Final Report
for
SARE Project #FNE07-620

Assess and Quantify the Benefit of Alternative and Renewable Energy for Greenhouse Operations

by

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Project Goals

Our project goal is to demonstrate and quantify the effectiveness and cost benefit of an alternative energy heating system for greenhouses. Our specific goals, as stated in the original proposal are:

Assess the qualitative & quantitative benefits of sustainable energy solutions for ag/horticulture and to educate and assist other regional farms in assessing and implementing renewable energy programs of their own.

Since a working sustainable energy system is already installed and operational at Emory Knoll Farms, we proposed a project to perform these objectives:

- Assess and document the installation & setup costs of an alternative energy heating system as compared to the costs for an equivalent conventional system;
- Determine the 'true' operational saving (or costs) of an alternative energy heating system;
- Develop an instrumentation system to measure energy consumption as a function of outside and greenhouse temperature profiles;
- Develop a website to present the information in real time;
- Develop presentation materials based on the finding;
- Provide presentation materials to area farmers, organizations, cooperative extensions;
- Present the findings at relative regional training events / seminars.

About Emory Knoll Farms

Emory Knoll Farms is a wholesale grower of Sedums and other succulent groundcovers for the green roof industry. We are the only nursery in the US which is completely dedicated to providing plants to the green roof industry and to date we have provided plants for over 85 acres of green roofs across the USA and Canada. Emory Knoll Farms currently employs 7 full-time and 2 part-time employees, and does slightly less than $1 million in annual sales. We have grown between 40% and 100% annually for the past five years.

Although we are a relatively small operation, we are a leader in our small segment. This has enabled us to establish national accounts, and we have partnered with other nurseries across the USA to provide plants nationally. As a leader, we are now in a position to set standards for green roof plant products, growing practices, and services such as delivery and consulting. We see sustainable horticulture as an important part of this leadership and we intend to extend the positive parts of our growing practices to our partner nurseries.

We also have endeavored to be a leader in our industry and are attempting to increase the intellectual capital of the green roof industry. We are active in industry associations (Green Roofs for Healthy Cities, Maryland Nursery & Landscape Association, American Society of Landscape Architects). We support green roof research at several major universities, and were instrumental in establishing a green roof program at the University of Maryland. One of the owners, Ed Snodgrass, has written two successful books – "*Green Roof Plants, a Resource and Planting Guide*", and "*The Green Roof Manual, A Professional Guide To Design, Installation, and Maintenance*". We continue to test 100's of plants every year and support plant testing in other parts of the country.

Background on Emory Knoll Farms' Sustainability

Emory Knoll Farms desires to be as completely sustainable as is practical given technical, financial, and other business limitations. We have established a corporate culture of sustainability based largely on *The*

Natural Step as well as other practices and frameworks for sustainability and for effective and efficient business operations. This corporate mindset guides virtually every aspect of our operation, including hiring & human resources, planning, building, and the way we manage our finances. See an extensive outline of our sustainability initiatives at http://www.greenroofplants.com/sustainability.

Benefit Corporation

On October 1st 2010, Emory Knoll Farms registered to become one of the very first corporations to become a 'Benefit Corporation', under Maryland's new Benefit Corporation Statute. As a Benefit Corporation, Emory Knoll Farms is recognized as including within its mission the intention of providing a public benefit (both environmental and social), as well as being a for-profit corporation. In accordance with the statute, Emory Knoll Farms will provide an annual report on the progress of our environmental and social sustainability initiatives. This transparency protects companies that are genuinely sustainable in their operations from being labeled as 'greenwashers' and helps prevent non-sustainable businesses from making such claims. Emory Knoll Farms is being widely recognized as a leader in sustainability in Maryland as well as in our industrial segments.

Sustainability and Alternative Energy Initiatives

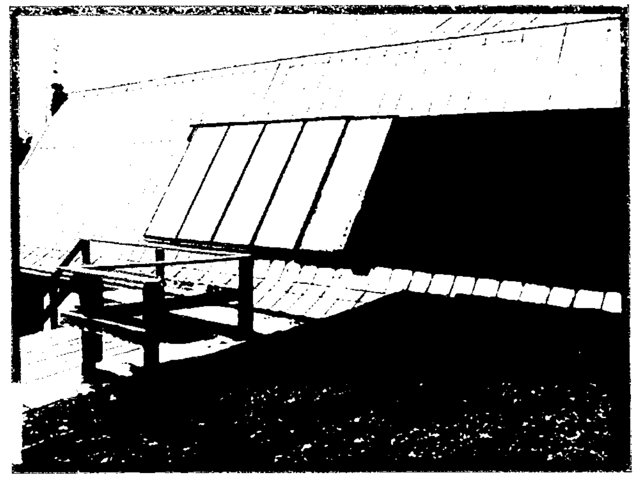
Since Emory Knoll Farms is a growing business, we are necessarily expanding our operation. All projects such as increasing greenhouse space, purchasing equipment, installing heating systems, and building work spaces are considered in terms of sustainability before they are implemented. Recently, we have implemented several projects relating to alternative and renewable energy. The project relating to this grant request is the installation of a comprehensive heating project which includes solar and waste oil heat utilizing waste vegetable oil (WVO) as the primary fuel. This heating system has been implemented over the past few years and was completed in the fall of 2006. Combined with our current photovoltaic array and biodiesel production, this new heating system has the potential to make our farm become nearly carbon-neutral.

Our heating system consists of these components:

- A Clean Burn CBT-350 – 350,000 BTU / hour coil tube waste oil boiler.
- 6,500 gallons of storage and filtering capacity for waste cooking oil.
- Hydronic distribution loops to provide hot water to three areas of our operation: Offices, 4 greenhouses, and the lower level of a converted dairy barn that serves as our winter work area and year-round storage, staging, and shipping area.
- Four greenhouses with heat for propagation and overwintering of tender plants (Figure 1):
    - Koko Taylor– 75' x 14' with Delta-T bench heat for propagation.
    - Gatemouth Brown– 85' x 20' with a 6' x 85' Delta-T heated bench and 75' x 12' hydronic heated floor for seed germination and propagation
    - Lucille – 16' x 35' shed house with 2-zone hydronic floor heat under pavers for germination and overwintering.
    - Van Morrison – Newest heated house, 75' x 20' , with 4-zone hydronic floor heat under pavers for R&D and overwintering of tender plants.

Photo 1 - Greenhouse with Benchtop Heat

- Five rooftop solar water panels supplying 240 gallons of storage water to augment the boiler. (This was our first system, originally designed and built in-house to heat the small Lucille greenhouse, it now provides supplemental solar heat.)
- A 120,000 BTU / hour oil fired residential-grade boiler for auxiliary and backup heat. This boiler currently burns traditional fuel oil or biodiesel fuel.
- Associated heat exchangers, low-power circulator pumps, and controls.



