Promoting Adoption of Biomass Fuels for Heating Vegetable Greenhouses in Vermont

Final Report on Work Supported by

High Meadows Fund

Green Mountain Power
Community Energy & Efficiency Development Fund (CEED Fund)

Vermont Agency of Agriculture

The University of Vermont Extension

September 4, 2015

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Executive Summary

In the Northeast, early and late season production of food crops using greenhouses requires the addition of heat to maintain temperature and also to control humidity. The heating fuel used is generally propane or other fossil fuels. The use of greenhouses, and greenhouse heating, are on the increase in Vermont as growers respond to increased demand for local food throughout the year. Greenhouse production is also on the rise because it allows growers to protect against extreme weather events such as heavy rain or drought, and it affords better control of the growing environment, leading to improved yield and quality. However, using fossil fuels to control the growing environment is costly and these fuels also contribute to greenhouse gas emissions. Vermont greenhouse growers produce $24.5 million in crops using 2.6 million square feet of growing area at an estimated annual heating cost of $1.8 million. Many of these growers are interested in alternatives to fossil fuels for heating in order to improve their profitability and/or reduce their environmental impact.

This project demonstrated the use of biomass heating for greenhouse vegetable production at sites across Vermont. From 2008 through 2015, 25 growers received cost-share funds for greenhouse biomass heating systems. The total installed cost of these systems was $312,766; the average cost per system was $12,511 and the average cost-share (i.e. sponsor funding) on these projects was 44% of the total cost. The growers installed a variety of system types depending on desired fuel, heating load and method of heat distribution (hot air or hot water). The project started in 2008 and the systems have operated for the equivalent of 96 growing seasons in total with an average of 3.8 growing seasons per system, an average net fuel savings of $2,696 per system per year, and an average payback of 4.8 years (at full cost). From 2008 through 2015 a total of 15.3 trillion BTU of biomass energy was provided to these greenhouses, equivalent to 167,000 gallons of propane. The cumulative equivalent carbon dioxide emissions avoided by this substitution of fuel is estimated to be 2.14 million pounds. This is roughly equivalent to the annual emissions from 204 cars, or 2.3 million miles of car travel.

Background and Situation

Greenhouse production in Vermont covers 2.6 million square feet and produces $24.5 million in crops, of which about $5 million are fruits and vegetables. This translates to 60 acres of covered production with gross revenues of $408,000/acre overall and $224,000/acre for fruits and vegetables. Growing crops under cover in greenhouses and high tunnels (which are simple greenhouse structures,) provides a more protected and controlled environment compared to field production. This protection has become increasingly important to Vermont farmers as the incidence of extreme weather events has increased in recent years. At the same time, Vermont farmers are expanding their greenhouse and high tunnel production in order to meet the growing demand for local food, which continues even when crops are 'out of season'.

However, the production of greenhouse crops often requires the addition of heat in early spring and late fall to protect against cold temperatures. That heat is generally derived from non-renewable fossil fuels such as propane and fuel oil. The estimated economic and environmental impact of this situation is summarized in Table 1. In short, heating greenhouses in Vermont is estimated to cost $1.8 million annually and it results in equivalent carbon emissions equal to those from 724 passenger vehicles or 8.2 million miles of car travel. Additional details about Vermont's greenhouse production are provided in Table 2and are based on the 2012 USDA Census of Agriculture.

		2007	2012
Area	sq. ft.	2,050,015	2,621,263.00
Heated Space	sq. ft.	1,168,509	1,494,119.91
Heating Intensity	Million BTU/yr	59,360	75,901.29
Propane	gal	303,253	387,756.60
	$	732,660	1,341,637.83
Fuel Oil	gal	90,331	115,501.97
	$	219,955	469,977.50
Total Propane + Oil	$	952,616	1,811,615.32
Carbon Equivalents	Million lb/yr	5.93	7.58
	Million miles	6.4	8.2
	# cars	566	724

Table 1 - Estimated Vermont Greenhouse Heating Energy Use and Associated Carbon Emissions. Area is based on 2012 USDA Ag Census. Remainder is estimated by the authors based on 2009 Vermont grower survey results reported earlier.

