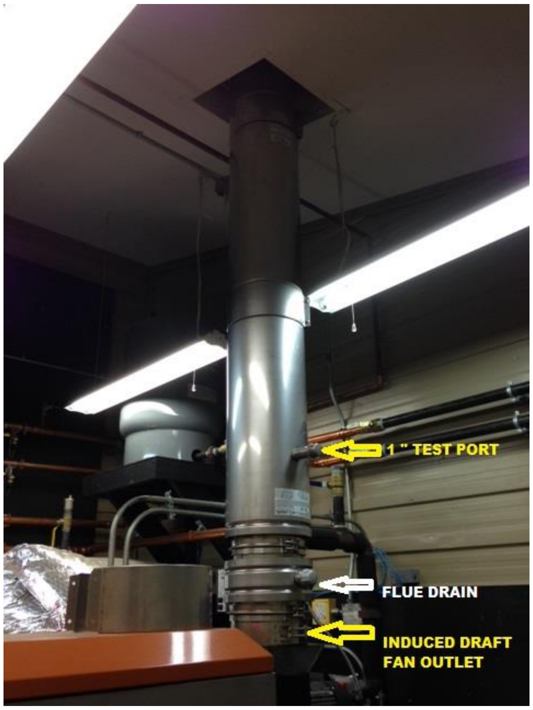


Figure 9 Evoworld HC 100 Eco boiler - 8" flue showing test port, 6-23-2015

Figure 10 Close-up of turbulators new and 890 hours of operation, 12-20-2016

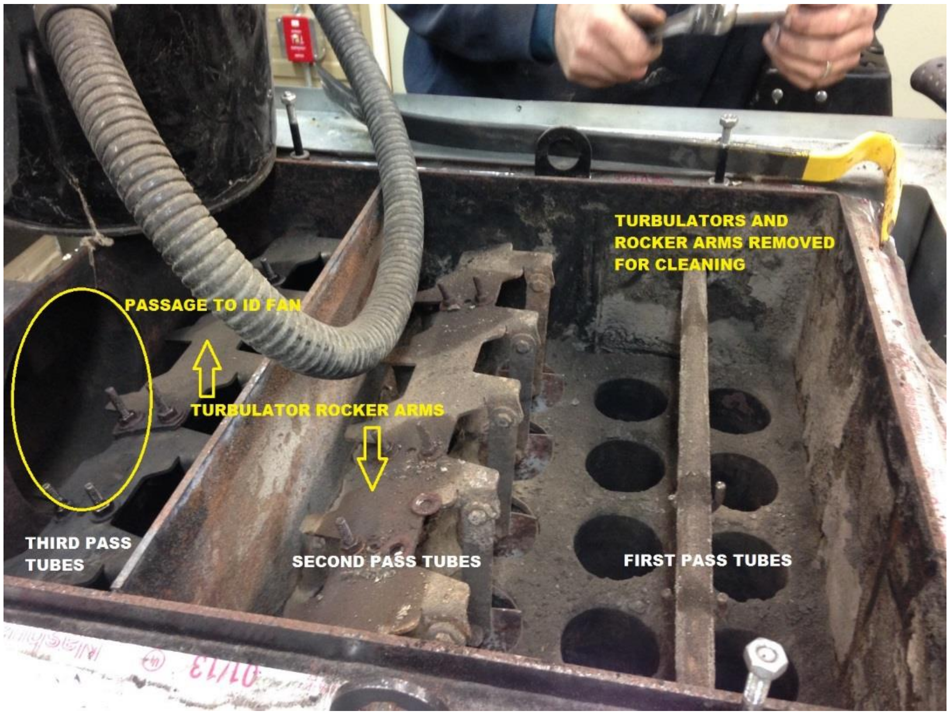


Figure 11 Top of boiler open for cleaning after 890 hours of operation, 12-20-2016

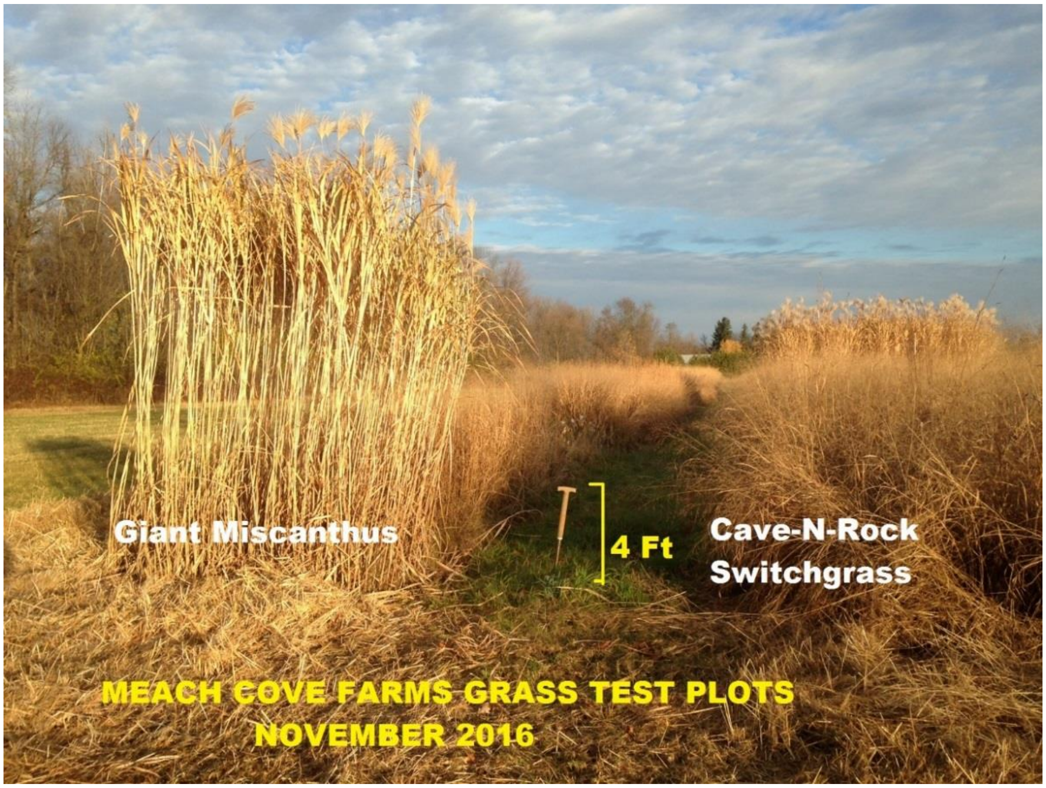


Figure 12 Meach Cove Farms grass test plots, 11-15-2016

Figure 13   Switchgrass round bales - Meach Cove 11-15-2016

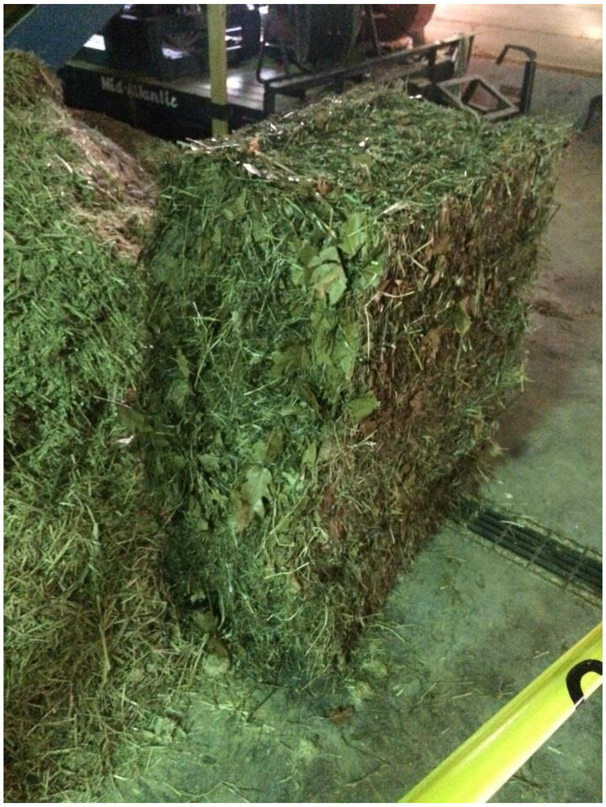


Figure 14 Meach Cove Ag Biomass bales before grinding, 11-23-2015 (Photo courtesy of C. Callahan)

Figure 15 Meach cove Ag biomass square bales with leaves, 11-23-2015(Photo courtesy of C. Callahan)

2” Puck Production

Figure 16 Adam Dantzscher explains biomass densification equipment (BHS “Slugger”), August 2015

