BIOMASS FURNACES FOR GREENHOUSE VEGETABLE GROWERS

Report to the High Meadows Fund. May 31, 2010

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EXECUTIVE SUMMARY

Greenhouse production in Vermont covers 2 million ft^2 and produces \$19 million in crops, of which about \$4 million are vegetables. We have calculated that the state uses 296,000 gallons of propane and 59,000 gallons of fuel oil each year to heat greenhouses. This equates to a cost of \$768,000/yr and 2,458 tons CO_2/yr - roughly equivalent to 6.2 million automobile miles.

This goal of this project is to help Vermont’s greenhouse vegetable growers adopt clean burning bio-mass furnaces, as an alternative to fossil fuels or outdoor wood-fired burners that can cause pollution. Help was provided as financial cost-share on the purchase of biomass systems, and in some cases, technical assistance from Callahan Engineering. Funds from this project leveraged grower investment, VT Agency of Agriculture grant funds, and UVM Extension funds.

Fourteen growers received cost-share funds for greenhouse biomass heating systems. The total expense of these systems was \$124,887; the average cost per farm was \$8,921 and the average cost-share on these projects was 31% of the total cost. The growers installed wood pellet or corn furnaces, a high efficiency cord wood boiler, and a used vegetable oil boiler. The systems have operated for two to three growing seasons, with average fuel savings of \$2,589 per farm per year, and an average payback of 3.4 years. From 2008-10 a total of 5.2 trillion BTU of biomass energy was provided to these greenhouses, equivalent to 56,592 gallons of propane. The net carbon dioxide emissions avoided by this substitution of fuel is estimated to be 110 cumulative tons.

Participating growers were generally enthusiastic about the use of biomass heating systems for their greenhouses. However, they identified challenges that must be addressed prior to widespread adoption. Using this feedback, and information gleaned from a statewide survey of greenhouse vegetable growers, specific strategies for ongoing work are suggested. They are:

1) Work with growers to assure that biomass heating systems are properly installed and optimally operated. Lessons learned from previous installations will be compiled and distributed. (Improving conservation strategies is a given with regard to all greenhouse heating systems.)

2) Work with manufacturers of relatively small-scale greenhouse heating systems to make minor but important modifications to improve reliability in greenhouse environments.

3) Explore the applicability of larger-scale biomass heating systems for Vermont’s vegetable farms with multiple greenhouses. These systems are needed to achieve significant conversion of the industry from fossil to biomass fuels.

4) Conduct research to identify combustion efficiency and emission levels of different biomass greenhouse heating systems operated under typical Vermont conditions. This information is needed to assist with selection of system type, size and installation but is currently lacking.

INTRODUCTION

There's a growing consensus that we need to develop farming and food systems that reduce our reliance on fossil energy. Given the upward trend in both price and worldwide demand for a finite supply of fossil fuel, coupled with concern about global climate change, many farmers would like to use renewable energy in their operations. Many energy options are worthy of consideration in agriculture, from wind and solar to biodiesel, grass pellets, corn and wood. The wider the range of options we explore now, the more experience we'll have as we develop our future energy systems.

In Vermont, it's important that we develop more energy and food systems based on a community scale, rather than an industrial scale. That way, infrastructure, marketing, and transportation costs can be minimized because neighbors are producing for neighbors. This also avoids the pitfalls of commodity markets where external factors have a big influence on price and profits, to the detriment our relatively small farms.

Heating of greenhouses in Vermont is an area where renewable energy, and energy conservation, is ripe for application. Greenhouse use extends the growing season and thus helps meet the rapidly growing demand for local produce, and greenhouse production is on the increase. However, most greenhouses in Vermont rely on fossil fuels for heating.

The short-term goal of this project is to help Vermont's diversified vegetable farms adopt clean burning bio-mass furnaces for their greenhouses, as an alternative to oil, propane, or outdoor wood-fired burners that can cause pollution. The long-term goal of this project is was to develop a learning community of greenhouse growers with interest in biomass heating for their operations as a defense against future fuel price and supply volatility.

The fuels adopted by growers in this project are all relatively easy to produce in Vermont. Cord wood, shell corn, and wood pellets are all readily available and most growers have some experience handling, storing and combusting these solid fuels. Used (or waste) vegetable oil is similar in its use to #2 fuel oil but it requires collection and transport infrastructure, filtration, and specially designed burners.

Figure 1 - Bill Llewellyn, Sr., of Five Points Farm in Northfield, MA produces shell corn for use as fuel. A former dairy farmer, he and his son provided the fuel used in the initial biomass furnace demonstration at Walker Farm and for several others greenhouse growers during the expansion phase of the project.

BACKGROUND AND GREENHOUSE GROWER SURVEY RESULTS

The U.S. Census of Agriculture reported that Vermont's greenhouse crop production was worth over $19 million in 2007: there were 115 Vermont farms producing greenhouse vegetables, herbs, and berries with a farm-gate value over $4 million, and 226 farms sold floriculture crops valued at $15 million. The crop production area under cover was nearly 2 million square feet [1].

To better understand current greenhouse heating practices a survey of Vermont greenhouse vegetable growers was conducted by the authors, with assistance from Debra Heleba of UVM Extension, in the Fall of 2009 [2]. This on-line survey was sent to 116 members of the Vermont Vegetable and Berry Growers Assn. via the association's listserv. It resulted in 51 individual growers responses (approximately 44% response rate). These responses represent 569,525 ft^2 of greenhouse growing area with 326,283 ft^2 (57% of area) being heated during growing season.

Survey respondents represent a diverse group of greenhouse scale of production. Approximately 29% grow in less than 1,000 ft^2 of heated greenhouse, 45% from 1,000 to 9,999 ft^2 and 26% grow in more than 10,000 ft^2. Respondents also utilize their greenhouses at different times, depending on the crops grown and the demands of their markets. Obviously, the size of greenhouse and the time it is in production affects the amount of heating, and fuel, required.