There's a growing consensus that we need to develop farming and food systems that reduce our reliance on fossil energy and minimize negative impact on the environment while supporting sustainable economic development. Given the volatility in both price and 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. Yet use of propane and fuel oil, the primary Vermont greenhouse fuels, have steadily increased over time (Figure 1). Many energy alternative options are worthy of consideration for greenhouse heating, including biodiesel, grass pellets, shell corn, solar hot water and wood. The wider the range of options we explore now, the more experience we'll have as we develop our future energy systems. Wood pellets, for example, are readily available with a predictable quality standard and are competitive on a cost per BTU basis as shown in Figure 2.

Use	Units	2007	2012	% Change
Vegetables	farms	111	294	165%
	sq. ft.	425,083	950,047	123%
	sales, $	$ 3,951,342	4,313,339	9%
Tomatoes	farms	98	263	168%
	sq. ft.	309,161	659,911	113%
	sales, $	$ 2,925,836	$ 4,907,637	68%
Floriculture Crops	farms	226	274	21%
	sq. ft.	1,492,557	1,464,211	-2%
	sales, $	$ 14,915,956	$ 15,365,029	3%
Vegetable Transplants	farms	17	79	365%
	sq. ft.	17,156	88,095	413%
	sales, $	$ 110,126	$ 284,089	158%
Fruits and berries	farms	4	21	425%
	sq. ft.	17,400	43,144	148%
	sales, $	$ 26,100	$ 44,366	70%
Nursery Stock	farms	11	21	91%
	sq. ft.	54,210	26,539	-51%
	sales, $	$ 5,268,772	$ 3,613,083	-31%
Vegetable Seeds	farms	7	16	129%
	sq. ft.	7,224	22,123	206%
	sales, $	N/A	$ 287,020.00	--
Cuttings, seedlings, etc.	farms	6	15	150%
	sq. ft.	25,800	20,756	-20%
	sales, $	$ 198,732	$ 573,552	189%
Mushrooms	farms	5	20	300%
	sq. ft.	10,585	6,348	-40%
	sales, $	$ 41,366	$ 42,324	2%
Totals		**387**	**740**	**91%**
		2,050,015	**2,621,263**	**28%**
		24,512,394	**24,522,802**	**0%**