Figure 17 1/4" diameter pellet form and 2" diameter "puck" form

Figure 18 Pucks in bulk bags at Meach Cove in storage waiting for testing

Figure 19 Evoworld chip conveyor in fuel bin, 2'' puck fuel, 2015

Figure 20 Evoworld HC 100 wood chip conveyor loaded with 2" pucks, March 2015

Figure 21 Mulch hay pucks during combustion cycle, March 2015

Pellet Production

Figure 22 Enviro Energy, Wells Bridge, NY - Hay chopping equipment, 12-6-2011

Figure 23 Enviro Energy pellet plant interior, grinder and dryer, 12-6-2011

Figure 24 Bob Miller (left) and his son Mike Miller, Enviro Energy, 12-6-2011

Figure 25 Enviro Energy 1/4" Diameter mulch hay pellets

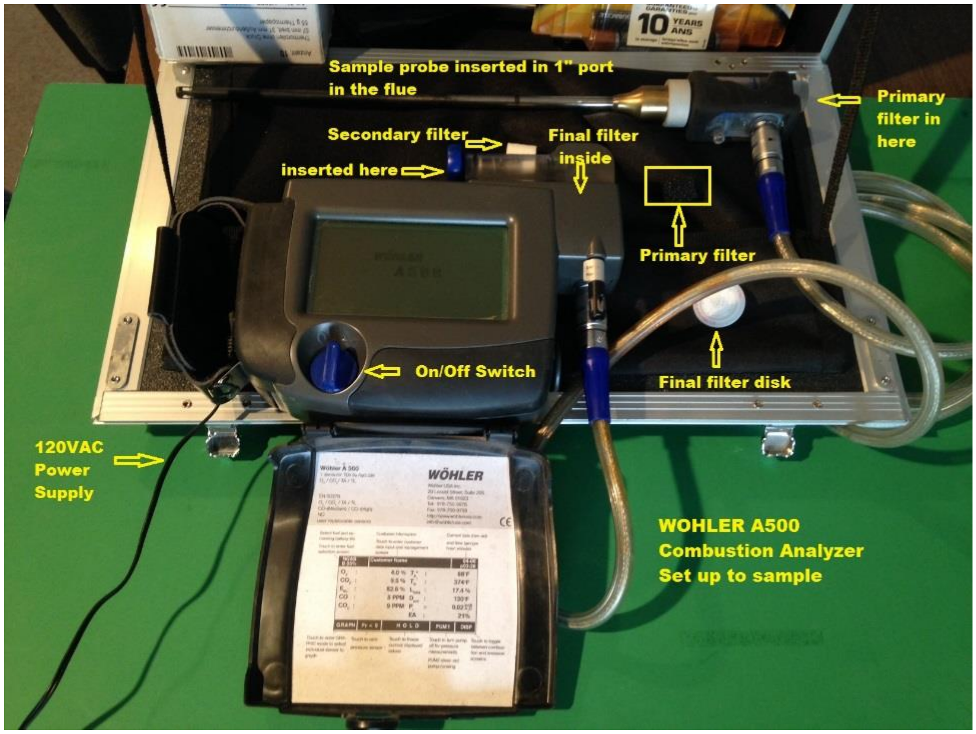


Figure 26 Wohler A500 Emission Analyzer

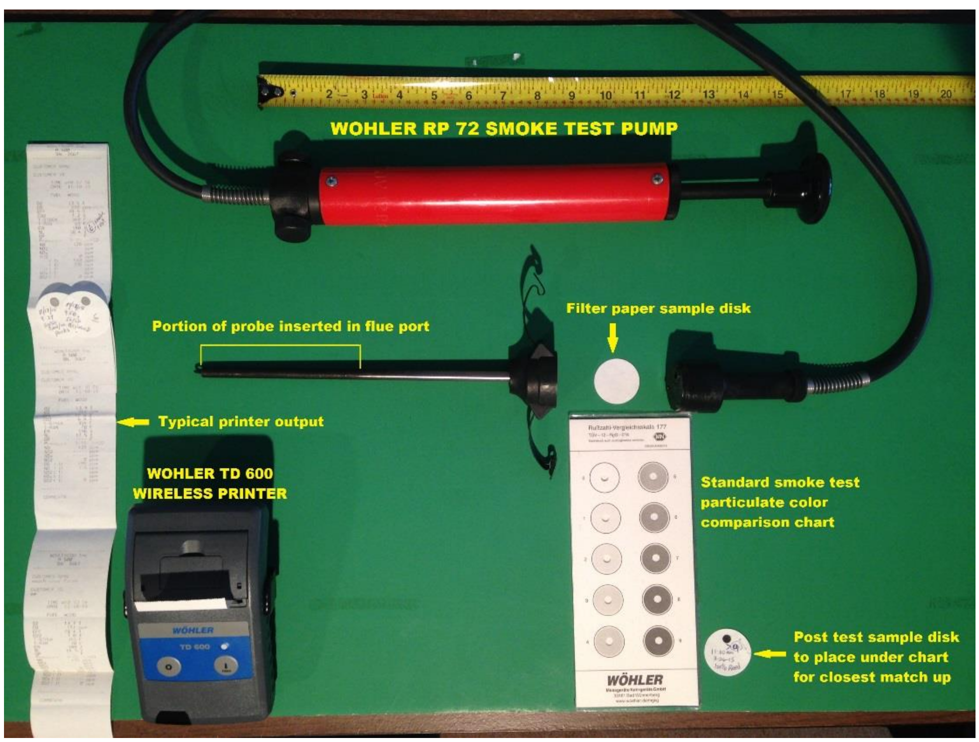


Figure 27 Wohler RP72 Smoke Test Pump

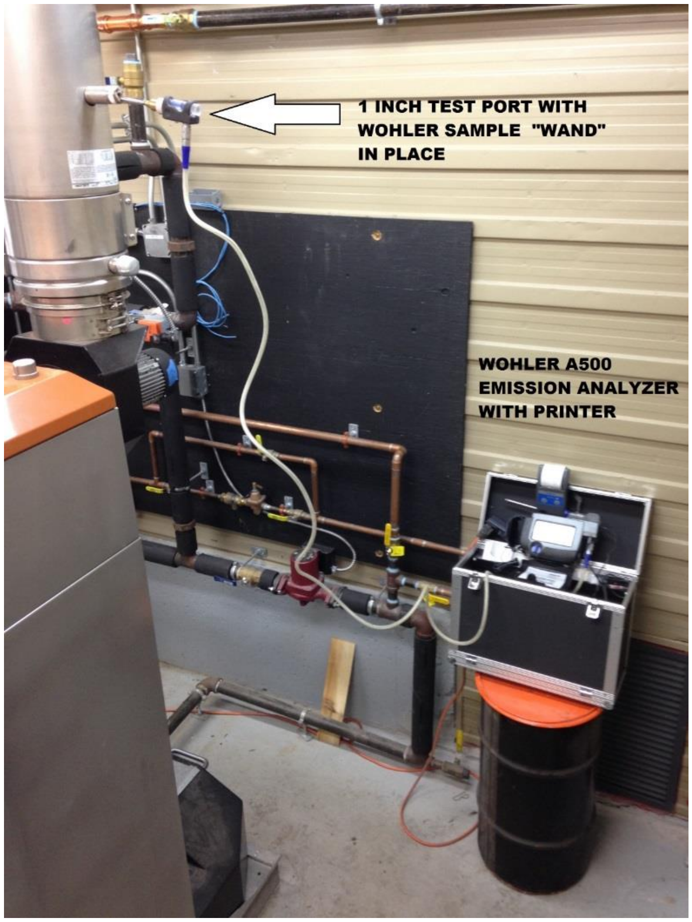


Figure 28 Wohler A500 set-up to sample, March 2015

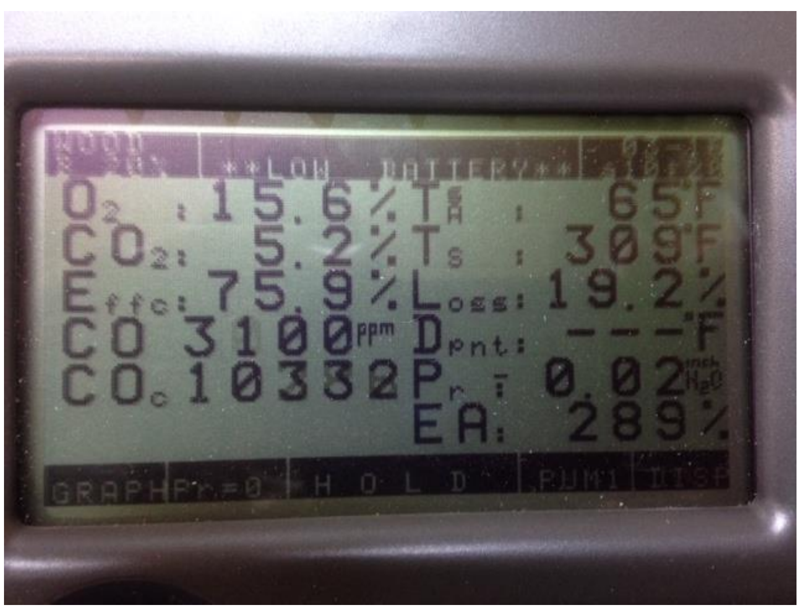


Figure 29 Wohler A500 screen view, mulch hay pellet test, and 3-16-2015

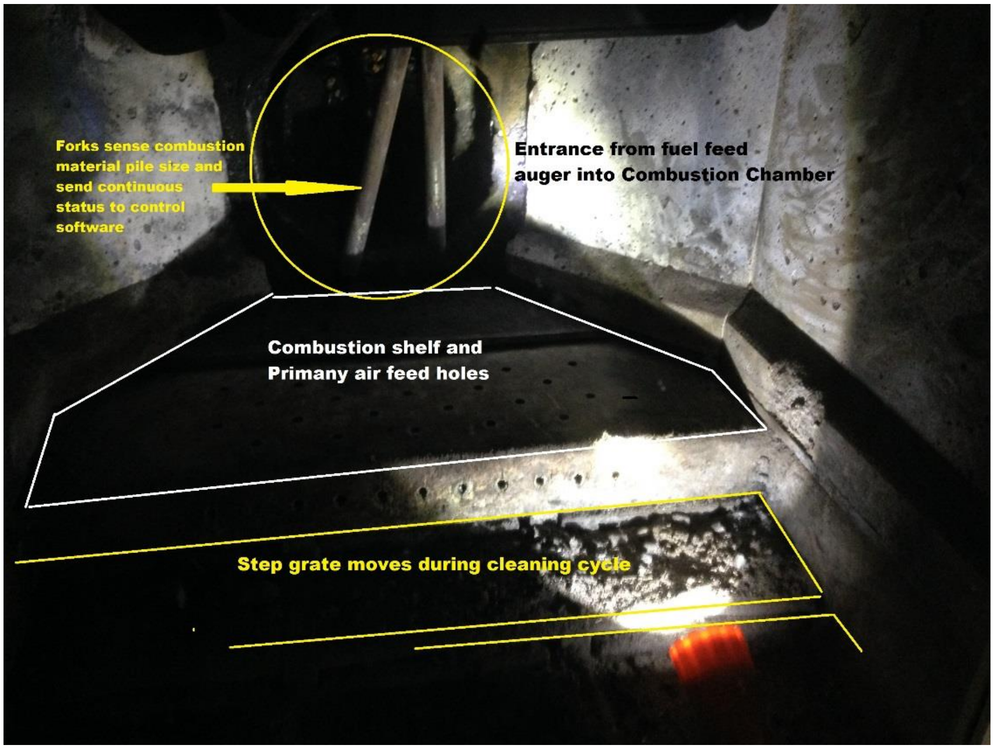


Figure 30 Clean combustion chamber with components labeled, 2015

Figure 31 Grass puck post burn residue in the combustion chamber, 2015

Figure 32 Evoworld HC 100 combustion chamber with grass pellet residue, March 2015