The total greenhouse growing area in Vermont is likely to increase in the future. Seventy-one percent of respondents indicate they are certain to construct new houses and/or high tunnels in the future.

The variety of heated greenhouse growing periods is demonstrated in Figure 2 which graphically summarizes the start and end dates reported by survey respondents for their main greenhouse. This graph helps to identify seasonal operation behavior and market driven greenhouse use common among groups of growers. One group of growers (16%) is growing in heated houses year round. Another group (12%) starts in early February. A third group (28%) starts growing in late February. The last major grouping of growers (16%) starts growing in early March. The remaining growers (28%) complete the spectrum of starting date. Two growers stand out from the rest of the group. One starts growing in the greenhouse in mid-February and ends in early January of the following year. The second starts growing in late September and ends in early June of the following year.

Fuel used to heat greenhouses is predominantly propane (47%), with secondary fuels being wood (14%) and fuel oil (14%). The remainder use vegetable oil, biodiesel, corn or other fuels (e.g. kerosene or natural gas.) These figures are not exclusive. For example several growers use cord wood as a primary fuel with propane for night-time backup only. They appear in both groups.

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[1] 2007 US Census of Agriculture; Vermont. Table 37. Nursery, Greenhouse, Floriculture, Sod, Mushrooms, Vegetable Seeds, and Propagative Materials Grown for Sale: 2007 and 2002
http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Vermont/st50_1_037_037.pdf

[2] This survey of the Vermont Vegetable and Berry Growers Association membership was conducted using an online survey service and was administered jointly by Debra Heleba (UVM), Vern Grubinger (UVM) and Chris Callahan (Callahan Engineering, PLLC).

Heating efficiency appears to vary dramatically from grower to grower. This metric (in units of $kBTU/ft^2/yr$) assesses the amount of energy used to heat each square foot of growing space for a one year period. By converting specific units of fuel (e.g. gallons of propane, cords of wood) to kBTU's one can more easily compare fuel use on equal terms; energy [3]. Average energy use for heating greenhouses in this group was 50.8 $kBTU/ft^2/yr$. Growers heating with propane (at least partially) appear to be the most efficient using an average of 43.4 $kBTU/ft^2/yr$. Users of fuel oil use 56.2 $kBTU/ft^2/yr$. Those burning cord wood or pellets use more energy, about 96.6 $kBTU/ft^2/yr$, on average.

The relatively low efficiency of wood heating demonstrated in this survey group is surprising. A review for any correlation between the use of large amounts of wood with harsh heating conditions (such as growing through the winter) revealed no such correlation. These growers are not growing deep in the winter when more energy would be required to maintain elevated inside temperatures. Thus, it seems, wood burning in greenhouses is currently a very inefficient practice needing some attention. Assuming most propane furnaces are operating at 75% overall efficiency, the average wood burning efficiency indicated by the survey results is 31%. When asked about their plans for future and alternative heating systems, many growers indicated interest in wood heat. This suggests an opportunity to apply technical assistance at the time of appliance selection, system design and installation which could improve the overall efficiency of converting one of Vermont's most obvious renewable fuels.

Burning fossil fuels results in a net addition of CO_2 to the atmosphere which does not result when burning sustainably harvested renewable fuels. For each gallon of propane burned, 12.17 lbs of CO_2 are emitted and result in a net addition of CO_2 to the atmosphere. Similarly, for each gallon of fuel oil burned, 22.38 lbs of CO_2 are emitted as a net addition to the atmosphere. Using the average heat energy intensity of 50.8 $kBTU/ft^2/yr$, the statewide covered growing area of 2 million ft^2, the 57% portion of that space that is heated (based on our survey), with 47% portion of the heated space fueled by propane and 14% by fuel oil one can estimate that the growers in Vermont use 296,000 gallons of propane and 59,000 gallons of fuel oil each year to heat greenhouses. This equates to a cost [4] of $768k/yr and 2,458 tons CO_2/yr. This CO_2 is roughly equivalent to 6.2 million automobile passenger miles (about 627 vehicles at 10,000 miles per vehicle per year).

Another conclusion from the survey is that many growers do not know their current fuel use with precision. In the case of purchased fuels, the growers often lack metering specific to a single house which makes an estimate of house efficiency difficult. In the case of fuels, such as wood, harvested locally many are not able to precisely measure or track their use. Thus the use is estimated in these cases. This conclusion becomes more apparent as one reviews responses dealing with costs of heating fuels. Qualitative responses varied from "insignificant" to "100%". Figure 3 displays this variance in response.

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[3] For the purposes of this report the following energy densities have been used: propane 92,000 BTU/gal, #2 fuel oil 138,110 BTU/gal, vegetable oil: 130,660 BTU/gal, biodiesel: 118,286 BTU/gal, wood: 20 million BTU/cord, and shell corn: 6,800 BTU/lb (15% moisture).

[4] For the purposes of this report, unless otherwise noted, fuel costs are assumes to be $2.00/gal for propane and $3.00/gal for fuel oil (both equal to $21.7 per million BTU).