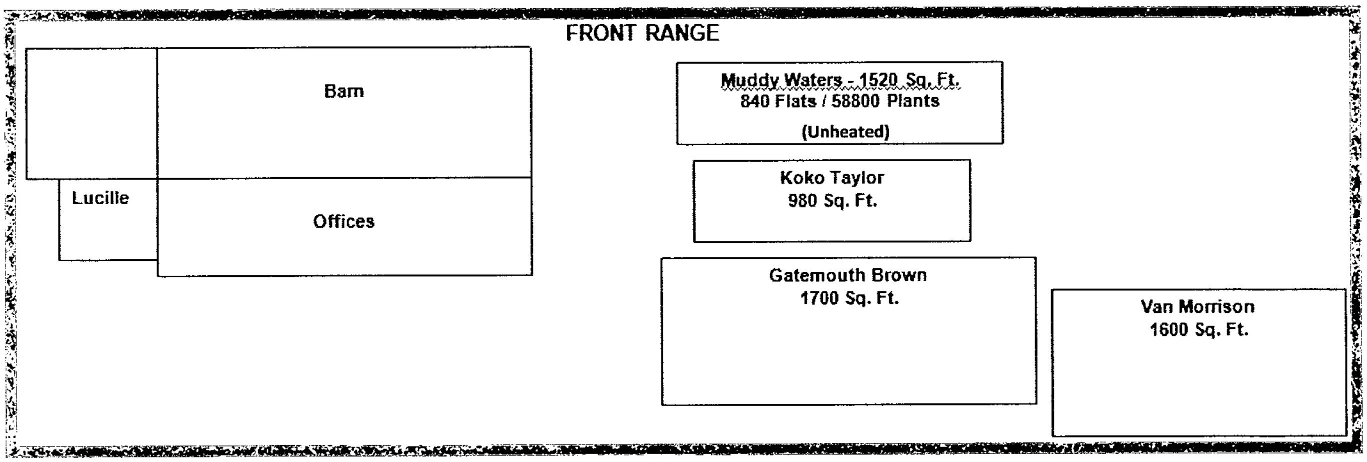


Figure 1 - Layout of Barn and Heated Greenhouses

Solar Irrigation

Emory Knoll Farms has also implemented several solar irrigation systems. The most extensive system is completely off-the-grid. In this system there are two subsystems that work together: A solar well, consisting of a deep well pump that runs directly on solar power and fills a 4,000 gallon reservoir; and a 40 gpm, 60psi pressure pump that provides water pressure throughout a network of underground waterlines with hydrants at each greenhouse and laydown area. The pressure pump operates from an array of large gel-cell batteries that are charged by another array of solar panels. This system operates autonomously with very little maintenance or operator controls.

We also have another solar well that fills a 1,500 gallon reservoir that provides water to an AC powered pressure pump. This system provides irrigation water to the barn and greenhouses shown in Figure 1.

Participants

Nursery Partners

In the course of two years, we have coordinated with several other nurseries to assess the heating systems used in other practices. They are:

North Creek Nurseries
388 North Creek Rd.
Landenberg, PA 19350
610-255-0100

North Creek is a wholesale propagation nursery that supplies starter plugs to wholesale and retail nurseries. As an established operation, North Creek has many various legacy heating systems. Their primary greenhouse heating approach is propane fire hot air unit heaters – this is commonly used in our area.

Heartwood Nursery
8957 Hickory Road
Felton, PA 17322
717-993-5230

Heartwood Nursery is a family business founded in 1992. They specialize in woody propagation and native woody propagation. Previously located in Monkton, Maryland, the entire nursery including containers and the propagation facility have been moved to Stewartstown PA. During the course of this project, John Shepley designed and installed a conventionally fueled, high efficiency heating system for their new propagation house. This system uses the same efficient root-zone heat system that is used at Emory Knoll Farms, but is fired by a traditional fuel-oil boiler.

Green Meadow Farm
130 S. Mount Vernon Road
Gap, PA 17527
717-442-5222

Green Meadow Farm is located on the eastern boundary of Lancaster County near the town of Gap, Pennsylvania. The business, originally Spring Grove Farm at a former location, now comprises 6 acres of gardens and 4200 sq. ft. of greenhouses. The focus is on growing specialty herbs and vegetables for restaurants in Philadelphia and Lancaster. Green Meadow uses its own growing method called minimum impact farming and includes methods borrowed from organic and sustainable practices. The main focus is on appropriate technology with lowest impact inputs. Current projects include working toward heating and electrically powering the farm and its vehicles using waste vegetable oil from the customer restaurants. The heating portion of the project has been running since 2001 and the electrical generator is soon to come on line. One vehicle has been converted to WVO fuel and more are planned. Other projects include a recent grant through the Fair Food Project for fencing several wooded acres to raise pigs in an arboreal system. Fertility inputs include on-site composting of neighborhood manures and waste hay. Cover cropping includes use of brassicas for harvest and weed suppression as well as nematicides. Primary insect control is accomplished through IPM and soap/vegetable oil emulsions.

Technical Advisors

David S. Ross of the University of Maryland was originally intended to our technical advisor. It is primarily our own fault that we did not reach out enough to him and get engaged together on this project. In Mr. Ross' stead, we worked with Stanton Gill and Joe Schuster, also of University of Maryland. Stanton Gill has been particularly helpful, especially in outreach (described in the Outreach section)

Glenn Brendle of Green Meadow Farm has inspired the heating system that Emory Knoll Farms uses in our installation. He has been using WVO as an energy source since 2001, and has partnered with the Clean Burn Company to assess the impact of using WVO fuel in their standard waste-oil boilers. Glenn provided a great deal of advice on using and burning WVO.

Fred Phillips of Clean Burn and Robert Bennett of Eco Heating Systems consulted with us on the operation of the Clean Burn burner and the challenges of burning WVO. They made several contributions that helped us get through many cold winter days and nights.

Business / Industry Partners

The ***Clean Burn Corporation*** of Leola PA has provided valuable assistance in helping us solve problems related to burning WVO as fuel in their boilers.

Eco-Heating Systems of Strasburg PA is our local authorized Clean Burn service provider. They have provided technical support and maintenance as well as spare parts for our project.

Thomas Somerville is a regional HVAC Supply company. Owen Hartlove and Owen Dickerson there have provided valuable advice & support, as well as recommending equipment for the 'conventional' hydronic parts of our project.

Biomedical Waste Systems of Glen Burnie, MD has provided us with a regular supply of relatively clean Waste Vegetable Oil. This oil is recovered from the kitchen of a local hospital.