Table 2 - Vermont Greenhouse Use Data - 2007 vs. 2012 USDA Census of Agriculture

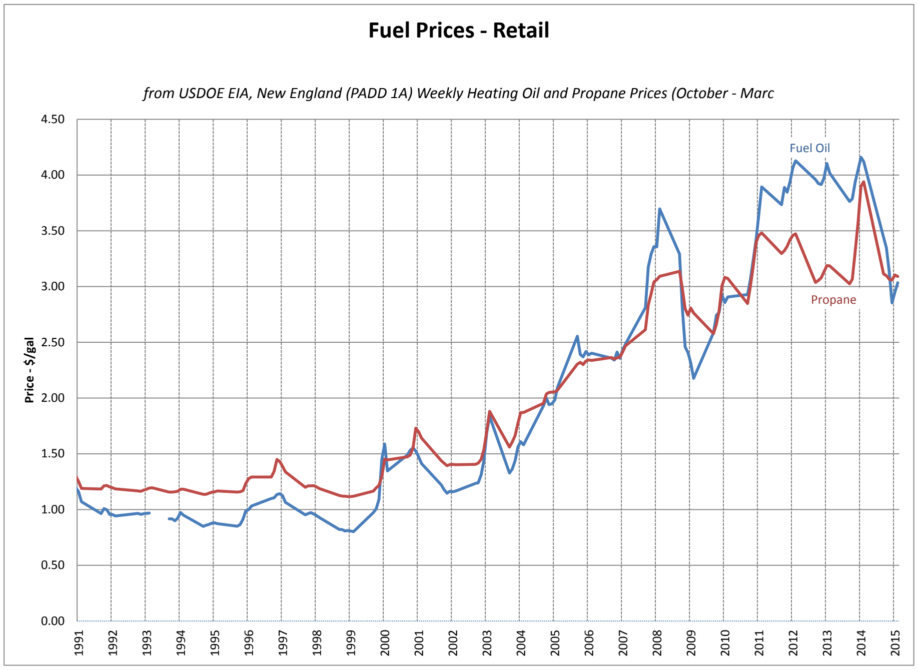

Figure 1 - Historical Fuel Prices - Fuel Oil and Propane

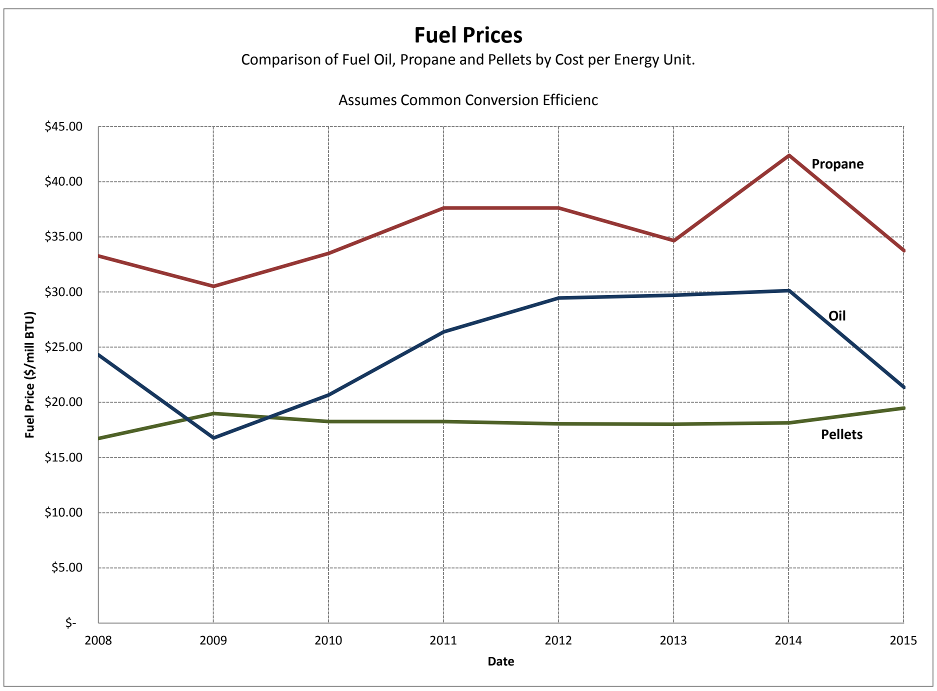

Figure 2 - Fuel Prices using a common unit, $ per million BTU of energy content. This does not consider appliance thermal efficiency which has become more consistent in recent years between propane, fuel oil and biomass appliances. Fuel oil and propane prices are from US DOE EIA. Pellet pricesand shell corn prices are actual prices paid by growers involved in this project. Corn fuel pricing was generally the same as wood pellets.

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. Our focus was on fuels that can be produced at the 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. There is also increased resilience in energy systems that have lower fuel-miles.

This overall goal of this project was 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 result in increased pollution. Additional goals were to identify obstacles to the adoption of such fuels and to identify and share best practices for biomass heating. Support for this work was provided as financial cost-share on the purchase of biomass systems, and in some cases, technical assistance. Funds for this project came from growers, The High Meadows Fund, the Vermont Agency of Agriculture Food and Markets, Green Mountain Power (CEED) and University of Vermont Extension.