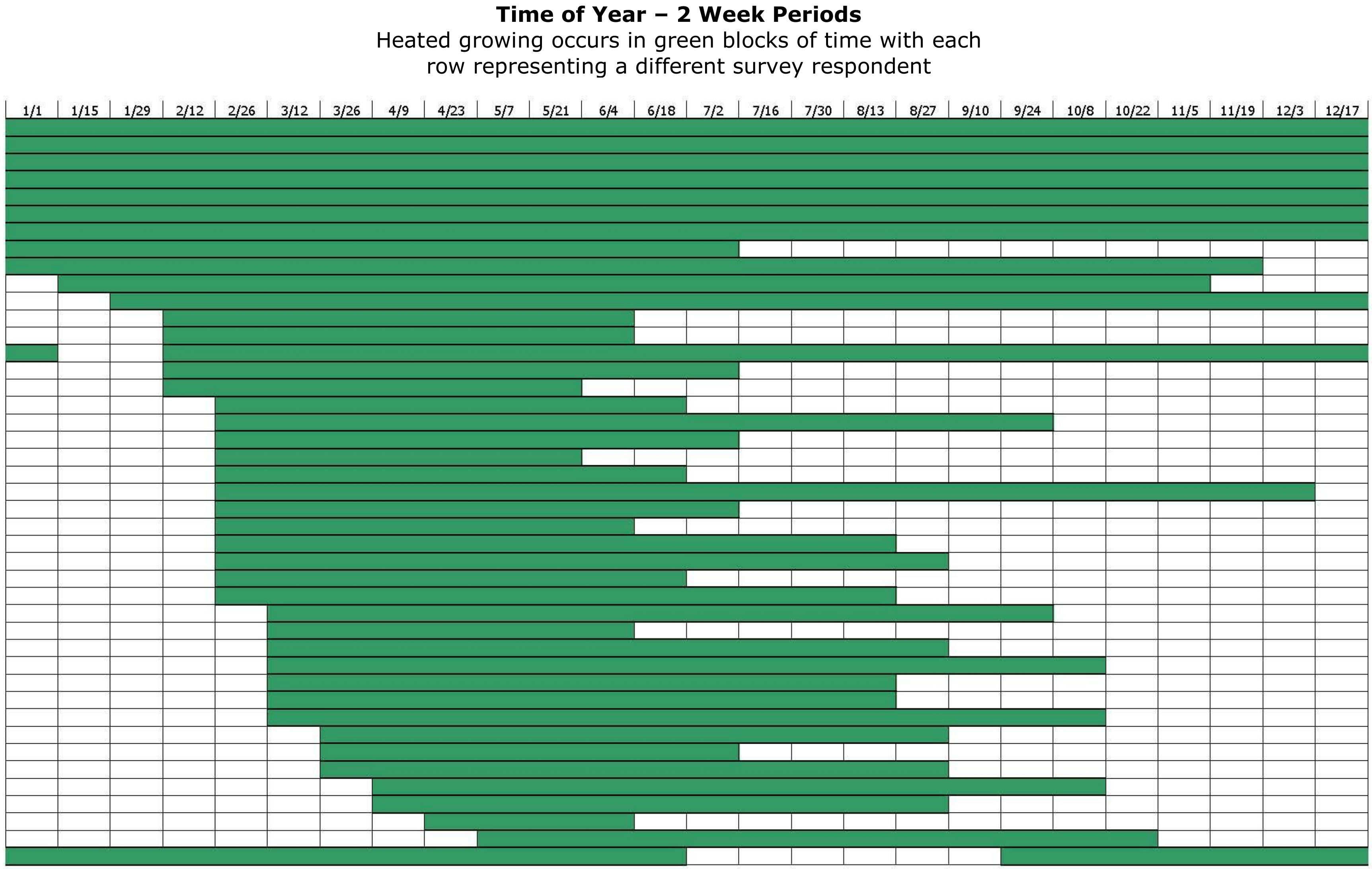

Figure 2 - Summary of greenhouse growing seasons as reported by 51 Vermont greenhouse growers.