Atlantic Biofuels of Baltimore, MD provides waste oil collection services with the intention that the collected oil would go to sustainable uses such as biodiesel. Atlantic Biofuels has become our WVO supplier, and delivers clean oil to our facility seasonally.

Project Activities

In our project, we have accomplished most of our original goals, although the data collected has been much less detailed than was originally anticipated. Therefore our analysis is somewhat more of a qualitative, rather than a quantitative nature. However, as will be shown in this report, the conclusions are still valid, if less detailed.

In this project we compared our heating system to 3 other comparable heating systems. Two of these are more closely related to ours, and the third system is somewhat difficult to compare directly.

Changes to Original Project Scope

The specific objective that was not accomplished is "Develop an instrumentation system to measure energy consumption as a function of outside and greenhouse temperature profiles; and develop a website to present the information in real time". For several reasons, we have not been successful in collecting the real-time data that we intended. The primary reasons are:

- Numerous technical problems that affected the reliability of our heating system (described later in this report) took a great deal of time and energy away from this project.

- Our fuel supply was unreliable enough that we were not able to use Waste Vegetable Oil (WVO) for extended periods sufficient to analyze the performance of the system on WVO.
- The technical challenges of installing instrumentation our nursery were greater than anticipated – perhaps we were overly ambitious in our expectations of how much was involved with the instrumentation. We didn't attempt to install instrumentation in other nurseries.
- Our own growth worked against us. As a small operation, sometimes we are faced with unexpected business challenges that absorb a significant amount of our resources.

As a result of these changes, our analysis is more of a qualitative nature than quantitative. We do, however, feel that our results are clear, and we will make all efforts to demonstrate the reasoning behind our conclusion.

We did perform more detailed modeling of the greenhouses and heat loads and flows of heat. The Hydronic System Software from Taco makes modeling easy, and we used heat loss computations from the internet to estimate the losses of the various greenhouses based on their construction and dimensions. These models proved to be helpful and the results were consistent with our actual experiences.

Cost Analyses

The cost analysis is based on actual installation expenses and / or cost estimates from reputable installers.

Upfront / Installation Costs

We compare the cost of 3 heating systems, including the equipment, installation, and ancillary systems such as fuel tanks.

Table 1 - Installation Costs:

System	*Base Unit*	*Additional Components*	*Installation*	*Total Cost*
Cleanburn Waste Oil Boiler (Estimate from Clean Burn)	$12,995	$360	$2,250	$15,605
Conventional Oil-Fired Boiler (Actual Cost from Heartwood)	$2,405.20		$2,000†	$4,405
Propane / Natural gas Heater (Catalog Price for Equipment)	$1,985 x 3		$1,000†	$7,995

† Estimated

Operational Costs

We compare the cost of heating systems, including the equipment, installation, and ancillary systems such as fuel tanks.

Table 2 - Operational Costs:

System	*Fuel Consumed / Season*	*Annual Fuel Cost*	*BTU Delivered*	*$ / million BTU*	*Maintenance*	*Total Annual Cost*
Cleanburn Waste Oil Boiler	6,000 gal. (22,710 l.)	$9120	710,317,248	**$12.83**	$400.00	$9,520
Conventional Oil-Fired Boiler	1,500 gal. (5,741 l.)	$4,500	203,000,000	**$22.42**	$250.00 †	$4,750

† Estimated

The information in Table 2 shows that for an equivalent amount of total heat energy delivered, the Cleanburn system is much less expensive than a conventional system, since the fuel cost is approximately ½ the cost of heating oil.

Results / Assessment

Waste Oil vs. Petroleum Fuel

The use of Waste Vegetable Oil (WVO) has been problematic. Some of the problems have been due to our approach, and some are endemic to the nature of WVO as a fuel. In the end, most of the significant problems were solved or reduced to manageable proportions and we are comfortable using WVO. Certainly the cost and environmental benefits outweigh the few remaining difficulties.

Here are the primary fuel considerations:

Waste Vegetable oil - WVO

The fuel itself has proved to be the cause of many operational issues that are separate from issues that are specific to the equipment or installation.

1. Fuel Sources – Of the various cooking oil products used in the food service industry, the best to use for heating applications are liquid, non-hydrogenated oils such as peanut, canola, or corn oil. This is often provided as a blended product to the restaurants. Cooking causes a partial breakdown of the oil, and it will stay liquid well below 32 degrees F. Finding a regular source of WVO has been difficult. The best kind of oil is commonly used in Asian restaurants, but sometimes it is difficult to communicate with owners in order to establish a relationship what will allow us to collect the oil. Even restaurants that are willing to give us oil are often unwilling to give up their contract with the local renderer.
2. Collection Difficulties – Initially we collected our own oil from local restaurants. Most restaurants have a dumpster or barrels that are placed by the rendering company that they are contracted with for oil removal. Technically, the oil becomes the property of the rendering company when it is placed into their dumpster; which means that even if the restaurant owner agrees to give oil to us, we cannot legally remove it from the dumpster. The restaurateur must package it separately, or we must provide our own dumpster or barrel.
3. Contamination – Often, water, food waste, and other contaminates are in the oil we collect from restaurants. This puts a heavy burden on us to let the water settle out and filter the oil. Contaminates such as flour and batter remnants, peanuts, and other small particles are hard on pumps and filter elements. In a few cases, we have been successful in convincing the kitchen staff to avoid putting excess contaminates in the oil, but this is a constant battle. Oil collected from hospital kitchens and donated to us by Biomedical Waste Systems proved to be of such poor quality at times that it had to be discarded. After BWS interceded with the hospital kitchen to not put wash-water in with their oil, the quality increased significantly.
4. The Nature of Vegetable Oil – WVO has a tendency to harden over time when in contact with the air, causing a buildup of crusty black oxidized oil on everything it touches (think of linseed oil). This creates a challenge in keeping pumps, hoses, trucks, etc., clean
5. Combustion – WVO burns very well, but creates several unique problems. Between heating cycles (when the burner is not running), the burner nozzle is exposed to very high heat radiating back from the combustion chamber of the boiler. A small bit of residual oil still inside the nozzle can carbonize and create a creosote-like buildup inside the nozzle. Even worse, a thick waxy substance precipitates out of the oil within the nozzle which can clog the nozzle within a matter of days. Several spare nozzles

have to be kept on hand, and the nozzles must be changed and cleaned on a rigorous schedule or the spray pattern will begin to deteriorate causing incomplete combustion, soot, and oil buildup on the burner assembly.

6. Energy Density – Vegetable oil has approximately 10% less energy per unit of volume than home heating oil. This means the boiler produces approximately 10% less energy than its rating when burning WVO than when burning petroleum.