Figure 33 Enviro Energy hay pallets, clinker, 3-10-2015

Figure 34 Sid Bosworth presenting to a UVM Biomass Energy class at Meach Cove, 3-25-2016

Figure 35 Sid Bosworth, UVM Extension, tapes a report for WCAX TV 3 Across the Fence, Sept. 2015

Figure 36 Fox 22/44 reporter does a broadcast on the project, 10-24-2015

Figure 37 WCAX Channel 3 Across the Fence report being taped, 10-29-2015

Figure 38 Field to Flue Open House poster, October 2015

Figure 39 Meach Cove Farms Open House display presentation, 10-23-2015

Raw Combustion Data

Field Combustion Measurements March-June 2015

100% VT Wood Pine Pellets

Run #1	Stack Temp	Blend:	100%	VT Wood				Test date:	3/13/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
7:46:00	375	10.60%	187	10.10%	81.00%	102.00%	52	1				
8:05:32	372	10.20%	190	10.40%	81.70%	94.00%	52	0	9			
8:15:59	390	10.40%	294	10.20%	80.90%	98.00%	52	1				
Avg	379	10.40%	224	10.23%	81.20%	98.00%	52	1	9			
Run #2	Stack Temp	Blend:	100%	VT Wood				Test date:	4/2/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
2:04:05	370	11.30%	1123	0.00%	0.00%	0.00%	50	10		.8/1.0/1.2	90/90/20	
3:11:48	404	10.90%	1438	9.80%	79.90%	108.00%	35	27	>9	.1.2	88/90/20M	
3:20:27	399	12.00%	962	8.70%	78.60%	133.00%	27	16		1.2	82/10/22A	
Avg	391	11.40%	1174	6.17%	52.83%	80.33%	37	18	>9			
Run #3	Stack Temp	Blend:	100%	VT Wood				Test date:	4/3/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
11:20:27	339	12.50%	406	8.20%	80.70%	147.00%	43	3		.8/1.0/1.2	80/10/22A	
11:34:34	379	11.40%	302	9.30%	80.30%	119.00%	42	0	>9	1.2	79/10/22	
11:56:21	384	15.30%	41	5.50%	72.10%	268.00%	7	0		1.2	77/10/22	
Avg	367	13.07%	250	7.67%	77.70%	178.00%	31	1	>9			
Run #4	Stack Temp	Blend:	100%	VT Wood				Test date:	4/10/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
10:31:27	370	11.50%	1098	9.20%	80.10%	121.00%	42	14		1.2	79/20/22	15
11:02:46	386	14.70%	119	6.10%	73.20%	233.00%	9	0	>9		84/20/22	16
11:17:34	397	15.90%	58	4.90%	68.10%	312.00%	6	3			83/20/22	16
Avg	384	14.03%	425	6.73%	73.80%	222.00%	19	6	>9			
100% VT Wood Avg	380	12.23%	518	7.70%	71.38%	144.58%	35	6	>9			

100% Energex Wood Blend Pellets

Run #1	Stack Temp	Blend:	100%	Energex Wood Blend				Test date:	3/4/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
3:44:23	341	9.70%	82	10.90%	83.70%	86.00%	72	1				
3:58:53	339	9.50%	66	11.10%	84.40%	83.00%	69	0	7			
4:17:54	329	15.70%	659	5.10%	75.80%	296.00%	33	4				
Avg	336	11.63%	269	9.03%	81.30%	155.00%	58	2	7			
Run #2	Stack Temp	Blend:	100%	Energex Wood Blend				Test date:	4/10/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
2:40:15	352	14.80%	243	6.00%	75.60%	239.00%	48	2		1.2	76/20/22	14
3:01:29	381	9.40%	245	11.20%	82.20%	81.00%	65	1	9	1.2	76/20/22	14
3:20:37	395	9.40%	351	11.20%	81.70%	81.00%	64	4		1.2	76/18/23	15
Avg	376	11.20%	280	9.47%	79.83%	133.67%	59	2	9			
100% Energex Wood Blend Avg	356	11.42%	274	9.25%	80.57%	144.33%	59	2	8			

Field Combustion Measurements March-June 2015- continued

100% Enviro Energy Mulch Hay Pellets												
Run #1	Stack Temp	Blend:	100%	Hay (Enviro Energy)				Test date:	3/10/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
7:49:33	338	15.60%	2857	5.20%	73.30%	289.00%	107	14				
8:08:59	359	14.40%	39	6.40%	76.20%	218.00%	120	27	8			
8:25:57	363	14.60%	2688	6.20%	87.20%	228.00%	128	19				
Avg	353	14.87%	1861	5.93%	78.90%	245.00%	118.3333	20	8			
Run #2	Stack Temp	Blend:	100%	Hay (Enviro Energy)				Test date:	3/23/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
1:30:16	208	18.90%	1669	2.00%	69.20%	900.00%	44	26		.4/.5/.8	85/25/22	
1:51:23	212	19.20%	1475	1.70%	64.50%	999.00%	39	139	>9	.4/.6/.8	70/60/40	
2:06:25	213	19.40%	1387	1.50%	60.50%	999.00%	40	99			78/60/28	
Avg	211	19.17%	1510	1.73%	64.73%	966.00%	41	88	>9			
Run #3	Stack Temp	Blend:	100%	Mulch Hay				Test date:	3/27/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
1:41:32	366	10.60%	3562	10.10%	81.80%	102.00%	138	66		.8/1.0/1.5	84/70/19	
1:58:13	363	11.30%	0	9.40%	81.40%	116.00%	122	231	5	1.5	88/70/19	
2:19:02	341	15.20%	0	5.60%	75.80%	262.00%	106	20		1.5	88/70/19	
Avg	357	12.37%	1187	8.37%	79.67%	160.00%	122	106	5			
Run #4	Stack Temp	Blend:	100%	Mulch Hay				Test date:	3/30/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
11:20:09	375	11.00%	2000	9.70%	88.80%	110.00%	159	66		.6/.8/1.2	85/83/19	
11:34:46	366	12.30%	2000	8.40%	88.60%	141.00%	153	95	7		86/83/19	
11:48:06	375	11.30%	2000	9.40%	88.70%	116.00%	148	68			86/83/19	
Avg	372	11.53%	2000	9.17%	88.70%	122.33%	153.3333	76	7			
Run #5	Stack Temp	Blend:	100%	Mulch Hay				Test date:	3/30/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
2:07:03	329	10.10%	3000	10.50%	91.00%	93.00%	133	171		.6/.8/1.2	82/80/20	
2:19:33	381	11.50%	3000	9.20%	88.30%	121.00%	151	43	9	1.2	87/85/20	
2:34:34	375	12.80%	181	7.90%	87.80%	156.00%	142	28		1.2	90/85/20	
Avg	362	11.47%	2060	9.20%	89.03%	123.33%	142	81	9			
100%Hay Avg	331	13.88%	1724	6.88%	80.21%	323.33%	115	74	>7			