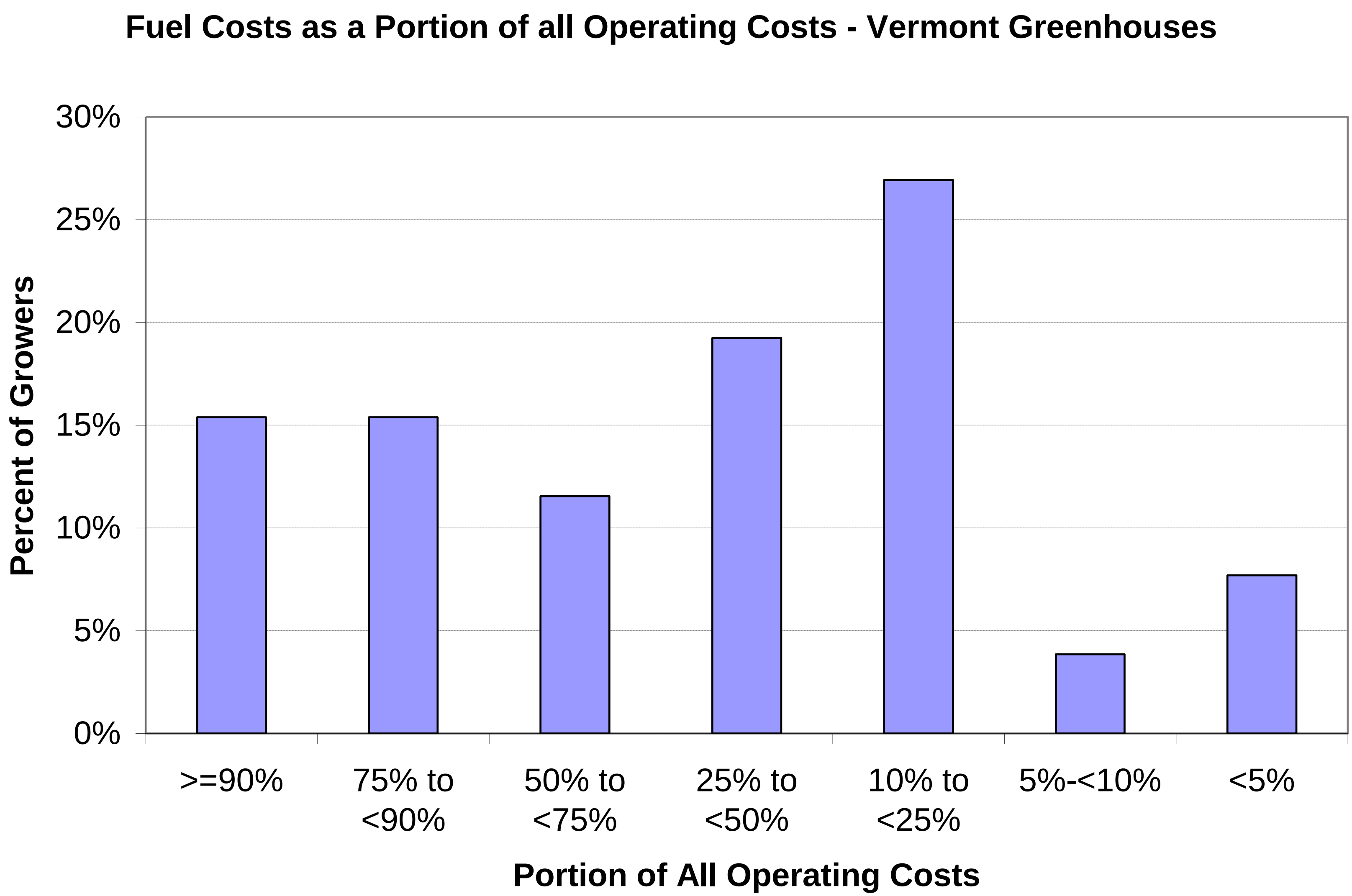

Figure 3 – Reported fuel costs as a portion of overall operating costs.

BIOMASS HEATING SYSTEM INSTALLATIONS AND DEMONSTRATIONS

Fourteen growers have received funding to assist with the purchase and installation of biomass greenhouse heating appliances with funding from this project. The first demonstration site was Walker Farm, in Dummerston, funded by UVM Extension. Additional sites were added based on initial findings at Walker Farm and this expansion was funded by a gift from the High Meadows Fund.

The total purchase and installation expense of these heating systems was $124,887. The average cost per farm was $8,921, and the average cost-share per farm (proportion of total costs supported by funds from this project) was 31 percent. Two growers also received REAP (Renewable Energy for Agriculture) grants from the Vermont Agency of Agriculture to help with their project planning. Most growers installed either wood pellet or corn furnaces. One grower installed a high efficiency cord wood boiler and one grower installed a used vegetable oil boiler.

These heating systems have now been operated for two to three growing seasons by each grower to heat a total of 39,281 ft^2 (average of 2,806 ft^2 per farm). The collective periods of biomass greenhouse heating amount to a total of 29 heated growing seasons. Performance data from these demonstrations is provided in Table 2 and are discussed in the remainder of this section.

The growers in this project reported fuel use that equates to heating intensity of 45.7 kBTU/ft^2/yr which is close to the survey average of 50.8 kBTU/ft^2/yr above. The average fuel cost savings per farm is $2,589 per year and about $36,242 total for the farmers included in this demonstration group. This results in a simple payback period for the biomass heating systems of 3.4 years (2.4 years when crediting the cost-shared portion.)

Records of fuel use by the growers from 2008-2010 indicate a total of 5.2 trillion BTU of energy being provided to these greenhouses from biomass sources as a result of these installations (equivalent to 56,592 gallons of propane), with a typical annual biomass energy use of 2.5 trillion BTU (approximately 27,087 gallons of propane equivalent). The growers in this project pay an average of $13.34 per million BTU for their fuels (compared to $21.70 per million BTU for $3.00/gal fuel oil or $2.00/gal propane.)

The net carbon dioxide emissions avoided by this substitution of fuel is estimated to be 110 cumulative tons at an average, normalized annual avoidance rate of 5.8 lbs CO_2/ft^2/yr (taking into account the greenhouse area heated). This latter figure allows for an estimate of the total carbon dioxide avoidance possible in Vermont. If the portion of the Vermont’s 2 million square feet of greenhouse growing area heated by fuel oil or propane (35%) were to be heated by renewable biomass sources, approximately 2,016 tons of CO_2 emissions would be avoided each year. This is approximately equal to 5.1 million automobile passenger miles (about 515 vehicles at 10,000 miles per vehicle per year). The difference between this figure and the maximum potential estimated in the previous section is due to current partial use of biomass heaters in the growing area of this project.

Most growers still used some fossil fuel to provide backup heating, and in some cases the underperformance of the biomass heater necessitated co-firing of biomass and fossil fuel heaters.

The growers involved in this project were asked to summarize their experiences and lessons learned. More detailed responses are provided in the case study pages that follow. Table 1 is a summary of the key lessons learned in this project, which should enable other adopters to start higher on the learning curve.

Percent Reporting	Lesson Learned
64%	**Biomass systems appear to be initially less reliable and require significant oversight and maintenance when compared to conventional oil and propane units.** Most growers have learned to adapt their operation to these needs, and schedule cleaning and tending to prevent failures.
36%	**Chimney setup needs to be considered carefully to prevent back-draft issues, particularly on warmer days.** The most successful installations use double and trible wall flue pipe in "as straight as possible" runs to maximize draft control.
36%	**Starting the fire can be challenging, and takes some learning specific to each stove and installation.** Most learned that starting with a very small fire worked well to establish draft prior to operation at higher burn rate. Supplemental fire starting materials seem to be used by all growers.
36%	**Pay attention to fuel quality and source, there are differences even within the same fuel type.** Several growers reported increased operational problems when switching fuel type or fuel supplier. The switch was usually motivated by cost.
29%	**The performance of some units appears to be lower than the manufacturer's claims (BTU/hr).** At least one grower had equivalent corn and propane units and noted that the propane unit would maintain an appropriate temperature difference while the corn unit would not.
21%	**These systems may require more integration & design than a conventional heater.** Hopper location, plumbing design, and controls may require specific attention that a propane or oil heater doesn't.
14%	**Fuel storage can be more challenging than conventional fuels.** Growers are used to fuel being stored in oil or propane tanks with little difficulty moving the fuel from tank to the heater. The use of solid fuels presents some specific, but not insurmountable, challenges in this area.
7%	**Our customers love that we use it.** One grower noted that customers noticed the use of the heater without prompting and were glad to see the innovation. Perhaps, there is potential to leverage the alternative heating systems in marketing activities.
7%	**It provides us fuel flexibility and freedom.** One grower noted the ability to control their own fuel costs and supply as being one of the main reasons for making the switch. They see this benefit as being critical to them as a small business in dependant on relatively high levels of energy as an input.