Project Results

This project demonstrated the use of biomass heating for greenhouse vegetable production at sites across Vermont. From 2008 through 2015, 25 growers received cost-share funds for greenhouse biomass heating systems. The total installed cost of these systems was $312,766; the average cost per system was $12,511 and the average cost-share (i.e. sponsor funding) on these projects was 44% of the total cost. The growers installed a variety of system types depending on desired fuel, heating load and method of heat distribution (hot air or hot water). The project started in 2008 and the systems have operated for the equivalent of 96 growing seasons in total with an average of 3.8 growing seasons per system, an average net fuel savings of $2,696 per system per year, and an average payback of 4.8 years (at full cost). From 2008 through 2015 a total of 15.3 trillion BTU of biomass energy was provided to these greenhouses, equivalent to 167,000 gallons of propane. The cumulative equivalent carbon dioxide emissions avoided by this substitution of fuel is estimated to be 2.14 million pounds. This is roughly equivalent to the annual emissions from 204 cars, or 2.3 million miles of car travel.

The systems installed and, in some cases, technically supported as part of this project are summarized in Table 3.

Farm	Location	Appliance	Installed Cost	Cost Share	Funding	Fuel	Heated Area (ft2)	Period	Average Annual Energy Input (mill BTU)	Normalized Fuel Cost ($/mill BTU)	Normalized Energy (kBTU/ft2/yr)	Net savings ($/yr)	Simple payback (years)	Avoided CO2 (ton/yr)
Biomass - Wood Pellets or Corn														
Atlas Farm	Deerfield MA	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 10,000	$ 1,500	HMF, UVM	Multi Fuel - Corn and Pellets	5,040	2009-2014	127	$16.02	25.2	$ 2,106	4.7	8.4
Berry Creek Farm	Westfield	Central Boiler Maxim 250	$ 15,658	$ 7,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,880	2015	98	$16.16	34.2	$ 1,619	8.6	6.5
Burnt Rock Farm	Huntington	Central Boiler Maxim 250	$ 14,323	$ 7,000	HMF, UVM	Multi Fuel - Corn and Pellets	3,600	2015	98	$15.24	27.3	$ 1,709	8.2	6.5
Cedar Circle Farm	E. Thetford	LDJ Amaize-ing Furnace (165kBTU/hr) - Moved to Walker Farm in 2013.	$ 4,529	$ 3,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,880	2009	9	$16.91	3.1	$ 142	31.8	0.6
Clearbrook Farm	Shaftsbury	American Royal Multifuel Boiler. 200 kBTU	$ 9,157	$ 3,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,688	2010-2011	16	$17.65	6.1	$ 244	37.5	1.1
		Central Boiler Maxim 250	$ 14,131	$ 7,000	GMP CEED	Multi Fuel - Corn and Pellets	8,400	2014-2015	33	$15.85	3.9	$ 550	25.7	2.2
Gildrien Farm	Leicester	Central Boiler Maxim 250	$ 14,945	$ 7,000	GMP CEED	Multi Fuel - Corn and Pellets	2,880	2015	61	$15.51	21.3	$ 1,046	13.4	4.0
Harlow Farm	Westminster	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 4,410	$ 1,500	HMF, UVM	Multi Fuel - Corn and Pellets	2,800	2009-2012	49	$16.91	17.5	$ 1,537	5.7	6.5
		LDJ Amaize-ing Furnace (165kBTU/hr)	$ 4,410	$ 1,500	HMF, UVM	Multi Fuel - Corn and Pellets	2,800	2009-2012	49	$16.91	17.5	$ 1,537	5.7	6.5
		Central Boiler Maxim 250*	$ 16,578	$ 7,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,880	* - Not yet in use						