Waste Motor Oil

Waste motor oil is a recycled product and is appropriate for use in our clean burn boiler. Overall, motor oil burned very well and reliably in our boiler.

The only problem encountered with motor oil was when sludgy thick oil was not sufficiently filtered.

Home Heating / Diesel Oil

All home heating oil we tried burned reliably with no problems.

Biodiesel

We did not have a reliable source of 100% biodiesel. When we briefly tested it, it burned reliably with no problems.

High-Efficiency Hydronic & Root Zone Heat

In our system, we used different methods to apply heat: For greenhouses, we used the Delta-T system (EPDM tubing) for both bench and under-floor heat and we also used PEX under-floor hydronic heat. For work spaces, we used baseboard hot water and also hot water unit heaters. All systems draw heat from our primary boiler through a series of primary, secondary, and tertiary loops and heat exchangers – See diagram.

Here is a list of important design considerations and features of our system:

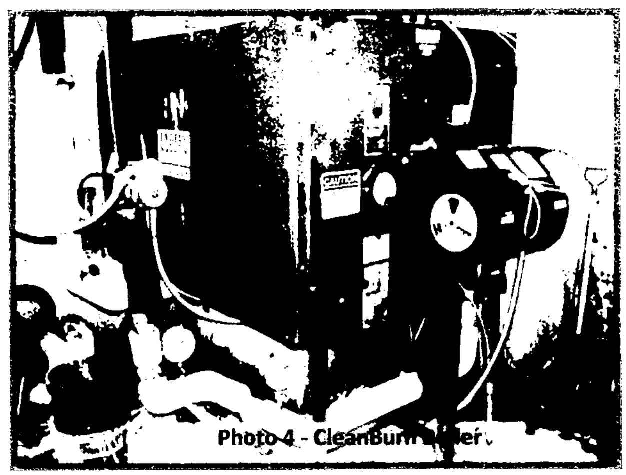


Photo 4 - CleanBur[illegible]er

1. The Clean Burn boiler is a central heat source. It is a 350,000 BTU / Hour waste oil boiler. It is located in our barn and is about 150 feet from our heated greenhouses. The Boiler has a primary loop that circulates water through a manifold that supplies heat to the office and workspaces. The primary loop also feeds a 300 foot long run of 40mm PEX tubing (greenhouse loop) that delivers approximately 140,000 Btu / Hour to our greenhouses.

   Both the main Boiler and loops and the greenhouse water use a 30% glycol solution to protect from freezing in the even the system is off due to power failure, etc.

Photo 5 - Hot [illegible] s for

2. The greenhouse loop circulates water from the boiler to a heat exchanger that transfers the heat to the greenhouse water. The bench heat uses EPDM tubing which is not impervious to oxygen. Because of this, the fluid circulating in the greenhouses can contain corrosive oxygen and must be isolated from the boiler.

3. The greenhouse heat is comprised of the indirect hot water heater and an auxiliary residential grade boiler that provides an additional 120,000 BTU / hour connected in series with a distribution loop. The oil fired heater burn home heating oil and provides backup heat in the event that the Clean Burn boiler fails or auxiliary heat for very cold weather. These two tanks serve to store heat, and from them the water is distributed through mixing valves to provide 140 degree water to each of 3 greenhouses.

    a. The first greenhouse (Koko) uses bench heat - a Delta-T heat system which is an industry standard bench heat system. Two 4' benches run the length of the greenhouse are heated with tubing on 2" spacing. This provides about 90 BTU's / Hour per square foot for a total maximum of approximately 25,000 BTU / Hour. This greenhouse has a single layer of polycarbonate covering
    b. The second greenhouse (Gatemouth) also uses the Delta-T system. It is a combination of one bench – 5 x 80 feet, and a heated floor area approximately 10 x 60 feet. In the floor system the Delta-T system is embedded in about 2" of crushed stone and insulated by a double bubble insulation layer beneath it. This greenhouse uses an inflated double layer of PE greenhouse film.
    c. The third greenhouse uses PEX tubing embedded in the floor. The system has 4" of expanded polystyrene insulation below the floor, about 3 inches of crushed stone with the PEX loops on 9" centers tubing embedded in it, and pavers for thermal mass. There is a 4 inch wide thermal barrier around the periphery of the house that extends 18" into the ground. This house is intended to be our warmest house, where we keep tender plants. It is covered with twinwall polycarbonate.

The figure below shows a worst case analysis of the greenhouse heat loads. (NOTE: The analysis includes additional hot water unit heaters. These were not included as the bench and floor heat provides sufficient heat in the coldest weather.)