Table 1 - Summary of lessons learned from growers in this project.

Farm	Appliance	Installed Cost	Cost Share	Fuel	Heated Area (ft2)	Typical Annual Energy Input (mill BTU)	Normalized Fuel Cost ($/mill BTU)	Normalized Energy (kBTU/ft2/yr)	Cost Savings ($/yr)	Simple payback (years)	Avoided CO2 (ton/yr)
Walker Farm	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 6,000	$ 4,000	Corn	2,688	27	$14.71	10.1	$ 591	10.1	1.8
Intervale Community Farm	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 6,502	$ 3,000	Wood Pellets & Corn Mix	2,880	57	$16.77	19.9	$ 1,360	4.8	3.8
Your Farm	Harman PF100	$ 3,452	$ 1,726	Wood Pellets	1,248	57	$15.34	46.0	$ 1,435	2.4	3.8
Cedar Circle Farm	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 4,529	$ 3,000	Corn	2,880	54	$16.91	18.9	$ 1,183	3.8	3.6
River Berry Farm	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 5,169	$ 2,635	Wood pellets	2,850	98	$13.72	34.5	$ 2,300	2.2	6.5
Pete's Greens	Clean Burn 5000	$ 11,496	$ 3,000	WVO	6,000	261	$0.00	43.6	$ 5,676	2.0	21.2
Vermont Herb and Salad	Sequoia Paradise model E3400 wood furnace. (320 kBTU/hr)	$ 30,000	$ 3,000	Cord wood	5,400	1,500	$2.50	277.8	$ 14,000	2.1	52.2
Harlow Farm	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 8,820	$ 3,000	Corn	5,600	136	$16.91	24.3	$ 2,957	3.0	9.0
New Leaf CSA	Amaiziblaze 2100 (30kBTU/hr)	$ 1,226	$ 817	Corn	408	16	$17.65	38.3	$ 604	2.0	1.0
Old Shaw Farm	Harman PF100	$ 4,310	$ 2,000	Wood pellets	1,008	43	$16.22	42.3	$ 926	4.7	3.5
Atlas Farm	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 10,000	$ 1,500	Corn	5,040	109	$15.74	21.6	$ 2,365	4.2	7.2
Clearbrook Farm	American Royal Multifuel Boiler. 200 kBTU	$ 9,157	$ 3,000	Corn	2,688	54	$17.65	20.2	$ 887	10.3	3.6
High Ledge Farm	Central Boiler E Classic 2300 dual fuel	$ 21,226	$ 6,103	Cord wood	2,580	60	$5.00	23.3	$ 1,500	14.2	4.0
UVM Youth Ag Project	Buckner Corn Stove BR-7	$ 3,000	$ 2,500	Corn	1,000	18	$17.65	18.4	$ 459	6.5	1.2
Total		$ 124,887	$ 39,281		42,270	2,492			$ 36,242		122.4
Average		$ 8,921	$ 2,806		3,019	178	$13.34	45.7	$ 2,589	3.4	8.7
			31%								

Table 2 - Summary of biomass heater demonstration sites and performance.

Walker Farm
Jack Manix
Dummerston
Appliance: LDJ Amaize-ing Furnace (165kBTU/hr)
Fuel: Corn
Project Cost: $6,000
Annual Savings: $591
Payback Period: 10.1 years
CO_2 avoidance: 1.8 ton/yr

Lessons Learned in the Grower's Own Words:

'I love the furnace, but it is a "pain in the ass." Not reliable enough operation to depend on for high value crops (like spring organic bedding plants). Works best when it is cold out (i.e. use in your coldest house, or the one you use during the coldest months). Good for a one or two house grower, hard to imagine multiples working well for a large grower. Electric ignition would be a definite plus; these are difficult to get started sometimes, especially in a warm house. The exhaust is clean water vapor and people like the smell of corn muffins. An alarm system and backup heater is a must given the lack of reliability in feed and burner setup. Overall, I am glad I have it.'

Figure 4 - Corn furnace at Walker Farm.

Intervale Community Farm
Andy Jones
Burlington
Appliance: LDJ Amaize-ing Furnace (165kBTU/hr)
Fuel: Wood Pellets & Corn Mix.
Project Cost: $6,502
Annual Savings: $1,360
Payback Period: 4.8 years
CO2 avoidance: 3.8 ton/yr

Lessons Learned in the Grower's Own Words:

‘A: Buy good quality fuel with low fines content. B: Route a straight chimney inside greenhouse using double-wall stovepipe and triple-wall chimney pipe. C: Set greenhouse louvers to open prior to fan switching on to prevent backdrafting of flue gasses into greenhouse.’

Figure 5 - Becky Madden, Asst. Farm Manager, with the Intervale Community Farm corn furnace.

<u>Your Farm</u>
Kevin Channel
Fairlee
Appliance: Harman PF100
Fuel: Wood Pellets
Project Cost: $3,500
Annual Savings: $1,435
Payback Period: 2.4 years
CO2 avoidance: 3.8 ton/yr

Lessons Learned in the Grower's Own Words:

'The furnace requires daily refilling, daily scraping of the burnpot and scheduled maintenance that must be performed for every ton burned. This is a forced hot air furnace so supplemental bench heat is desirable. Pellets are pretty stable and available...buy in the off season if possible.'

Figure 6 - Kevin and Laura Channel with their Harman wood pellet furnace.