Field Combustion Measurements March-June 2015- continued

100% Switch Grass Pellets

Run #1	Stack Temp	Blend:	100%	Switchgrass				Test date:	3/6/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
3:16:18	325	13.20%	202	7.50%	79.80%	169.00%	158	0				
3:29:02	347	12.10%	238	8.60%	80.20%	136.00%	151	0				
4:07:05	273	17.70%	220	3.20%	70.10%	536.00%	63	2				
Avg	315	14.33%	220	6.43%	76.70%	280.33%	124	1				
Run #2	Stack Temp	Blend:	100%	Switchgrass				Test date:	3/13/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
11:51:26	257	18.40%	387	2.50%	66.10%	708.00%	62	3		.4/.6/.8	80/20/35	
12:09:28	242	18.60%	200	2.30%	66.20%	775.00%	47	0			75/30/40	
12:29:28	221	18.50%	170	2.40%	70.80%	740.00%	61	1	7		85/30/40	
12:49:23	246	18.70%	106	2.20%	64.80%	813.00%	63	0			85/30/40	
1:04:54	231	19.40%	134	1.50%	55.50%	999.00%	40	0				
Avg	239	18.72%	199	2.18%	64.68%	807.00%	57	1	7			
Run #3	Stack Temp	Blend:	100%	Switchgrass				Test date:	3/24/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
11:56:33	271	17.50%	553	3.40%	71.40%	500.00%	75	0		.4/.6/.9	100/60/28	
12:18:13	240	18.40%	386	2.50%	68.80%	708.00%	60	0		.4/.6/1.0	90/50/22	
12:34:09	235	18.50%	647	2.40%	68.40%	740.00%	60	0	7	.4/.6/1.0	90/50/22	
2:15:34	334	10.30%	147	10.30%	83.00%	96.00%	182	0		.4/.6/.8	80/0/30	
Avg	270	16.18%	433	4.65%	72.90%	511.00%	94	0	7			
Run #4	Stack Temp	Blend:	100%	Switchgrass				Test date:	3/25/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
1:19:43	206	19.10%	252	1.80%	65.30%	999.00%	59	0		.4/.5/1.6	75/25/25	
1:32:20	239	18.60%	408	2.30%	67.10%	775.00%	73	0	7	.4/.5/1.6	74/40/20	
1:50:59	237	18.80%	406	2.10%	65.70%	855.00%	66	0		.4/.5/2.0	74/75/20	
Avg	227	18.83%	355	2.07%	66.03%	876.33%	66	0	7			
Run #5	Stack Temp	Blend:	100%	Switchgrass				Test date:	4/1/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
12:12:33	348	14.40%	435	6.40%	88.20%	218.00%	112	0		.8/1.0/1.2	90/90/20	
12:28:22	348	14.10%	924	6.70%	88.50%	204.00%	118	8	9	1.5	92/90/20	
12:47:58	336	15.10%	432	5.70%	88.50%	256.00%	124	0		1.2	88/90/20	
Avg	344	14.53%	597	6.27%	88.40%	226.00%	118	3	9			
Run #6	Stack Temp	Blend:	100%	Switchgrass				Test date:	4/1/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
3:07:50	375	10.30%	2400	0.00%	0.00%	0.00%	130	7		.8/1.2/1.2	92/90/20	
3:26:31	354	14.50%	507	0.00%	0.00%	0.00%	101	0	>9	1.3	92/90/20	
3:44:24	352	14.90%	525	0.00%	0.00%	0.00%	113	0		1.3	90/90/20	
Avg	360	13.23%	1144	0.00%	0.00%	0.00%	115	2	>9			
Run #7	Stack Temp	Blend:	100%	Switchgrass				Test date:	4/2/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
8:36:24	368	12.00%	920	0.00%	0.00%	0.00%	79	3		.8/1.2/1.3	91/90/20	
8:54:22	347	14.40%	342	0.00%	0.00%	0.00%	65	0	8	1.3	90/90/20	
9:15:53	329	16.30%	388	0.00%	0.00%	0.00%	95	0		1.3	88/90/20	
Avg	348	14.23%	550	0.00%	0.00%	0.00%	80	1	8			
Run #8	Stack Temp	Blend:	100%	Switchgrass				Test date:	4/6/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
12:13:01	327	20.20%	37	70.00%	0.00%	0.00%	15	0		.6/1.0/1.2	10/73m/22	13
12:23:30	343	14.90%	724	5.90%	75.50%	244.00%	88	0	none taken	.6/1.0/1.2	90/80m/22	15
12:38:05	320	15.90%	355	4.90%	74.30%	312.00%	65	0		1.5	76/88m/10m	
Avg	330	17.00%	372	26.93%	49.93%	185.33%	56	0				
Run #9	Stack Temp	Blend:	100%	Switchgrass				Test date:	4/13/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
12:50:03	341	12.80%	592	7.90%	80.10%	156.00%	117	2		.8/1.0/1.4	76/50/22	12
1:09:17	330	14.90%	259	5.90%	76.70%	244.00%	107	0	8	1.4	77/50/22	15
1:27:33	329	15.00%	384	5.80%	76.70%	250.00%	113	0		1.4	75/20/25	16
Avg	333	14.23%	412	6.53%	77.83%	216.67%	112	1				
100% SW Avg	302	15.92%	456	5.81%	56.39%	381.10%	89	1	>6			

Field Combustion Measurements March-June 2015- continued

6% - 24% Switch Grass Pellets

Run #1	Stack Temp	Blend:	6%	Switchgrass (S5)				Test date:	3/5/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
2:40:14	375	9.10%	108	11.50%	82.40%	76.00%	76	3				
2:51:20	379	9.60%	78	11.00%	81.80%	84.00%	72	0				
3:02:14	372	9.90%	101	10.70%	81.80%	89.00%	70	0				
Avg	375	9.53%	96	11.07%	82.00%	83.00%	73	1				

Run #1	Stack Temp	Blend:	12%	Switchgrass (S4)				Test date:	3/6/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
8:35:35	365	9.30%	190	11.30%	82.40%	79.00%	82	1				
8:42:45	381	8.90%	93	11.70%	82.20%	74.00%	82	0				
8:59:12	390	9.60%	87	11.00%	81.40%	84.00%	79	7				
Avg	379	9.27%	123	11.33%	82.00%	79.00%	81	3				

Run #1	Stack Temp	Blend:	24%	Switchgrass				Test date:	3/6/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
11:26:37	354	9.90%	131	10.70%	82.60%	89.00%	93	0				
11:32:44	356	9.50%	127	11.10%	82.90%	83.00%	94	1				
11:47:53	370	10.00%	92	10.60%	81.80%	91.00%	94	1				
Avg	360	9.80%	117	10.80%	82.43%	87.67%	94	1				

100% Switch Grass Pucks												
Run #1	Stack Temp	Blend:		Switchgrass pucks(10-12% moisture)				Test date:	4/7/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
1:38:24	375	13.70%	459	7.00%	76.30%	188.00%	103	0			97/50/22	
1:54:21	374	13.80%	627	6.90%	76.40%	192.00%	103	0	9		96/45/22	
2:14:30	370	11.00%	465	9.70%	80.90%	110.00%	138	0			84/42/22	9
2:18:06	383	11.00%	419	9.70%	80.30%	110.00%	135	0			88/44/22	15
Avg	376	12.38%	493	8.33%	78.48%	150.00%	115	0	9			
Run #2	Stack Temp	Blend:		Switchgrass pucks(10-12% moisture)				Test date:	4/8/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
11:48:06	386	11.70%	336	9.00%	79.20%	126.00%	105	0		1.5/3.0/5.0	87/44/22	14
12:03:14	383	12.70%	447	8.00%	77.90%	153.00%	109	0	8	5.0/3.5sec	87/45/22	12
12:17:36	383	12.10%	420	8.60%	78.90%	136.00%	107	0		5.0/5sec	87/45/22	14
Avg	384	12.17%	401	8.53%	78.67%	138.33%	107	0	8			
Run #2	Stack Temp	Blend:		Switchgrass pucks(10-12% moisture)				Test date:	4/8/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
2:40:27	384	11.70%	520	9.00%	79.20%	126.00%	109	0		5.0/5sec	88/44/22	9
3:12:58	383	14.60%	480	6.20%	73.60%	228.00%	71	0	7		93/50/22	16
3:36:32	393	13.70%	531	7.00%	75.40%	188.00%	88	1			92/50/22	14
Avg	387	13.33%	510	7.40%	76.07%	180.67%	89	0	7			
Run #3	Stack Temp	Blend:		Switchgrass pucks(10-12% moisture)				Test date:	4/14/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
9:51:47	339	14.60%	491	6.20%	76.80%	228.00%	86	0		1.5/3.0/5.0	82/50/22	12
10:28:46	338	15.10%	511	5.70%	75.70%	256.00%	78	2	7		83/50/22	8
10:50:16	347	13.80%	520	6.90%	78.30%	192.00%	88	1		1.5/3.0/5.0	83/50/22	11
Avg	341	14.50%	507	6.27%	76.93%	225.33%	84	1	7			
Run #4	Stack Temp	Blend:		Switchgrass pucks(+-18% moisture)				Test date:	6/3/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
11:24:25	345	12.60%	603	8.10%	80.10%	150.00%	110	3				
11:42:34	374	12.90%	366	7.80%	78.30%	159.00%	105	0	7			
11:52:56	365	14.50%	292	6.30%	75.40%	223.00%	79	1				
AVG	361	13.33%	420	7.40%	77.93%	177.33%	98	1	7			
Run #5	Stack Temp	Blend:		Switchgrass pucks(+-18% moisture)				Test date:	6/3/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
1:21:29	327	15.80%	191	5.00%	74.30%	304.00%	73	0		Manual	100/38/40	
1:32:24	323	16.90%	140	3.90%	70.10%	412.00%	56	1	5.5		100/38/40	
1:45:37	323	15.90%	214	4.90%	74.40%	312.00%	76	0			100/38/38	
AVG	324	16.20%	182	4.60%	72.93%	342.67%	68	0	5.5			
SW grass pucks Avg	363	13.58%	423	7.15%	76.92%	199.63%	96	0	7.25			

100% Reed Canary Grass Pellets

Run #1	Stack Temp	Blend:	100%	Reed Canary Grass (MCF)				Test date:	3/11/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
1:35:10	307	16.70%	144	4.10%	71.90%	388.00%	73	0		.4/.6/.8	77/20/22	
1:47:52	294	17.20%	100	3.60%	70.50%	453.00%	68	0	7	.4/.6/.6	77/30/22	
2:18:35	285	17.80%	142	3.10%	67.90%	556.00%	56	0		.4/.6/.8	85/40/22	
Avg	295	17.23%	129	3.60%	70.10%	465.67%	66	0	7			
Run #2	Stack Temp	Blend:	100%	Reed Canary Grass (MCF)				Test date:	3/26/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
9:31:12	339	12.00%	481	8.70%	80.80%	133.00%	120	0		.8/1.0/1.2	76/76/16	
9:47:54	354	11.80%	824	8.90%	80.50%	128.00%	119	1	>9	.8/1.0/1.5	81/76/18	
10:16:54	323	13.10%	373	7.60%	80.20%	166.00%	117	6		.6/1.0/1.5	78/76/16	
Avg	339	12.30%	559	8.40%	80.50%	142.33%	119	2	>9			
Run #3	Stack Temp	Blend:	100%	Reed Canary Grass (MCF)				Test date:	3/27/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
8:05:31	361	9.10%	1440	11.50%	83.00%	76.00%	130	10		.6/1.0/1.5	79/76/16	
8:16:11	354	12.00%	387	8.70%	80.60%	133.00%	120	3	>9	.6/.8/1.5	79/76/16	
8:31:21	350	13.50%	181	7.20%	78.60%	180.00%	104	4		.6/.8/1.5	83/76/16	
Avg	355	11.53%	669	9.13%	80.73%	129.67%	118	6	>9			
Run #4	Stack Temp	Blend:	100%	Reed Canary Grass (MCF)				Test date:	3/31/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
8:34:20	366	7.30%	3999	13.30%	90.30%	53.00%	124	48		.6/.8/1.2	76/88/20	
8:51:54	379	9.50%	3000	11.10%	89.30%	83.00%	135	0	9	1.2	75/88/20	
9:11:05	370	11.20%	285	9.50%	89.00%	114.00%	128	0		1.2	74/88/20	
Avg	372	9.33%	2428	11.30%	89.53%	83.33%	129	16	9			
Run #5	Stack Temp	Blend:	100%	Reed Canary Grass (MCF)				Test date:	3/31/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
12:13:37	383	12.50%	3000	8.20%	87.70%	147.00%	94	0		.6/.8/1.2	80/88/20	
12:28:27	375	12.90%	255	7.80%	87.80%	159.00%	121	0	>9	1.2	90/88/20	
12:43:13	375	13.10%	417	7.60%	87.70%	166.00%	117	0		1.2	91/88/20	
Avg	378	12.83%	1224	7.87%	87.73%	157.33%	111	0	>9			
Run #6	Stack Temp	Blend:	100%	Reed Canary Grass (MCF)				Test date:	4/1/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
8:35:12	392	11.40%	303	9.30%	87.90%	119.00%	139	0		.8/1.0/1.2	90/88/20	
8:50:40	379	13.60%	254	7.10%	0.00%	0.00%	114	1	8	.8/1.0/1.2	90/88/20	
9:05:10	368	13.90%	466	6.80%	87.50%	196.00%	108	1		1.2	90/88/20	
Avg	380	12.97%	341	7.73%	58.47%	105.00%	120	1	8			
100% RC Avg	353	12.70%	892	8.01%	77.84%	180.56%	112	4	7->9			