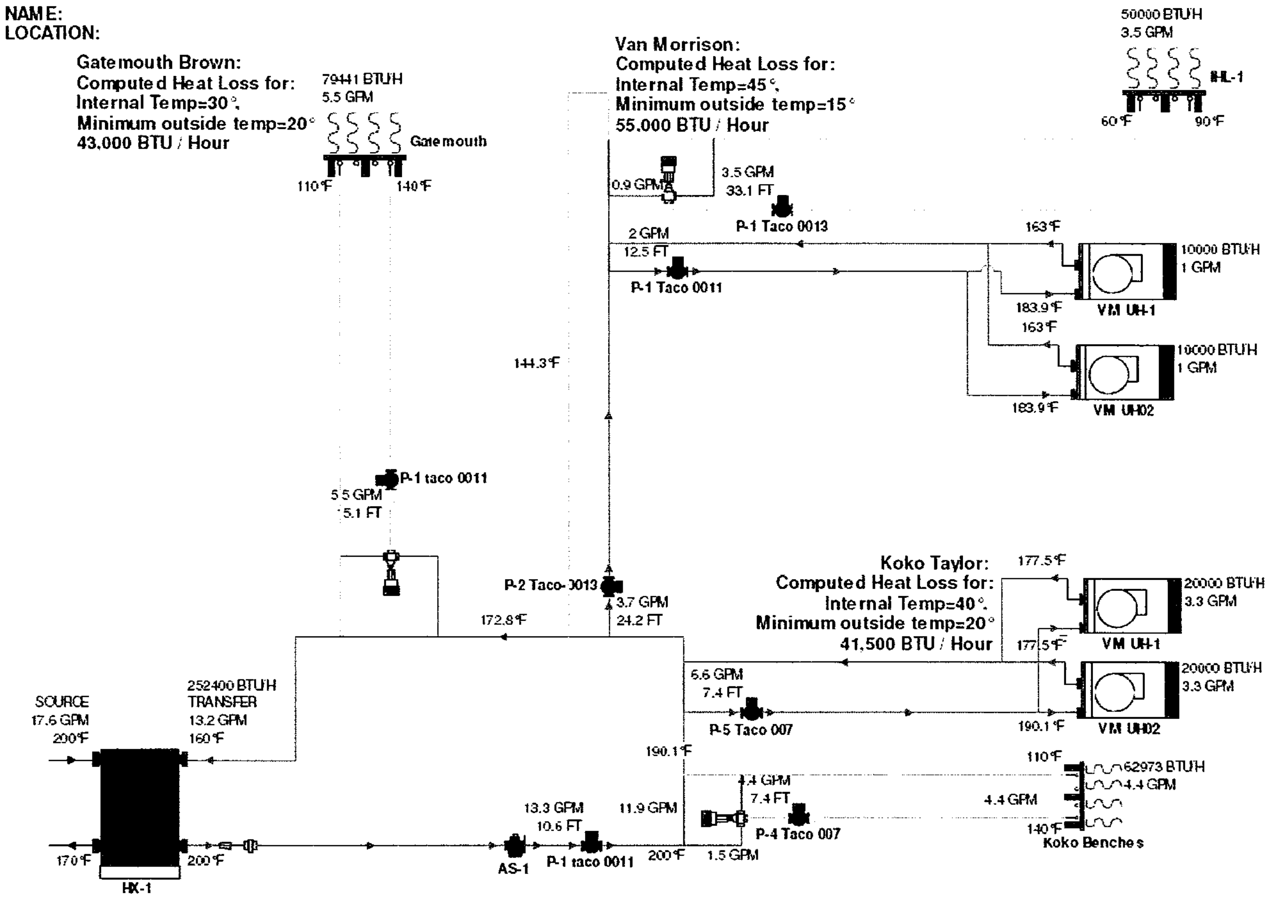


Figure 2 - Emory Knoll arms Greenhouse Heating Loops

Baseboard and Hot Water Unit Heater Heat

We also used baseboard heaters in our existing offices and small forced air unit heaters in our lunch room. All of these provide adequate heat for the space. The table below shows the computed heat loads for each space. Under floor hydronic heat would be preferable because it is typically more efficient than baseboard heat, but was not an option in our already-built office spaces.

Photo 6 - Backup Boiler

Back-Up and Auxilliary Heat

Based on the model, above, we knew that the worst case amount of heat required by the greenhouses (252,400 btu / hr.) would be greater than the amount of heat that can be delivered through the underground path (about 200,000 btu / hr.) We also desired to have a secondary source of heat in case of failure of the Clean Burn boiler or any associated systems. Therefore we implemented a backup boiler. This system consists of:

- A Used Sears 120,000 btu / hr. residential boiler
- A 275 gallon oil tank
- Circulator and controls
- Heat Exchanger

Photo 7 - Building for Backup and Greenhouse Manifolds

This system is housed in a small building built to hold it along with all the greenhouse heat circulator pumps and controls.

This is designed to come on at a lower temperature than the 'normal' hot water temperature. The secondary boiler comes on at about 140° F and runs until the water reaches 160° F. This runs autonomously, and will come on whenever the water temperature drops, whether the drop is due to extreme cold temperatures or due to the Clean Burn boiler tripping off.

While the secondary boiler does not have sufficient capacity to keep the greenhouses at optimum temperatures by itself, it will keep the houses and the rest of the heating system above freezing on even the coldest nights.

Comparative System – Heartwood Nursery

During the time this project was underway, nearby Heartwood Nursery built a new propagation house. The greenhouse itself is innovative: It was constructed as a traditional wood post and beam shed building and the Nursery Owner had it covered with twin wall polycarbonate rather than sheet metal. The result was a very tight and well insulated greenhouse as well as saving considerable money as compared to a traditional gothic greenhouse structure. The prop house is 40 feet x 70 feet, and the owner specified two heated benches at 10 feet x 40 feet each.

For this system, reliability was critical. Heat modeling suggested the greenhouse would require less than 100,000 BTU / Hour, and we also wanted to heat a workshop building that would house the boiler. In order to have some reserve capacity and allow for future growth, we chose a Burnham 200,000 BTU / Hour residential oil-fired boiler. Similar to Emory Knoll Farms, the workshop the houses the boiler is about 300 feet from the greenhouse. A loop of 1" PEX tubing buried in an insulated pipe runs from the workshop to the greenhouse and feeds a flat plate heat exchanger at the greenhouse.

The Heartwood greenhouse heat is also a Delta-T bench heat system. The nursery owner wanted to reuse as many components from their old site as possible. We were able to use a thermostatic control system, and zone valves and incorporate them into the new system allowing for four separate zones on the benches. Later, to improve reliability and simplicity, the zones were eliminated and both benches are heated from a single control.

Provisions for hot water unit heaters were included in the design for both the workshop and the greenhouse. In the final implementation, we learned that unit heaters were not required in the greenhouse and a single 50,000 BTU / Hour unit heater was sufficient for the workshop. The diagram below shows the system and calculated worst case heat loads.