Cedar Circle Farm
Will Allen / Kate Duesterberg
E. Thetford
Appliance: LDJ Amaize-ing Furnace (165kBTU/hr)
Fuel: Corn
Project Cost: $4,529
Annual Savings: $1,183
Payback Period: 3.8 years
CO2 avoidance: 3.6 ton/yr

Lessons Learned in the Grower's Own Words:

'We're not currently using the furnace. We have had repeated problems with the pilot light blowing out when the house is ventilated, and also have had difficulty maintaining the chimney.'

(Note: the single wall chimney with several angles probably contributed to draft problems; this should be replaced with a straight triple wall stack.)

Figure 7 – Luke Joanis, assistant farm manager at Cedar Circle Farm

River Berry Farm

David Marchant
Fairfax
Appliance: LDJ Amaize-ing Furnace (165kBTU/hr)
Fuel: Wood pellets.
Project Cost: $5,169
Annual Savings: $2,300
Payback Period: 2.2 years
CO2 avoidance: 6.5 ton/yr

Lessons Learned in the Grower's Own Words:

'Lots of malfunctions with augers and motors. Thought we had everything figured out this year and then we switched brands of pellets to Vermont Wood Pellets and we had lots of smoke and draught issues and then bent another auger. This occurred just last week, so at this point were shelving it till next year. The unit operates well but with many glitches. Were committed to trying other systems. The exhaust, and smoke issues and ethylene damage on tomatoes have us wanting to try an outdoor unit. As our propane heaters age we have had some ethylene issues with them as well. Were looking forward to continuing the quest for the Holy Grail of an easy to use RELIABLE and EFFECTIVE biomass heater.'

Figure 8 - Dave Marchant (left) shows his LDJ furnace to other farmers at a biomass workshop held at River Berry Farm.

Pete's Greens
Pete Johnson
Craftsbury
Appliance: Clean Burn 5000
Fuel: WVO.
Project Cost: $11,496
Annual Savings: $5,676
Payback Period: 2.0 years
CO2 avoidance: 21.2 ton/yr

Lessons Learned in the Grower's Own Words:

'Higher maintenance and the pickup is a hassle but we do save some money.'

Figure 9 - Pete Johnson and his Clean Burn 5000 vegetable oil furnace.

Vermont Herb and Salad
Jared and Heather McDermott
Benson
Appliance: Sequoia Paradise model E3400 wood furnace. (320 kBTU/hr)
Fuel: Cord wood.
Project Cost: $30,000
Annual Savings: $14,000
Payback Period: 2.1 years
CO2 avoidance: 53.1 ton/yr

Lessons Learned in the Grower's Own Words:

'One of the main reasons we decided to put this system in is that we have access to wood on our own property. The furnace is so big and burns so hot that you don't need to relight it, even after 12-16 hours you can still throw some small branches in and turn on the forced draft fan and it re-lights. But wood is not oil; oil is easy. It may cost a lot but you just write a check and a guy pulls up in a truck and delivers millions of Btu's to your property and the heat comes on without you even knowing it. We have a lot of wood in Vermont, but it may not be practical for most people. We are a small business, and controlling our heating costs was important. This system gives us a lot more flexibility; we can pay ourselves to maintain our forest while we're collecting our fuel. Plus the cost of buying oil at unpredictable prices can be backbreaking, especially in winter when our cash flow is less.'

Figure 10 - The McDermott's in one of two leafy greens greenhouses heated by their wood gasification boiler.

Harlow Farm
Paul Harlow
Westminster
Appliance: Two LDJ Amaize-ing Furnaces (165kBTU/hr)
Fuel: Corn
Project Cost: $8,820
Annual Savings: $2,957
Payback Period: 3.0 years
CO2 avoidance: 9.0 ton/yr

Figure 11 - The LDJ Amaize-ing Furnace at Harlow Farm with a hopper extended to hold 21 bushels vs 14 in the default version.

Figure 12 - The greenhouses at Harlow Farm. Note the two exhaust stacks on the near houses which have both propane and corn heaters in them.

New Leaf CSA

Elizabeth Wood
Dummerston
Appliance: Amaiziblaze 2100 (30kBTU/hr)
Fuel: Corn.
Project Cost: $1,226.
Annual Savings: $604.
Payback Period: 2.0 years.
CO2 avoidance: 1.0 ton/yr.
Lessons Learned in the Grower's Own Words:

'Problems/things I didn't anticipate: 1) The hopper will only hold about 50 lbs of corn which is enough corn for about 12 hours of operation on its higher settings. 2) This stove puts out a lot less heat than my propane heater with the same Btu rating. 3) I had to buy lots of fire starter blocks. They're inexpensive but I had to make several trips to hardware stores. Some stores don't stock them in the spring because they think the heating season is over. 3) Although the corn stove and the propane heater are both rated at 30,000 BTU, the propane heater puts out a lot more heat. The corn stove alone is not sufficient to heat the greenhouse on cold nights. So I have been heating with both corn and propane most of the time. This is why corn has not replaced more of the propane used in the greenhouse.'

Figure 13 - Elizabeth Wood with her Amaiziblaze 2100.

Old Shaw Farm
Peter Griffin
Peacham
Appliance: Harman PF100
Fuel: Wood pellets.
Project Cost: $4,310.
Annual Savings: $926.
Payback Period: 4.7 years.
CO2 avoidance: 3.5 ton/yr.

Lessons Learned in the Grower's Own Words:

'Overall, we were extremely happy with the stove, and to be starting to find a way off of the oil habit. We also think it helped our marketing when we told customers that their seedlings were grown in a greenhouse heated by regional biomass, rather than oil. I will, however, offer a couple of observations. First, it is a little daunting to be among the first guinea pigs to try a new technology. Second, I would suggest following the cleaning instructions religiously. There were times we did not clean the burner pan daily, and after awhile, the carbon build up prevented the igniter from catching automatically. The result was that I would have to go out to the greenhouse every evening to make sure the stove had fired up, and if it hadn't, I had to manually start the fire. Third, we will have to work out a better system for storing the pellets. We kept ours on the pallets they arrived in, right outside the door to the greenhouse. They were in 50 pound plastic bags, and plastic wrapped on the pallet, but we still had some problems with moisture getting into some of the bags, and essentially ruining that bag of pellets. In 2010 we had some major mechanical problems with our unit. Although we have liked heating with regional biofuels, any other grower using a similar unit should be prepared to spend more time on maintenance and repair than on an oil furnace.'