Intervale Community Farm	Burlington	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 6,502	$ 3,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,880	2008-2015	107	$16.00	37.0	$ 1,771	3.7	7.1
Jericho Settler's Farm	Jericho	Central Boiler Maxim 250	$ 18,856	$ 7,000	GMP CEED	Multi Fuel - Corn and Pellets	16,000	2014-2015	105	$17.22	6.6	$ 1,615	8.7	6.9
Lewis Creek Farm	Starksboro	Central Boiler Maxim 250	$ 12,950	$ 7,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,880	2015	66	$16.77	22.8	$ 1,039	13.5	4.3
New Leaf CSA	Dummerston	Amaiziblaze 2100 (30kBTU/hr)	$ 1,226	$ 817	HMF, UVM	Multi Fuel - Corn and Pellets	408	2008-2014	12	$17.65	29.4	$ 179	6.8	0.8
Old Shaw Farm	Peacham	Harman PF100	$ 4,310	$ 2,000	HMF, UVM	Wood pellets	1,008	2009-2010	12	$16.22	11.8	$ 152	28.4	1.0
Pete's Greens	Craftsbury	Clean Burn 5000	$ 11,496	$ 3,000	HMF, UVM	WVO	6,000	2008-2014	579	$0.00	96.4	$16,759	0.7	46.9
Root 5 Farm (was Your Farm)	Fairlee	Harman PF100	$ 3,452	$ 1,726	HMF, UVM	Multi Fuel - Corn and Pellets	1,248	2008-2012, 2014-2015	48	$15.15	38.2	$ 832	4.1	3.2
River Berry Farm	Fairfax	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 5,169	$ 2,635	HMF, UVM	Multi Fuel - Corn and Pellets	2,850	2008-2015	84	$14.57	29.5	$ 1,516	3.4	5.6
		Central Boiler Maxim 250	$ 16,388	$ 7,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,850	2012-2015	148	$15.24	51.8	$ 2,563	6.4	9.8
Sam Mazza's Farm Market	Colchester	Superior Corn Furnace	$ 7,500	$ 3,750	HMF, UVM	Multi Fuel - Corn and Pellets	3,000	2011-2015	95	$12.87	31.7	$ 1,879	4.0	6.3
Walker Farm	Dummerston	LDJ Amaize-ing Furnace (165kBTU/hr)	$ 6,000	$ 4,000	HMF, UVM	Multi Fuel - Corn and Pellets	2,688	2008-2012	22	$14.71	8.1	$ 390	15.4	1.4
		LDJ Amaize-ing Furnace (165kBTU/hr) #2 - Acquired from Cedar Circle in 2013.*			HMF, UVM	Multi Fuel - Corn and Pellets	2,688	* - Minimal use to date, anticipate increase.						
Wood's Market Garden	Brandon	LEI BioBurner 500	$ 41,400	$ 30,000	NRCS	Multi Fuel - Corn and Pellets	10,400	2012-2015	221	$14.65	21.3	$ 3,170	13.1	17.9
Cord Wood														
Vermont Herb and Salad	Benson	Sequoia Paradise model E3400 wood furnace. (320 kBTU/hr)	$ 30,000	$ 3,000	HMF, UVM	Cord wood	5,400	2009-2011	700	$2.50	129.6	$18,524	1.6	52.2
High Ledge Farm	Woodbury	Central Boiler E Classic 2300 dual fuel	$ 21,226	$ 6,103	HMF, UVM	Cord wood	2,580	2010-2014	125	$5.88	48.4	$ 3,341	6.4	8.3
Solar														
Old Athens Farm	Putney	Solar thermal panels	$ 18,150	$ 10,000	HMF, UVM	Solar	1,440	2011-2015	17	$0.00	11.7	$ 489	37.1	1.4
Total			$312,766	$136,531			101,168	96 seasons	2,880			$64,708		215.2
Average			$ 12,511	$ 5,461			3,891		120	$13.61	30.4	$ 2,696	4.8	9.0
				44%										
By Fuel Source														
Wood Pellet / Corn	Early		$ 59,165	$ 24,678					49.5	16.0	18.4	965.1	14.2	3.9
	Later		$165,229	$ 86,000					103.8	15.8	23.6	1663.7	12.2	7.3
Cord Wood	Large		$ 30,000	$ 3,000					700.0	2.5	129.6	18523.7	1.6	52.2
	Small		$ 21,226	$ 6,103					125.0	5.9	48.4	3341.1	6.4	8.3
Solar			$ 18,150	$ 10,000					16.9	0.0	11.7	488.9	37.1	1.4
Waste Vegetable Oil			$ 11,496	$ 3,000					578.6	0.0	96.4	16758.7	0.7	46.9

Table 3 - Summary of project sites, alternative heating systems, cost, payback and CO2 avoidance by fuel type.