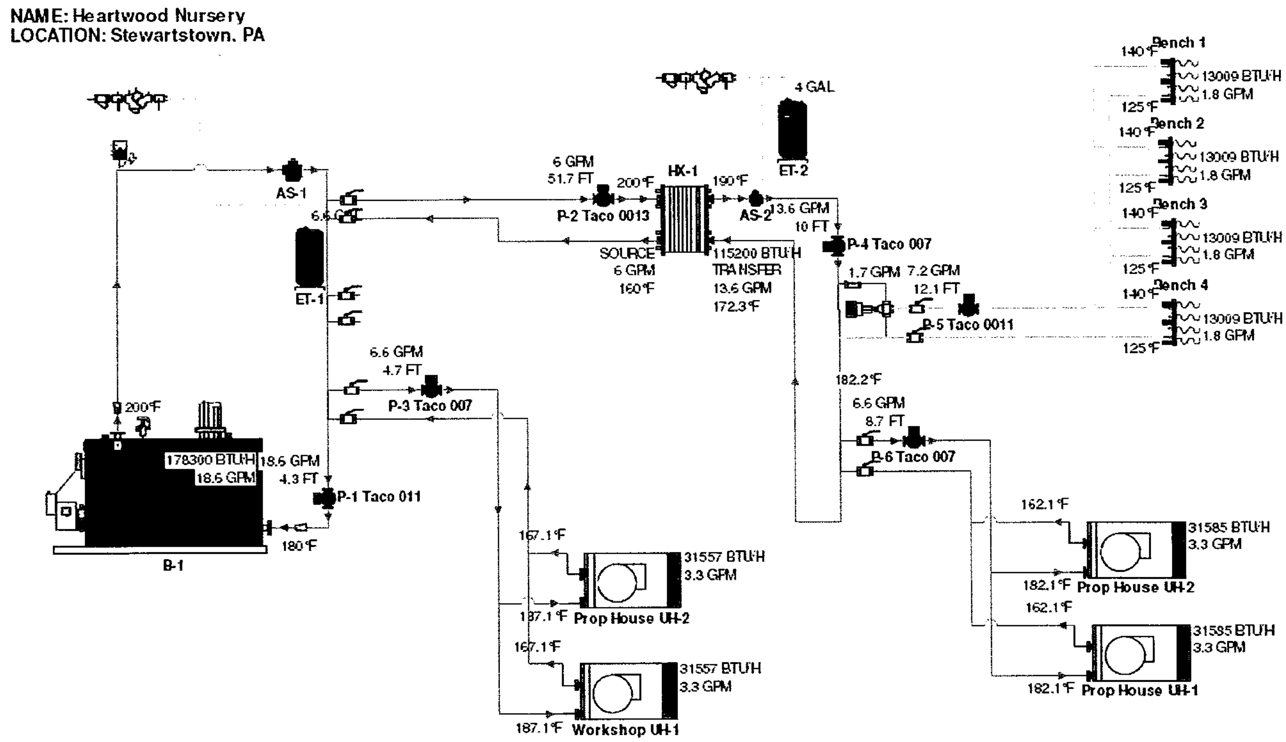


Figure 3 - Heartwood Nursery Greenhouse Heating System

Comparative System – Green Meadow Farm

Green Meadow Farm has been heating greenhouses with WVO for many years. They grow organic produce in the summer, and organic greens & specialty root vegetables in heated houses in the winter for restaurants in the Philadelphia area. Owner Glenn Brendle has been an inspiration to our adoption of WVO heating and a source of technical and practical expertise.

Green Meadow Farms originally used a typical outdoor wood-fired furnace that had been modified to burn WVO. About the time our project began, they switched to a new heating plant comprised of two Clean Burn CBT-350 boilers, the same model we are using. They also have the advantage of being close to the manufacturer, Clean Burn, Inc. They collaborated with the engineers at Clean Burn to modify the boilers for use with WVO. Their early success at using WVO in a Clean Burn boiler gave us confidence that our choices would work, even as we experienced difficulties in implementing our project.

Summary of Problems & Lessons Learned

We experienced extremely poor reliability of the Clean Burn boiler during the first two years of operation. These reliability issues were not caused by any intrinsic problems with the boiler itself, as it is a proven unit that burns all types of petroleum based waste oils with no problems. Rather, the reliability issues were caused by the WVO fuel, and the incompatibilities of this as a fuel for the Clean Burn. We will detail the issues we experienced, and our solutions for them, but in summary the magnitude of these issues caused us to shift our focus from quantifying the benefits of using WVO to addressing the more practical issues of achieving reliable operations with WVO.

Fuel Quality

Throughout this project, the quality and availability of was a significant issue. Initially we collected our own fuel from local restaurants. The fuel was stored in 330 gallon plastic 'totes' and was initially cleaned by racking the oil from one tote to another. The cleaner, dryer oil tends to rise to the top of a container and the water, food residue, and other contaminants tend to sink. By pumping oil from the top of containers into a newer clean container multiple times, very clean oil can be obtained over a period of several months.

However, the time required to perform racking procedure and the space & cleanliness issues associated with the totes, as well as the effort required to collect oil, made this process too time-consuming and costly. Often, if fuel ran low, we would draw some less clean fuel into the boiler supply and we would clog filters, nozzles, and foul the boiler.

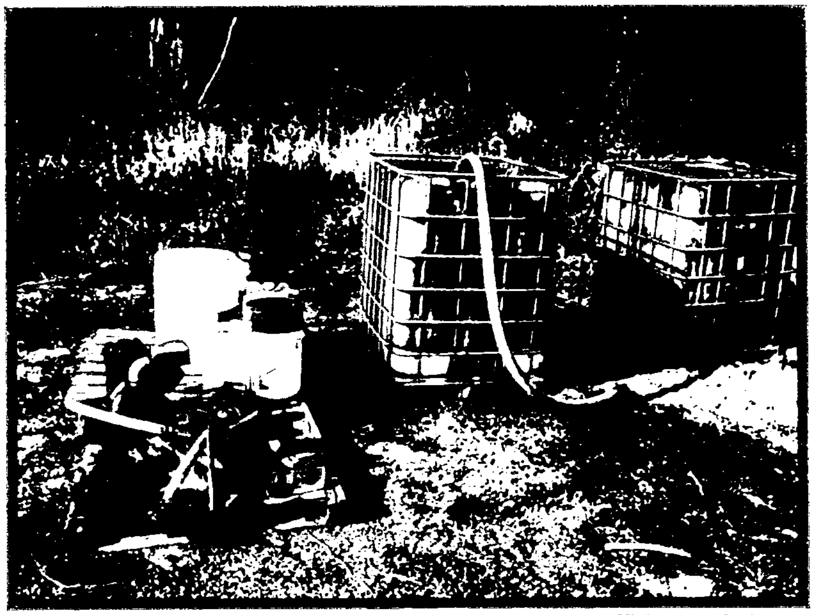
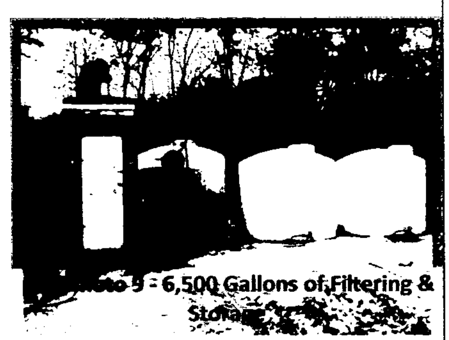


Photo 8 - Original Storage and Filtering System was Inefficient and Dirty

Fuel Quality Problems:

Problem:	**Solutions:**
Excessive time spent on racking & prefiltering fuel: For each 330 gallon tote of fuel, approximately 10 hours were spend in collection, transferring, and filtering the fuel.	Switched from 330 gallon totes to a 1,500 gallon intake tank and 2 x 2,500 gallon storage tanks. The intake tank has a cone-shaped bottom and all fuel is initially stored there for about 1 month. This allows water and food waste to settle. An outlet above the 'cone' allows clean fuel to be drawn off and transferred to the storage tanks. After the first storage tank is filled, the fuel has settled in it  **Photo 9 - 6,500 Gallons of Filtering & Storage**

	for several more months. Then the oil is drawn from an outlet about 8" above the bottom to the second storage tank. The remaining oil is sent back to the intake tank to settle more. The process is repeated with additional oil so that all our oil is double racked. Connections between all the tanks, filters, and pump are permanently connected and the desired transfer/filtering is accomplished by switching valves. A timer is placed on the pump motor to ensure that the pump will not run more than one hour at time. This helps prevent cases where the pump runs dry or overflows a tank.
The 100 micron filter for the boiler would often clog (sometimes weekly) with food particles, and heavy, waxy substances. When the filter clogged completely, the seals in the oil pump would get damaged and the pump would require replacement.	Added high capacity pre-filters. In the racking process, the already relatively clean oil is passed through a two-stage filter. Two household water filter cartridges are used – the first with a 50 micron filter, and the second with a 10 micron filter. Pressure gauges indicate when a filter must be changed. Every transfer of oil after the initial loading into the intake tank passes through these filters, so the oil is filtered multiple times. These filters also allow for *Oil Polishing*. We can pump oil from a tank, through the filters and back into the same tank. Generally we can run the pump for several days, resulting in 5 to 10 passes through the filter. This eliminated virtually all particles down to 10 microns, which is $1/10^{th}$ of the particle specified for the boiler.
We often found a buildup of a thick waxy substance that would clog the 100 micron boiler filter, even with clean fuel that had passes through the 10 micron filter in warmer weather.	Waxy build-up is addressed by pre-heating. WVO contains many substances which may be liquid at warmer temperatures but which may solidify and precipitate out of the oil as the weather turns cooler. The solution to this is to pre-heat the oil stored in the 'day tank' a 330 gallon tote that the boiler draws from. A loop of PEX tubing circulates hot boiler water through the tank to warm the oil to approximately 100 degrees F. At this temperature, the waxy substances pass through the 100 micron filter to the boiler where they are burned.  **Photo 10 - The Day Tank Stores and Pre-Heats Oil Before the Boiler Uses It**

Small particles that could pass through the 100 micron filter could coalesce in the boiler's pre heater & nozzle, resulting in a clogged nozzle.	Better fuel filtering addressed this also.
If the oil had residual water in it, the water would accumulate in our buffer tank that the boiler draws from. As the water built up, it could be taken in by the boiler in sufficient quantity to cause a flame out.	Use of a cone-bottom tank as an initial intake makes it easier to eliminate water.

Combustion Problems

Even with clean oil, we experienced many issues with burning the oil in the Clean Burn boiler. While there where many reasons that all contributed to the combustion problems, the result was always the same: The boiler would eventually trip off and lock out, resulting in a loss of all heat.