Field Combustion Measurements March-June 2015-continued

6% - 24% Reed Canary Grass Pellets

Run #1	Stack Temp	Blend:	6%	Reed Canary Grass (R4)				Test date:	3/10/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
10:45:28	370	12.50%	276	8.20%	79.40%	147.00%	54	3				
11:00:29	386	10.40%	186	10.20%	81.40%	98.00%	67	0				
11:12:47	384	11.00%	245	9.70%	80.70%	110.00%	63	4				
Avg	380	11.30%	236	9.37%	80.50%	118.33%	61	2				

Run #1	Stack Temp	Blend:	12%	Reed Canary Grass (R3)				Test date:	3/11/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
7:18:16	318	13.50%	167	7.20%	80.80%	180.00%	59	1				
7:30:25	356	11.60%	128	9.10%	81.40%	123.00%	72	0				
7:47:48	379	11.10%	124	9.60%	81.00%	112.00%	77	0				
Avg	351	12.07%	140	8.63%	81.07%	138.33%	69	0				

Run #1	Stack Temp	Blend:	24%	Reed Canary Grass (R2)				Test date:	3/11/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
11:16:40	347	16.30%	319	4.50%	75.40%	347.00%	50	3				
11:29:06	312	16.60%	251	4.20%	73.00%	377.00%	50	0				
11:45:21	303	16.60%	193	4.20%	73.90%	377.00%	50	0				
Avg	321	16.50%	254	4.30%	74.10%	367.00%	50	1				
6-24% Reed Canary Avg	351	0	210	0	1	2	60	1	7.25			

6% - 24% Mulch Hay Pellets

Run #1	Stack Temp	Blend:	6%	Mulch Hay				Test date:	3/9/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
8:56:05	392	10.20%	375	10.40%	80.90%	94.00%	68	1				
9:05:24	395	10.10%	169	10.50%	81.00%	93.00%	73	1				
9:18:06	406	10.70%	278	10.00%	80.00%	104.00%	71	2				
9:24:18	406	10.50%	190	10.20%	80.40%	100.00%	73	0				
Avg	400	10.38%	253	10.28%	80.58%	97.75%	71	1				

Run #1	Stack Temp	Blend:	12%	Mulch Hay (M3)				Test date:	3/9/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke	Fuel feed	Fan speed	Pa
11:49:52	343	11.30%	152	9.40%	81.60%	116.00%	90	1				
11:58:51	370	9.30%	169	11.30%	82.40%	79.00%	106	5				
12:06:56	406	8.80%	186	11.80%	81.50%	72.00%	109	0				
Avg	373	9.80%	169	10.83%	81.83%	89.00%	102	2				

Run #1	Stack Temp	Blend:	24%	Mulch Hay (M2)				Test date:	3/9/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
2:18:48	298	15.90%	164	4.90%	76.30%	312.00%	66	0				
2:30:06	345	12.00%	215	8.70%	81.30%	133.00%	108	0				
2:38:16	375	9.10%	269	11.50%	82.60%	76.00%	139	0				
Avg	339	12.33%	216	8.37%	80.07%	173.67%	104	0				
6-24% Mulch Hay Avg	374	0	217	0	1	1	90	1	7->9			

Field Combustion Measurements October - November 2015

100% Energex Wood Blend Pellets

Run #1	Stack Temp	Blend:	100%	Energex Wood Blend				Test date:	10/14/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
1:35:42	307	12.00%	319	8.70%	83.10%	133.00%	59	1	>9	baseline settings		
2:15:47	343	9.50%	364	11.10%	83.80%	83.00%	66	0	>9	higher feed 4,6		8
2:28:47	379	8.60%	432	12.00%	83.10%	69.00%	73	0				10;+-1
2:36:19	386	9.20%	450	11.40%	82.50%	78.00%	70	0				
2:38:04	386	9.30%	378	11.30%	82.40%	79.00%	70	2		80/20/25		12;+-1
2:43:10	386	10.10%	268	10.50%	81.60%	93.00%	67	0		80/20/25		14;+-1
Avg	365	9.78%	369	10.83%	82.75%	89.17%	68	1	>9			

100% Enviro Energy Hay pellets

Run #1	Stack Temp	Blend:						Test date:	11/30/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
11:52:00	249	18.30%	1185	2.60%	68.20%	678.00%	54	23			71/90/12	
11:58:38	235	18.80%	813	2.10%	65.10%	855.00%	48	118			69/90/12	
12:06:15	217	19.40%	549	1.50%	58.90%	999.00%	37	139	7		65/90/12	
Avg	234	18.83%	849	2.07%	64.07%	844.00%	46	93	7			

100% Switch Grass Pucks

Run #1	Stack Temp	Blend:		Switchgrass pucks(10-12% moisture)				Test date:	10/14/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
8:52:17	271	17.90%	251	3.00%	69.30%	577.00%	46	0		Higher/45%fill level		
9:03:52	300	16.30%	342	4.50%	75.00%	347.00%	75	0				
9:13:02	332	14.40%	351	6.40%	78.10%	218.00%	98	0	7	45% feed in firebox		
9:29:36	357	13.90%	223	6.80%	77.60%	196.00%	102	0				
9:30:10	361	13.30%	230	7.40%	78.60%	173.00%	109	0	7			
9:53:25	345	13.60%	97	7.10%	79.00%	184.00%	99	0	6	underpass 15->5Pa;5->1%Pa		
9:58:24	356	12.70%	101	8.00%	79.90%	153.00%	113	0				
Avg	332	0	228	0	1	3	92	0	7			
Run #2	Stack Temp	Blend:		Switchgrass pucks(17% moisture)				Test date:	11/19/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
10:17:43	365	11.40%	388	9.30%	81.00%	119.00%	114	8		17% moisture		7.0 pa
10:24:28	368	13.50%	209	7.20%	77.70%	180.00%	99	0	6	70% humidity		2.0 top
10:34:23	370	12.80%	256	7.90%	78.90%	156.00%	108	0				
10:42:41	361	13.70%	240	7.00%	77.90%	188.00%	93	0				
10:50:26	347	14.60%	241	6.20%	76.80%	228.00%	90	0				
Avg	362	13.20%	267	7.52%	78.46%	174.20%	101	2	6			
Run #3	Stack Temp	Blend:		Switchgrass pucks(15% moisture)				Test date:	11/23/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
10:40:34	357	13.60%	481	7.10%	77.20%	184.00%	98	0		15% moisture		jet 5.0 pa
10:46:11	357	13.60%	481	7.10%	77.20%	184.00%	98	0	6	5% humidity		tolerance 2.0 top
Avg	357	13.60%	481	7.10%	77.20%	184.00%	98	0	6			
SW grass pucks Avg	350	13.80%	325	6.93%	77.48%	207.40%	97	1	6.3			

50% Switchgrass & 50% Wood pucks

Run #1	Stack Temp	Blend:						Test date:	10/13/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
02:02:19	239	17.10%	271	3.20%	75.20%	536.00%	56	0				
02:07:05	253	17.40%	219	3.40%	75.10%	483.00%	66	0				
02:13:55	253	17.70%	231	3.20%	73.50%	536.00%	57	0				
02:18:34	267	18.00%	195	2.90%	69.70%	600.00%	50	0	8.5	2:27		
Avg	253	17.55%	229	3.18%	73.38%	538.75%	57	0	8.5			

Field Combustion Measurements October - November 2015-continued

100% Reed Canary Grass pucks												
Run #1	Stack Temp	Blend:	100%	Reed Canary Grass (MCF)				Test date:	11/17/2015			
Time	°F	O_2	CO	CO_2	EFF	Ex Air	NO	SO_2	Smoke	Fuel feed	Fan speed	Pa
3:31:51	325	13.70%	207	7.00%	79.10%	188.00%	106	0		8% moisture; 53.6% humidity		
3:39:25	361	13.60%	185	7.10%	77.30%	184.00%	131	0		used 2100% SW puck settings		
3:44:16	354	16.50%	160	4.30%	68.40%	367.00%	83	0	7			
Avg	347	14.60%	184	6.13%	74.93%	246.33%	107	0	7			