Figure 14 - Peter Griffin in his biomass heated tomato greenhouse.

Atlas Farm
Gideon Porth
Deerfield (MA)
Appliance: LDJ Amaize-ing Boiler (165kBTU/hr)
Fuel: Corn.
Project Cost: $10,000.
Annual Savings: $2,365.
Payback Period: 4.2 years.
CO_2 avoidance: 7.2 ton/yr.

Lessons Learned in the Grower's Own Words:

'In 2009 we didn't have many issues, but have had lots of problems in 2010, mostly having to do with the corn not burning well. We modified the combustion blower to blow outside (less humid air) and have adjusted the controls every which way possible, but have continued to have problems. We are pretty convinced that the corn we have been buying is just too high in moisture and therefore, is not burning well. We had a few tons of leftover corn from 2009 that we tried burning this spring and it burned very well. Our corn supplier also changed the variety of corn he grew last year and the new variety has a larger kernel and more starch and seems to not dry down as well. We've also had many problems with the feed auger on our LDJ boiler failing and have heard similar reports from others.' (Note: LDJ makes an upgraded auger that can replace earlier auger units.)

Figure 15 - Gideon Porth and his LDJ corn boiler.

Clearbrook Farm
Andy Knafel
Shafstbury
Appliance: American Royal Multifuel Boiler. 200 kBTU
Fuel: Corn.
Project Cost: $9,157
Annual Savings: $887
Payback Period: 10.3 years
CO_2 avoidance: 3.6 ton/yr

Lessons Learned in the Grower's Own Words:

‘Need more thermal storage (more hot water), manufacturer ratings of boilers are suspect; don't oversize heat exchanger, there are differences between hot water and hot air that were not completely appreciated, if you can plumb the system yourself do so, avoid open water systems as they limit your ability to optimize performance.’

Figure 16 - The American Royal multifuel boiler and hopper at Clearbrook Farm.

High Ledge Farm
Paul Betz
Woodbury
Appliance: Central Boiler E Classic 2300 dual fuel
Fuel: Cord wood
Project Cost: $21,226
Annual Savings: $1,500
Payback Period: 14.2 years
CO2 avoidance: 4.0 ton/yr

Figure 17 - Paul Betz with his Central Boiler outdoor wood gasification boiler.

Lessons Learned in the Grower's Own Words:

‘Don’t skimp on the piping. While I was shocked at the $13.00 a foot price, I should have gone for it. I got some for $6.95, and the insulation is not as adequate, and since it’s not a filled pipe, if the outer sleeve gets nicked, it will fill with water and defeat the insulation... I am considering pulling up the pipe that I have installed and doing it again. When I add any other buildings, I will definitely be using the other pipe. When buying the exchangers, be sure to check the Btu ratings. When they are listed they give the ratings for steam, not hot water. The end result is the exchangers are a little undersized that I got for the houses…I will be most likely changing them as well next year. Despite what the sales people will tell you, they are finicky to get lit, and require some babysitting. Once it is going, it does what it’s supposed to do, which is burn clean and make hot water.

UVM Youth Ag Project
Liz Kenton / Sam Rowley
Brattleboro
Appliance: Buckner Corn Stove BR-7
Fuel: Corn
Project Cost: $2,500
Annual Savings: $459
Payback Period: 5.4 years
CO2 avoidance: 1.2 ton/yr

Figure 18 - UVM Youth Agriculture Project

Lessons Learned in the Grower's Own Words:

'Starting: The corn stove, if not running constantly can be difficult to start. I have been successful starting the stove with a little experimentation. Running the stove is easy after it has started. I have encountered few issues once the stove has reached the auto-feed stage. Cleaning must be done regularly to prevent any problems while running. The recommended method of shutting the stove down is to set the feed rate to nothing and let the auto-off setting do its work. In auto-off, the stove is meant to shut off when the hopper becomes empty and the fire dies due to lack of fuel. The stove senses the lower temperature and shuts down completely.

***Figure 19 - The Buckner corn stove at the UVM Youth Agriculture Program greenhouse*.**

Cleaning is the biggest hassle involved with this stove. The stove came with an oversized pipe cleaner to brush out the ash that collects in the heat exchanger/exhaust tubes. The design is such that the tubes go from the combustion box to another settling box and then to the chimney. The chimney is a double wall vent. The inner chimney carries the combustion gasses out. The outer space around the inner chimney draws air from the outside in for combustion. I like this feature as the combustion air is not taken from the interior, heated air of the greenhouse. However, the entire stove, and the chimney, must be cleaned to remove any hardened ash that deposits in the tubes and in the settling box. During long burns of overnight and through the day, removal of the clinker is necessary. Removal of the clinker is more difficult after it has sat and cooled to room temperature and when humidity is low. This can be a messy, frustrating, and a possibly injurious task. It is best to remove the clinker as soon as it has cooled to reasonable temperatures, such as an hour after shutdown. There is little question the corn stove has offset our propane use. Of course it is not as easy as setting a thermostat and walking away.

Figure 20 – 'clinkers' form as shell corn is combusted

CONCLUSIONS

Based on review of the greenhouse heating survey results and performance assessment of the biomass heating demonstrations detailed above, the following conclusions can be drawn regarding Vermont greenhouses:

1. **Vermont's heated greenhouse area has been determined along with its heating efficiency.** Statewide heated greenhouse area is estimated to be 741,000 ft^2 and is heated with an average efficiency of 50,800 BTU/ft2/yr (about equivalent to ½ gallon of propane per ft^2 or $1.10 per ft^2).