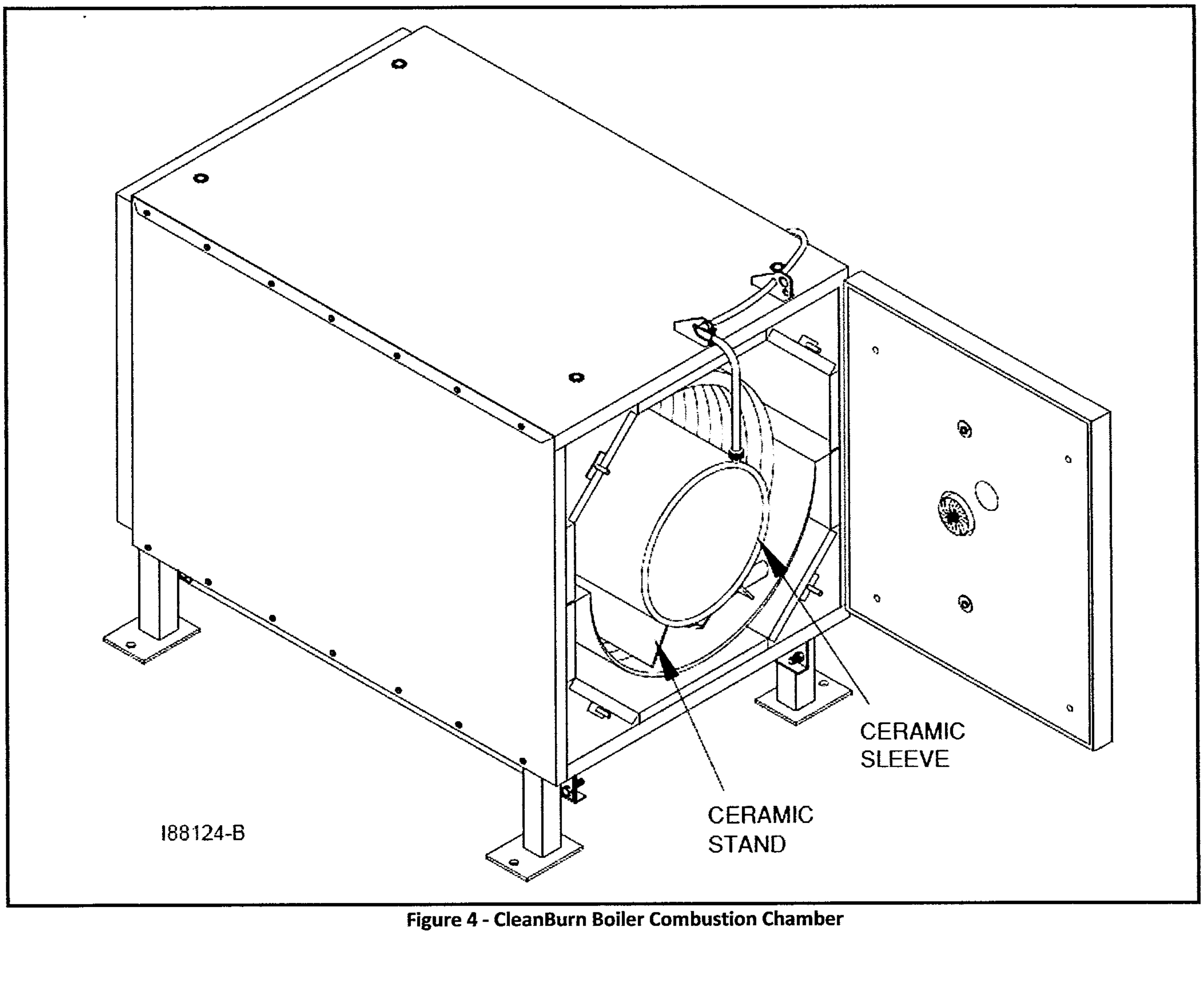


Figure 4 - CleanBurn Boiler Combustion Chamber

Problem:	Solutions:
Poor Draw: When the boiler has cycled off, the air in our 40' masonry flue would immediately begin to cool. The next time the boiler tried to start, it had to overcome this heavy column of cooler air in order to have appropriate draft. Often the boiler would fail on attempting to restart, especially in cold weather at night.	1. First we installed a draft inducer in the flue that would run with the boiler. This helped but did not solve the problem by itself[1]. 2. In the 2009-10 heating season, we replaced the standard combustion controller with a new one that allows for Pre- and Post Purge. This runs the fan and draft inducer for 30 seconds before turning on fuel & ignition to bush the column of cold air out of the flue. These along with other combustion improvements have effectively eliminated the startup problems.
Clogged Nozzles: Depending on the fuel quality, the nozzle would clog within a few days to one or one or two weeks of operation. Even when burning fairly dirty petroleum oil, the nozzles rarely clog in normal operation with petroleum. The nozzles can be disassembled and cleaned. We would find two primary causes of the clogs: occasionally food particles would coalesce into larger particles that could clog the nozzle. But regularly, we would find a clear granular substance built up inside the nozzle. We don't actually know what this substance is, but it is the consistency of a hard wax. Glenn Brendle of Green Meadow Farms reports that when a boiler cycles on & off the buildup is worse. He usually has one of his two boilers that burns nonstop in cold weather and he says there is never any buildup in a nozzle that burns all the time. When the boiler cycles off, the nozzle is exposed to extremely high temperatures inside the combustion chamber. It seems that this waxy substance precipitates out of residual oil left in the nozzle between times that the burner runs. A partially clogged nozzle will have a poor spray pattern which results in back-spray and incomplete combustion. The incomplete combustion results in a buildup of soot inside the combustion chamber and a buildup on the flame-retention head. (See below)	We have established a process for cleaning the nozzles on a regular basis. We have several spares and always put a clean nozzle in the boiler before a weekend or period of extremely cold weather. We use an ultrasonic jewelry cleaner and carburetor or engine cleaner on the nozzle and clean the pieces with cloth & 'Q-tips'. The Pre- and Post-Purge combustion controller helps with this issue. When the boiler cycles to 'off', the fan & compressed air continue to run, but the oil is shut off for a period of 2 minutes. This draws some of the residual oil out of the nozzle and it also cools the combustion chamber. The Nozzles still must be cleaned every one to two weeks. However this is a great improvement over initial operations when 2-3 days was the limit.

[1] At the beginning of the 3rd year of operation, we discovered that the motor on the draft inducer was no longer turning. After we took it apart to find the problem, we found the carcass of a 'char-broiled' bird wedged in the inducer blades, jamming it. Apparently this is a common problem and we now check the operation of the inducer at the start of every season.

Buildup on the Flame Retention Head: All oil burners have a flame retention head, which serves to shape the airflow around the nozzle and to form the shape of the flame. A flame retention head consists of a tube that surrounds the nozzle that narrows slightly near the end (close to the flame), and a set of fins that forces the air flow into a circular pattern. We have chronically experienced a buildup of unburned oil on the head. The oil hardens in the presence of heat and becomes a varnish that gets thicker with time. Eventually the buildup will disrupt the air flow to the degree that the burner will no longer operate correctly and will flame out.

We have had to clean the flame retention head as often as once a day up to once per week.

Adjustments to the draft controls have made small incremental improvements to this situation but failed to solve the problem. In the middle of the 2009-10 heating season, we discovered an internal component of the combustion chamber that was incorrectly positioned (Figure 4). When this was corrected, we experienced a dramatic improvement in flame retention head build-up. A related problem required replacement of a part which wasn't completed until after the heating season. We are hopeful that this will virtually solve the problem. (Green Meadow Farms does not have a problem).

It's notable that even when factory-approved service technicians have positioned these components, they did not put them in the correct position. It may be that when burning WVO the burner is much less tolerant of errors than when burning petroleum.

Conclusions / Adoption

We will present the adoption by discrete components as we have addressed these components in other areas of the report.

Alternative / Renewable Fuel

Alternative Fuel: Ultimately, the Waste Vegetable Oil fuel has proven to be viable for our application. The net results are:

- We are now nearly 100% carbon neutral for heat energy
- Our cost for fuel is approximately ½ the cost of heating oil
- Our production has increased as a result of a ready source of heat for our propagation houses

Hydronic Heating

While our basic boiler / Hydronic heating system has a few minor problems, primarily due to our own expertise in the design & installation stages; the fundamental principal is sound. We will continue to use hydronic heat systems and recommend them.

The primary result of this project is that we've proven that bench root-zone heat and under-floor hydronic heat are efficient, effective, and reliable. We are able to keep greenhouse air temperatures down, yet keep newly-propagated plants in a growth mode throughout the winter. This type of heat makes maximum use of the available heat with very little loss.

The Modeling system we used (Obtained free from Taco company – Taco's Hydronic Heating Solution software) provided valuable analysis and design validation. By plugging the rated heat transfer for our Delta-T heating system into the modeling tool, we were able to model the actual heat consumption for each greenhouse.

Outreach

We have provided outreach in many areas and often it is combined with information about our core market / product, Green Roofs. Because green roofs are energy & environmentally positive building elements, we often have the opportunity to speak about our alternative / renewable energy systems when we are also talking about green roofs.

Presentations Given

John has made presentations on the various alternative / renewable energy systems in use at Emory Knoll Farms at several regional events, including the annual Energy Field Day sponsored by the MD Cooperative Extension and MD Greenhouse Growers Association.

- November 8, 2007 - Getting Green: Sustainable Energy Use for the Green Industry, Timonium Fairgrounds, Timonium, MD
- November 11, 2008 - Energy Program for the Green Industry - Moving Toward Sustainability, Montgomery College, Rockville, MD
- November 30, 2010 – 3rd annual Chesapeake Green Energy Conference, Howard County Fairgrounds, West Friendship MD
- Visits to our nursery by various schools and environmental organizations. These schools visit our farm annually, and an overview of our alternative / renewable energy systems are always a part of the tour:
  - Franklin and Marshall College
  - Harford Friends School
  - Roland Park Country School

Publications

We have been featured in several articles and also on the Sundance Channel:

Real-World Energy Efficiency, Practical ways garden centers are saving the planet - and protecting their bottom lines, by Lisa Duchene www.gardenchic.com (http://www.begardenchic.com/articles/CHIC0308_EcoGardenCenter.pdf)

Emory Knoll Farms, A Profile of a Green, Green Nursery, Green Roof Infrastructure Monitor, 2007 http://www.greenroofs.org/resources/GRIM_Spring2007.pdf

Eco-Green Series: Emory Knoll Farms, Sundance Channel, 2007. Presented an overview of our renewable energy heating system. http://www.sundancechannel.com/films/500203099/

Consulting

This project has provided visibility and exposure to other agricultural organizations and allowed us to share lessons learned in relation to particular projects that others are planning. We consulted with the Beltsville Agricultural Research Center, part of the US Department of Agriculture for one of their greenhouses located in Beltsville, MD.