50% Reed Canary Grass/50% Wood pucks												
Run #1	Stack Temp	Blend:						Test date:	11/18/2015			
Time	°F	O_2	CO	CO_2	EFF	Ex Air	NO	SO_2	Smoke Test	Fuel feed	Fan speed	Pa
10:18:49	357	14.30%	272	6.50%	76.30%	213.00%	118	0	0	20% moisture;53% humidity		
10:22:56	348	13.50%	210	7.20%	78.50%	180.00%	336	0	6			
10:30:01	354	13.90%	144	6.80%	77.50%	196.00%	126	0	0			
10:33:14	345	13.70%	151	7.00%	78.40%	188.00%	135	0	0			
10:37:55	336	14.90%	163	5.90%	76.40%	244.00%	107	0	6			
Avg	348	14.06%	188	6.68%	77.42%	204.20%	164	0	6			

100% Miscanthus pucks												
Run #1	Stack Temp	Blend:						Test date:	11/18/2015			
Time	°F	O_2	CO	CO_2	EFF	Ex Air	NO	SO_2	Smoke Test	Fuel feed	Fan speed	Pa
11:56:04	361	13.50%	172	7.20%	78.20%	180.00%	70	0		16% moisture; 53% humidity		
12:01:44	343	14.20%	96	6.60%	77.80%	209.00%	63	0	5			
12:08:53	361	14.20%	82	6.60%	76.70%	209.00%	62	0				
12:15:00	350	14.60%	66	6.20%	76.50%	228.00%	59	0	4			
12:36:24	345	13.70%	54	7.00%	78.90%	188.00%	66	0				
12:42:34	345	13.70%	54	7.00%	78.90%	188.00%	66	0				
Avg	351	13.98%	87	6.77%	77.83%	200.33%	64	0	4.5			

50% Miscanthus/50% Wood pucks												
Run #1	Stack Temp	Blend:						Test date:	11/18/2015			
Time	°F	O_2	CO	CO_2	EFF	Ex Air	NO	SO_2	Smoke Test	Fuel feed	Fan speed	Pa
3:14:49	314	15.80%	128	5.00%	75.40%	304.00%	75	0	6	53% humidity		2
3:35:55	329	16.30%	122	4.50%	72.40%	347.00%	65	0	6			
Avg	322	16.05%	125	4.75%	73.90%	325.50%	70	0	6			

100% MC Mulch Hay pucks												
Run #1	Stack Temp	Blend:		11% moisture				Test date:	11/24/2015			
Time	°F	O_2	CO	CO_2	EFF	Ex Air	NO	SO_2	Smoke Test	Fuel feed	Fan speed	Pa
12:51:47	350	15.80%	288	5.00%	71.90%	304.00%	84	0			97/48/35	12;+-5
12:57:53	379	12.70%	229	8.00%	78.10%	153.00%	131	0			97/48/35	
1:02:48	377	13.20%	195	7.50%	77.30%	169.00%	122	0	5.5			
1:06:10	366	13.90%	194	6.80%	76.50%	196.00%	114	0	5		97/48/35	10-12;+-5
Avg	368	13.90%	227	6.83%	75.95%	205.50%	113	0	5.25			

50% MC Mulch Hay & 50% Wood pucks												
Run #1	Stack Temp	Blend:		21% moisture				Test date:	11/23/2015			
Time	°F	O_2	CO	CO_2	EFF	Ex Air	NO	SO_2	Smoke	Fuel feed	Fan speed	Pa
2:58:22	289	16.50%	288	4.30%	74.90%	367.00%	80	0		21% moist.	90/38/38	5;+-2.5
3:07:12	307	16.30%	229	4.50%	74.20%	347.00%	86	0	6		85/38/38	
3:13:52	314	16.00%	195	4.80%	74.80%	320.00%	92	0				
3:22:48	320	16.10%	233	4.70%	74.10%	329.00%	88	8	6		90/38/38	
Avg	308	16.23%	236	4.58%	74.50%	340.75%	86	0	6			

Field Combustion Measurements October - November 2015-continued

100% Ag. Biomass pucks												
Run #1	Stack Temp	Blend:						Test date:	11/23/2015			
Time	°F	O2	CO	CO2	EFF	Ex Air	NO	SO2	Smoke Test	Fuel feed	Fan speed	Pa
11:43:45	354	14.60%	294	6.20%	75.50%	228.00%	113	0				
11:46:27	368	12.70%	269	8.00%	78.60%	153.00%	136	0				
11:50:25	141	11.90%	233	8.80%	90.40%	131.00%	145	0	5.5			
12:55:15	366	10.50%	293	10.20%	81.60%	100.00%	156	0			85/40/25	8;+-4
Avg	307	12.43%	272	8.30%	81.53%	153.00%	138	0	5.5			

Laboratory Reports

Twin Ports Testing Inc.

Twin Ports Testing, Inc.
1301 North 3rd Street
Superior, WI 54880
p: 715-392-7114
p: 800-373-2562
f: 715-392-7163
www.twinportstesting.com

Analytical Test Report

Report No: USR:W217-0127-01
Issue No: 1

Client: MEACH COVE TRUST
P.O. Box 309
Shelburne, VT 05482
Attention: Christopher W. Davis

PO No:

Signed: Katy Mickelson
Katy Mickelson
Senior Chemist
Date of Issue: 2/20/2017

THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Sample Log No:	W217-0127-01	**Sample Date:**	2/6/2017
Sample Designation:	Energex, Canada 50% Softwood/50% Hardwood	**Sample Time:**	
Sample Recognized As:	Wood Pellets	**Arrival Date:**	2/9/2017

Test Results

	METHOD	UNITS	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM E871	wt. %		5.16
Ash	ASTM D1102	wt. %	0.68	0.65
Volatile Matter	ASTM D3175	wt. %	80.62	76.47
Fixed Carbon by Difference	ASTM D3172	wt. %	18.69	17.73
Sulfur	ASTM D4239	wt. %	0.010	0.009
SO_2	Calculated	lb/mmbtu		0.021
Net Cal. Value at Const. Pressure	ISO 1928	GJ/tonne	18.85	17.76
Net Cal. Value at Const. Pressure	ISO 1928	J/g	18854	17756
Gross Cal. Value at Const. Vol.	ASTM E711	J/g	20165	19125
Gross Cal. Value at Const. Vol.	ASTM E711	Btu/lb	8670	8223
Carbon	ASTM D5373	wt. %	50.24	47.64
Hydrogen*	ASTM D5373	wt. %	6.02	5.71
Nitrogen	ASTM D5373	wt. %	< 0.20	< 0.19
Oxygen*	ASTM D3176	wt. %	> 42.85	> 40.64
Chlorine	ASTM D6721	mg/kg	102	97
Fluorine	ASTM D3761	mg/kg		
Mercury	ASTM D6722	mg/kg		
Bulk Density	ASTM E873	lbs/ft^3		
Fines (Less than 1/8")	TPT CH-P-06	wt.%		
Durability Index	Kansas State	PDI		
Sample Above 1.50"	TPT CH-P-06	wt.%		
Maximum Length (Single Pellet)	TPT CH-P-06	inch		
Diameter, Range	TPT CH-P-05	inch		to
Diameter, Average	TPT CH-P-05	inch		
Stated Bag Weight	TPT CH-P-01	lbs		
Actual Bag Weight	TPT CH-P-01	lbs		

*Note: As received values do not include hydrogen and oxygen in the total moisture.

Comments

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Superior, WI 54880
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p: 800-373-2562
f: 715-392-7163
www.twinportstesting.com

Analytical Test Report

Report No: USR:W217-0127-01
Issue No: 1
This report replaces all previous issues

Client: MEACH COVE TRUST
P.O. Box 309
Shelburne VT 05482
Attention: Christopher W. Davis

PO No:

Signed: Katy Mickelson
Katy Mickelson
Senior Chemist
Date of Issue: 2/20/2017

THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Sample Log No:	W217-0127-01	**Sample Date:**	2/6/2017
Sample Designation:	Energex, Canada 50% Softwood/50% Hardwood	**Sample Time:**	
Sample Recognized as:	Wood Pellets	**Arrival Date:**	2/9/2017

Test Results

ASH FUSION - ASTM D1857

Reducing Atmosphere	
Initial Def. Temp.	2530 ° F
Softening Temp.	2600 ° F
Hemispherical Temp.	2625 ° F
Fluid Temp.	2630 ° F

Oxidizing Atmosphere	
Initial Def. Temp.	2500 ° F
Softening Temp.	2565 ° F
Hemispherical Temp.	2575 ° F
Fluid Temp.	2625 ° F

MINERAL ANALYSIS OF ASH - ASTM D3682

Silicon Dioxide in Ash	wt. %
Aluminum Oxide in Ash	wt. %
Titanium Dioxide in Ash	wt. %
Iron Oxide in Ash	wt. %
Calcium Oxide in Ash	wt. %
Magnesium Oxide in Ash	wt. %
Potassium Oxide in Ash	wt. %
Sodium Oxide in Ash	wt. %
Sulfur Trioxide in Ash	wt. %
Phosphorus Pentoxide in Ash	wt. %
Strontium Oxide in Ash	wt. %
Barium Oxide in Ash	wt. %
Manganese Dioxide in Ash	wt. %
Undetermined	wt. %
Total	wt. %

Comments

Twin Ports Testing, Inc.
1301 North 3rd Street
Superior, WI 54880
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p: 800-373-2562
f: 715-392-7163
www.twinportstesting.com

Report No: USR:W217-0127-03
Issue No: 1

Analytical Test Report

Client: MEACH COVE TRUST
P.O. Box 309
Shelburne, VT 05482
Attention: Christopher W. Davis

PO No:

Signed: Katy Mickelson
Katy Mickelson
Senior Chemist
Date of Issue: 2/20/2017

Sample Details

Sample Log No:	W217-0127-03	**Sample Date:**	2/6/2017
Sample Designation:	Vermont Wood Pellet 100% Pine	**Sample Time:**	
Sample Recognized As:	Wood Pellets	**Arrival Date:**	2/9/2017