2. **The amount of heated greenhouse areas is increasing.** A majority of growers (71%) are certain they will be constructing additional houses.

3. **Fossil fuels dominate the greenhouse heating demand** with 61% of heating being done by propane (47%) or fuel oil (14%).

4. **The annual cost of greenhouse heating has been estimated.** Approximately 269,000 gallons of propane and 59,000 gallons of fuel oil are consumed each year by Vermont greenhouse growers at an estimated annual cost of $768,000.

5. **Greenhouse growing is a significant source of net CO_2 emissions.** Net CO_2 emissions associated with fossil fuel-based greenhouse heating in Vermont are estimated to be 2,458 tons/yr. This is roughly equivalent to 627 passenger vehicles each traveling 10,000 miles each year.

6. **Growers who currently use biomass (e.g. cord wood, pellets, shell corn) appear to be heating less efficiently than those using conventional fuels.** Those using biomass heat with an efficiency of 90,000 BTU/ft2/yr vs. 43,400 BTU/ft2/yr for propane users and 56,200 BTU/ft^2/yr for fuel oil users. In other words, current biomass practices result in using more energy to heat the same growing area. Growers who took part in the demonstration portion of this project, however demonstrate excellent heating efficiency with an average of 45,700 BTU/ft2/yr. This indicates that there is nothing fundamentally inefficient in biomass heating and that existing inefficiencies can be resolved.

7. **Most greenhouse growers do not know their fuel use and heating efficiency with precision making targeted efficiency improvements difficult.** Responses to this section of the survey were coarse and variable, due largely to the way fuels are delivered and stored (i.e. serving multiple houses from the same tank.)

8. **Biomass fuels are cheaper per unit of energy than conventional fuels.** Growers in the demonstration projects paid an average of $13.34 per million BTU vs. $21.70 per million BTU for $2.00/gal propane or $3.00/gal fuel oil.

9. **Biomass fuels offer a pathway to CO_2 emissions reduction.** The use of biomass fuels in this demonstration project, alone, resulted in 110 tons of avoided net CO_2 emissions. The average rate of avoidance was 5.8 lbs/ft^2/yr.

10. **Practical lessons have been learned about the use of biomass for greenhouse heating.** Growers involved in the demonstration project report the need to incorporate increased care and preventative maintenance for the heating system when using biofuels. Chimney design, installation and maintenance also require more attention than a conventionally-fueled heater. Even units with integral pilots and starting systems may require development of skill in order to ignite the biomass fuel. Growers report marketing and customer relations benefits from the use of the biomass heater on their farm. Others found relief in the flexibility and freedom that variety of fuel source and selection affords their operation when using a multi-fuel biomass heater.

11. **Design feedback for manufacturers of biomass heaters has been collected.** Some of the heaters used in demonstration projects were clearly performing below the claimed heat output of the manufacturer. The increased variability of biomass fuel quality when compared to conventional fuels is one reason for this, but lack of industry standards for measuring this is the main culprit. Some of the units had clear design problems such as electrical malfunctions, bent feed augers, and broken parts.

NEXT STEPS

Based on the result of this project, the authors suggest the following:

1. **Work with growers to assure that biomass heating systems are properly installed and optimally operated.** We will ensure outreach and distribution of the project's results and grower's lessons learned. Most of the survey participants expressed great interest in hearing about the results of the survey. That, along with the results of the demonstration projects will be published on existing outreach websites such as eXtension Farm Energy site http://www.extension.org/pages/Introduction_to_Farm_Energy and the UVM Vegetable and Berry Grower site http://www.uvm.edu/vtvegandberry/. The authors will also seek opportunities to present the findings at educational conferences and meetings.

   In addition, follow-up funding will be provided to growers with demonstration projects to assist with corrections to their installation. Specifically, some systems need double or triple-wall chimneys for corn furnaces to assure proper draft and optimal operation. Other growers need to replace insulated pipe to reduce heat loss from hot water.

2. **Work with manufacturers of relatively small-scale greenhouse biomass heating systems to make minor but important modifications to improve reliability in greenhouse environments**. This will include providing design feedback from the demonstration project to the manufacturers. Ideally, a series of on-site workshops with growers and heater manufacturers would help to resolve some of the issues noted in this project: auger failure, insufficient draft, and corrosion of some parts.

The use of small-scale, residential-type biomass heaters have some design limitations when applied to greenhouse heating. Although they are very cost effective, these units (<200,000 BTU/hr) are not explicitly designed for service in the greenhouse environment.

3. **Explore larger-scale biomass heating systems for vegetable farms with multiple greenhouses**. Most of the project participants installed a single, small heater in a single greenhouse. A more complete conversion from fossil fuel greenhouse heaters to biomass heaters will require larger biomass units being shared by multiple houses at a single farm location. These must have an acceptable payback period (~10 years of less), meet current state regulations, and involve a feasible system of materials handling for busy growers.

   Existing, large units (>500,000 BTU/hr) include improved design elements such as integral fuel feed systems, burner controls, and modulating firing rates. However, these units are also quite expensive, limiting payback potential. A more thorough survey of larger-scale, centralized, biomass heaters should be conducted.

4. **Conduct research to identify combustion efficiency and emission levels of different biomass greenhouse heating systems operated under typical Vermont conditions.** Heat output from biomass heaters can vary depending on the specific fuel used, integration of the heater into the heating system, and combustion air control (e.g. chimney draft). Assessment of combustion efficiency and basic emissions with a combustion analyzer should become standard commissioning practice for all biomass heater installations. This device measures the amount of oxygen in the exhaust of the unit and determines the efficiency of combustion.

   If too little air is being provided to a biomass heating system, the fuel is only partially combusted. On the other hand if too much air is provided, the heat from combustion is wasted heating this excess air which then goes right up the chimney. Tuning of the heaters is required to ensure the right amount of combustion air is being provided, and that undesirable emissions such as CO_2 and fine particulates are limited.

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