Test Results

	METHOD	UNITS	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM E871	wt. %		6.43
Ash	ASTM D1102	wt. %	0.23	0.22
Volatile Matter	ASTM D3175	wt. %	81.44	76.20
Fixed Carbon by Difference	ASTM D3172	wt. %	18.33	17.15
Sulfur	ASTM D4239	wt. %	0.006	0.006
SO_2	Calculated	lb/mmbtu		0.013
Net Cal. Value at Const. Pressure	ISO 1928	GJ/tonne	19.70	18.28
Net Cal. Value at Const. Pressure	ISO 1928	J/g	19702	18277
Gross Cal. Value at Const. Vol.	ASTM E711	J/g	21033	19680
Gross Cal. Value at Const. Vol.	ASTM E711	Btu/lb	9043	8461
Carbon	ASTM D5373	wt. %	51.66	48.33
Hydrogen*	ASTM D5373	wt. %	6.12	5.73
Nitrogen	ASTM D5373	wt. %	< 0.20	< 0.19
Oxygen*	ASTM D3176	wt. %	> 41.79	> 39.10
Chlorine	ASTM D6721	mg/kg	27	25
Fluorine	ASTM D3761	mg/kg		
Mercury	ASTM D6722	mg/kg		
Bulk Density	ASTM E873	lbs/ft^3		
Fines (Less than 1/8")	TPT CH-P-06	wt.%		
Durability Index	Kansas State	PDI		
Sample Above 1.50"	TPT CH-P-06	wt.%		
Maximum Length (Single Pellet)	TPT CH-P-06	inch		
Diameter, Range	TPT CH-P-05	inch		to
Diameter, Average	TPT CH-P-05	inch		
Stated Bag Weight	TPT CH-P-01	lbs		
Actual Bag Weight	TPT CH-P-01	lbs		

*Note: As received values do not include hydrogen and oxygen in the total moisture.

Comments

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Analytical Test Report

Report No: USR:W217-0127-03
Issue No: 1
This report replaces all previous issues

Client: MEACH COVE TRUST
P.O. Box 309
Shelburne VT 05482
Attention: Christopher W. Davis

PO No:

Signed: Katy Mickelson
Katy Mickelson
Senior Chemist
Date of Issue: 2/20/2017

Sample Details

Sample Log No:	W217-0127-03	**Sample Date:**	2/6/2017
Sample Designation:	Vermont Wood Pellet 100% Pine	**Sample Time:**	
Sample Recognized as:	Wood Pellets	**Arrival Date:**	2/9/2017

Test Results

ASH FUSION - ASTM D1857

Reducing Atmosphere	
Initial Def. Temp.	2680 ° F
Softening Temp.	>2680 ° F
Hemispherical Temp.	>2680 ° F
Fluid Temp.	>2680 ° F

Oxidizing Atmosphere	
Initial Def. Temp.	2515 ° F
Softening Temp.	>2680 ° F
Hemispherical Temp.	>2680 ° F
Fluid Temp.	>2680 ° F

MINERAL ANALYSIS OF ASH - ASTM D3682

Silicon Dioxide in Ash		wt. %
Aluminum Oxide in Ash		wt. %
Titanium Dioxide in Ash		wt. %
Iron Oxide in Ash		wt. %
Calcium Oxide in Ash		wt. %
Magnesium Oxide in Ash		wt. %
Potassium Oxide in Ash		wt. %
Sodium Oxide in Ash		wt. %
Sulfur Trioxide in Ash		wt. %
Phosphorus Pentoxide in Ash		wt. %
Strontium Oxide in Ash		wt. %
Barium Oxide in Ash		wt. %
Manganese Dioxide in Ash		wt. %
Undetermined		wt. %
Total		wt. %

Comments

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Analytical Test Report

Report No: USR:W212-0135-04
Issue No: 1
This report replaces all previous issues

Client: MEACH COVE TRUST
PO Box 309
Shelburne VT 05482
Attention: Christopher Davis

PO No:

Signed: Kevin Anderson
Kevin Anderson
IT Manager
Date of Issue: 2/3/2012

Sample Details

Sample Log No:	W212-0135-04	**Sample Date:**	
Sample Designation:	Enviro Energy Grass	**Sample Time:**	
Sample Recognized As:	Pellets	**Arrival Date:**	1/31/2012

Test Results

	METHOD	UNITS	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM E871	wt. %		6.07
Ash	ASTM D1102	wt. %	4.98	4.65
Volatile Matter	ASTM D3175	wt. %	75.77	70.79
Fixed Carbon by Difference	ASTM D3175	wt. %	19.09	18.34
Sulfur	ASTM D4239	wt. %	0.166	0.155
SO_2	Calculated	lb/mmbtu		0.380
Net Cal. Value at Const. Pressure	ISO 1928	GJ/tonne	19.10	17.79
Net Cal. Value at Const. Pressure	ISO 1928	J/g	19097	17789
Gross Cal. Value at Const. Vol.	ASTM E711	J/g	19282	18013
Gross Cal. Value at Const. Vol.	ASTM E711	Btu/lb	8290	7745
Carbon	ASTM D5373	wt. %	2.41	2.25
Hydrogen	ASTM D5373	wt. %	0.53	0.49
Nitrogen	ASTM D5373	wt. %	< 0.20	< 0.19
Oxygen	ASTM D3176	wt. %	> 91.72	> 86.20
Chlorine	ASTM D6721	mg/kg	3703	3459
Fluorine	ASTM D3761	mg/kg		
Mercury	ASTM D6722	mg/kg		
Bulk Density	ASTM E873	lbs/ft^3		
Fines (Less than 1/8")	TPT CH-P-06	wt.%		
Durability Index	Kansas State	PDI		
Sample Above 1.50"	TPT CH-P-06	wt.%		
Maximum Length (Single Pellet)	TPT CH-P-06	inch		
Diameter, Range	TPT CH-P-05	inch		to
Diameter, Average	TPT CH-P-05	inch		
Stated Bag Weight	TPT CH-P-01	lbs		
Actual Bag Weight	TPT CH-P-01	lbs		

Comments

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Analytical Test Report

Report No: USR:W212-0135-04
Issue No: 1
This report replaces all previous issues

Client: MEACH COVE TRUST
PO Box 309
Shelburne VT 05482
Attention: Christopher Davis

PO No:

Signed: Kevin Anderson
Kevin Anderson
IT Manager
Date of Issue: 2/3/2012

Sample Details

Sample Log No:	W212-0135-04	**Sample Date:**	
Sample Designation:	Enviro Energy Grass	**Sample Time:**	
Sample Recognized as:	Pellets	**Arrival Date:**	1/31/2012

Test Results

ASH FUSION - ASTM D1857

Reducing Atmosphere	
Initial Def. Temp.	2340 °F
Softening Temp.	2420 °F
Hemispherical Temp.	2470 °F
Fluid Temp.	2520 °F

Oxidizing Atmosphere	
Initial Def. Temp.	2430 °F
Softening Temp.	2500 °F
Hemispherical Temp.	2550 °F
Fluid Temp.	2610 °F

MINERAL ANALYSIS OF ASH - ASTM D3682

Silicon Dioxide in Ash		wt. %
Aluminum Oxide in Ash		wt. %
Titanium Dioxide in Ash		wt. %
Iron Oxide in Ash		wt. %
Calcium Oxide in Ash		wt. %
Magnesium Oxide in Ash		wt. %
Potassium Oxide in Ash		wt. %
Sodium Oxide in Ash		wt. %
Sulfur Trioxide in Ash		wt. %
Phosphorus Pentoxide in Ash		wt. %
Strontium Oxide in Ash		wt. %
Barium Oxide in Ash		wt. %
Manganese Dioxide in Ash		wt. %
Undetermined		wt. %
Total		wt. %

Comments

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Analytical Test Report

Report No: USR:W212-0135-01
Issue No: 1
This report replaces all previous issues

Client: MEACH COVE TRUST
PO Box 309
Shelburne VT 05482
Attention: Christopher Davis

PO No:

Signed: Kevin Anderson
Kevin Anderson
IT Manager
Date of Issue: 2/3/2012
THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Sample Log No:	W212-0135-01	**Sample Date:**	
Sample Designation:	Meach Cove Reed Canary	**Sample Time:**	
Sample Recognized As:	Pellets	**Arrival Date:**	1/31/2012

Test Results

	METHOD	UNITS	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM E871	wt. %		8.50
Ash	ASTM D1102	wt. %	4.54	4.13
Volatile Matter	ASTM D3175	wt. %	77.41	70.39
Fixed Carbon by Difference	ASTM D3175	wt. %	17.95	16.89
Sulfur	ASTM D4239	wt. %	0.097	0.088
SO_2	Calculated	lb/mmbtu		0.225
Net Cal. Value at Const. Pressure	ISO 1928	GJ/tonne	17.83	16.11
Net Cal. Value at Const. Pressure	ISO 1928	J/g	17830	16108
Gross Cal. Value at Const. Vol.	ASTM E711	J/g	19102	17370
Gross Cal. Value at Const. Vol.	ASTM E711	Btu/lb	8213	7468
Carbon	ASTM D5373	wt. %	46.39	42.18
Hydrogen	ASTM D5373	wt. %	5.84	5.31
Nitrogen	ASTM D5373	wt. %	0.51	0.46
Oxygen	ASTM D3176	wt. %	42.62	39.33
Chlorine	ASTM D6721	mg/kg	1041	947
Fluorine	ASTM D3761	mg/kg		
Mercury	ASTM D6722	mg/kg		
Bulk Density	ASTM E873	lbs/ft^3		
Fines (Less than 1/8")	TPT CH-P-06	wt.%		
Durability Index	Kansas State	PDI		
Sample Above 1.50"	TPT CH-P-06	wt.%		
Maximum Length (Single Pellet)	TPT CH-P-06	inch		
Diameter, Range	TPT CH-P-05	inch		to
Diameter, Average	TPT CH-P-05	inch		
Stated Bag Weight	TPT CH-P-01	lbs		
Actual Bag Weight	TPT CH-P-01	lbs		

Comments

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Analytical Test Report

Report No:	**USR:W212-0135-01**
Issue No:	**1**

This report replaces all previous issues

Client:	MEACH COVE TRUST		
	PO Box 309		
	Shelburne	VT	05482
Attention:	Christopher Davis		
PO No:			

Signed: Kevin Anderson

Kevin Anderson
IT Manager

Date of Issue: 2/3/2012

THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Sample Log No:	W212-0135-01	**Sample Date:**	
Sample Designation:	Meach Cove Reed Canary	**Sample Time:**	
Sample Recognized as:	Pellets	**Arrival Date:**	1/31/2012

Test Results

ASH FUSION - ASTM D1857

Reducing Atmosphere	
Initial Def. Temp.	2230 ° F
Softening Temp.	2340 ° F
Hemispherical Temp.	2450 ° F
Fluid Temp.	2520 ° F

Oxidizing Atmosphere	
Initial Def. Temp.	2340 ° F
Softening Temp.	2450 ° F
Hemispherical Temp.	2550 ° F
Fluid Temp.	2640 ° F

MINERAL ANALYSIS OF ASH - ASTM D3682

Silicon Dioxide in Ash	wt. %
Aluminum Oxide in Ash	wt. %
Titanium Dioxide in Ash	wt. %
Iron Oxide in Ash	wt. %
Calcium Oxide in Ash	wt. %
Magnesium Oxide in Ash	wt. %
Potassium Oxide in Ash	wt. %
Sodium Oxide in Ash	wt. %
Sulfur Trioxide in Ash	wt. %
Phosphorus Pentoxide in Ash	wt. %
Strontium Oxide in Ash	wt. %
Barium Oxide in Ash	wt. %
Manganese Dioxide in Ash	wt. %
Undetermined	wt. %
Total	wt. %

Comments

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Analytical Test Report

Report No: USR:W212-0135-02
Issue No: 1
This report replaces all previous issues

Client: MEACH COVE TRUST
PO Box 309
Shelburne VT 05482
Attention: Christopher Davis

PO No:

Signed: Kevin Anderson
Kevin Anderson
IT Manager
Date of Issue: 2/3/2012

Sample Details

Sample Log No:	W212-0135-02	**Sample Date:**	
Sample Designation:	Meach Cove Switch Grass	**Sample Time:**	
Sample Recognized As:	Pellets	**Arrival Date:**	1/31/2012

Test Results

	METHOD	UNITS	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM E871	wt. %		8.02
Ash	ASTM D1102	wt. %	6.63	6.06
Volatile Matter	ASTM D3175	wt. %	75.17	68.73
Fixed Carbon by Difference	ASTM D3175	wt. %	18.01	17.02
Sulfur	ASTM D4239	wt. %	0.189	0.173
SO_2	Calculated	lb/mmbtu		0.442
Net Cal. Value at Const. Pressure	ISO 1928	GJ/tonne	17.59	15.99
Net Cal. Value at Const. Pressure	ISO 1928	J/g	17593	15986
Gross Cal. Value at Const. Vol.	ASTM E711	J/g	18880	17262
Gross Cal. Value at Const. Vol.	ASTM E711	Btu/lb	8117	7422
Carbon	ASTM D5373	wt. %	45.52	41.61
Hydrogen	ASTM D5373	wt. %	5.92	5.41
Nitrogen	ASTM D5373	wt. %	0.86	0.79
Oxygen	ASTM D3176	wt. %	40.89	37.93
Chlorine	ASTM D6721	mg/kg	2517	2301
Fluorine	ASTM D3761	mg/kg		
Mercury	ASTM D6722	mg/kg		
Bulk Density	ASTM E873	lbs/ft^3		
Fines (Less than 1/8")	TPT CH-P-06	wt.%		
Durability Index	Kansas State	PDI		
Sample Above 1.50"	TPT CH-P-06	wt.%		
Maximum Length (Single Pellet)	TPT CH-P-06	inch		
Diameter, Range	TPT CH-P-05	inch	to	
Diameter, Average	TPT CH-P-05	inch		
Stated Bag Weight	TPT CH-P-01	lbs		
Actual Bag Weight	TPT CH-P-01	lbs		

Comments

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Analytical Test Report

Report No: USR:W212-0135-02
Issue No: 1
This report replaces all previous issues

Client:	MEACH COVE TRUST PO Box 309 Shelburne VT 05482
Attention:	Christopher Davis
PO No:	

Signed: Kevin Anderson

Kevin Anderson
IT Manager

Date of Issue: 2/3/2012

Sample Details

Sample Log No:	W212-0135-02	**Sample Date:**	
Sample Designation:	Meach Cove Switch Grass	**Sample Time:**	
Sample Recognized as:	Pellets	**Arrival Date:**	1/31/2012

Test Results

ASH FUSION - ASTM D1857

Reducing Atmosphere	
Initial Def. Temp.	2230 ° F
Softening Temp.	2360 ° F
Hemispherical Temp.	2450 ° F
Fluid Temp.	2590 ° F

Oxidizing Atmosphere	
Initial Def. Temp.	2335 ° F
Softening Temp.	2460 ° F
Hemispherical Temp.	2545 ° F
Fluid Temp.	2690 ° F

MINERAL ANALYSIS OF ASH - ASTM D3682

Silicon Dioxide in Ash	wt. %
Aluminum Oxide in Ash	wt. %
Titanium Dioxide in Ash	wt. %
Iron Oxide in Ash	wt. %
Calcium Oxide in Ash	wt. %
Magnesium Oxide in Ash	wt. %
Potassium Oxide in Ash	wt. %
Sodium Oxide in Ash	wt. %
Sulfur Trioxide in Ash	wt. %
Phosphorus Pentoxide in Ash	wt. %
Strontium Oxide in Ash	wt. %
Barium Oxide in Ash	wt. %
Manganese Dioxide in Ash	wt. %
Undetermined	wt. %
Total	wt. %

Comments

Testing Methods

The combustion testing followed the same series of steps. We would isolate the heat distribution system so that the boiler was only heating the 550 gallon buffer tank. The temperature of the buffer tank was noted before and after each test burn which allowed estimates of the efficiency of the test burns to be calculated (Callahan, 2016). The fuel feed auger was vacuumed of all prior sample residue. The firebox was manually scraped down and the cleaning cycle operated until the firebox was clear of any ash and residue from the previous burn cycle. The boiler was started and allowed to run through the typical cleaning, start up and ignition sequence. Once the boiler reached the “full load” combustion stage the Project Director would begin to take emission and smoke samples. Samples were taken at 10-15 minute intervals over the course of about an hour with the boiler operating at “full load”. The data captured by the Wohler instrument and printed by the Wohler wireless printer as each sample was taken. Smoke test filters were labeled and stapled to the Wohler printouts as they were tested. We made adjustments to the air flow and fuel feed rates for the boiler during the test runs to minimize the CO levels and maximize the combustion efficiency.

Emission measurements with the Wohler A500 and the smoke tests were performed following the same process and as close to the same time interval for each test run by the Project Director for consistency. The raw data was transferred from the Wohler emission print outs and smoke test paper disks to the Excel spreadsheet manually by the Project Administrator.

Project Budget

USDA-NRCS-2011 Vermont Conservation Innovation Grant (CIG) program Meach Cove Real Estate Trust - 69-1644-11-08					
			Period 7/1/2015 to 9/30/2015		
	Current		**Current Cumulative**		**Previous Cumulative**
Federal Share/Budget$					
d. Equipment/$32,000	$0.00		$43,532.80		$43,532.80
e. Supplies/$11,700	$0.00		$21,924.03		$21,924.03
f. Contractual/$29,700	$0.00		$7,943.17		$7,943.17
Total/$73,400	**$0.00**		**$73,400.00**		**$73,400.00**
MCRET Cost Share/Budget$					
a. Personnel/$77,740	$698.90		$64,200.00		$63,801.10
b. Fringe Benefits/$36,400	$219.88		$21,189.71		$20,969.83
c. Travel/$1,500	$0.00		$522.54		$522.54
e. Supplies/$10,000	$0.00		$42,429.57		$42,429.57
Total/$125,640	**$918.78**		**$128,341.82**		**$127,723.04**
Total Federal and MCRET	**$918.78**		**$201,741.82**		**$201,123.04**

Biomass Boiler vs. Oil Boiler Installation Budget Estimate

Meach Cove Farms Biomass Boiler installation worksheet						
October 2013 - October 2014					No Biomass boiler	
					Add 2nd Oil boiler	
Refit boiler room to VT Code				$ 21,516.00	$16,516.00	
Boiler + chip and pellet loaders				$ 41,553.00	$ -	
Rigger to install boiler				$ 1,750.00	$ -	
Add Buderus oil boiler (294K BTU) & expansion tank					$ 5,000.00	
Add second 275 gal oil tank, tray & plumb it up					$ 2,200.00	
Stainless steel Flue				$ 2,115.00	$ 1,800.00	
Materials to build fuel bins to code				$ 2,100.00	$ -	
Plumbing contractor				$ 24,000.00	$15,000.00	
Move oil boiler & install tank				$ 3,000.00	$ 3,000.00	
Additional electrical work				$ 1,000.00	$ 1,000.00	
Meach Cove labor				$ 15,000.00	$ 7,500.00	
TOTAL				$112,034.00	$52,016.00	
			Gallons	Total Cost		
Oil used 1-1-14 thru 7-31-15			757	$ 2,844.00		
max price $ 3.26/gal						
min price $2.20/gal						
ave price $2.70/gal						
				tons	cost/ton	Total Cost
Wood pellets used 10/14/14 - 10/30/15				16	$269 - 279	$4,304-4,464
Square feet heated		4,313.00				
Cubic feet heated		63,250.00				