Lessons Learned

Operational

- **Fuel Prices Affect Grower Engagement** - Fossil fuel prices varied significantly from year to year over the course of this project. Immediately after a price rise, grower are typically quite receptive to trying renewable fuels and alternative heating systems. Once the fuel price stabilizes, or if it declines, growers' receptivity to change also declines, given the many demands on their time.
- **Lack of Incentives for Carbon Reductions** - While growers are aware of, and generally concerned about, the contribution of fossil fuel combustion to greenhouse gas emissions and thus global climate change, the amount of fuel they use in greenhouses is not extremely large compared to other sectors of the food system (transportation, storage, etc.) This, coupled with the lack of regulatory or marketplace incentives for carbon reductions, leaves them without a robust set of motivations to adopt alternative fuels, so they focus almost entirely on costs.
- **Qualified Fuels** - The use of alternative biomass fuels can outpace the regulatory environment. For example, fuel corn, grass biomass and other agricultural residues are not currently EPA qualified fuels and their use is technically illegal. Fuels are qualified on each specific appliance with emission being measured during a controlled test in order to be allowed. Most appliance manufacturers cannot justify the expense of these tests for the small market that greenhouse biomass users represent.
- **Quality Fuels** – Early attempts to use lower cost sources of fuels resulted in reduced reliability of heating systems. Growers found paying a bit extra for higher quality fuel led to less problems with ignition and clinker formation.
- **Multi-purpose Use of Heating Systems** – This project focused exclusively on heating vegetable greenhouses. This framework inherently limits the annual period of heating system use to just the few months when the crops are in place and the weather is cold – primarily in early spring. As a result, the payback period is longer than it would be if the systems were operated for more time each year (high capital divided by shorter savings period per year). A few growers found that if the systems were tied into other heating loads, e.g. residential heating, pack-shed heating, winter storage heating, then the systems were used for a longer period of time each year and their investment payback period was reduced.

Programmatic

- **Technical Assistance** - Technical assistance provided by this project was valuable to the growers and credited with the overall success of the installations. Future projects focused on demonstrations and implementations of alternative systems should plan to include a strong technical assistance component. In this case, many of the installed systems involved radiant PEX tubing and pumps for circulation of hot water. This is a new type of system for many and the support provided by the boiler manufacturers is often minimal in this area. Having technical assistance to correctly size, install and control the systems was critical to the growers.
- **Learning Community** - Toward the end of this project, one grower suggested having a small informal meeting of all the growers who have installed and used biomass in greenhouses as a

continued learning and sharing opportunity. This will be organized and we hope to continue it annually in some way, perhaps holding it at the same time as the annual Vermont Vegetable and Berry Growers Association Meeting in January each year. Future projects could include this as a component from the start.

Technical

- **Appliance Size Gap** - There remains a gap in heating appliance offerings that are well suited to Vermont greenhouses. This gap has two dimensions; (1) appliances with heating ratings well-matched to Vermont greenhouses (200,000-400,000 BTU/hr) and (2) appliances with construction and controls appropriate for the sometimes challenging greenhouse environment (e.g. high moisture, high load cycles, pressure variations)
- **Appliance Functionality Gap** – The diurnal nature of greenhouse heating and multifaceted nature of the grower's management role requires heating appliances that are reliable and automated. Early adopters in this program struggled with the nuance and lack of reliability in the lower cost, simpler systems. The program's evolution and developments by appliance manufacturers resulted in better systems being installed toward the end of the project period. The key characteristics of the improved systems were (1) automated ignition, (2) propane backup, (3) induced draft, (4) improved combustion (less clinkers), (5) improved ash handling and (6) increased heat output rating.
- **Moving Heat** – This project involved a number of different systems and multiple methods for delivering heat to the crop being grown in the greenhouse. Typically propane unit heaters are used to heat air which is circulated through-out the entire greenhouse space. With the introduction of boilers (making hot water), the growers in this project were able to explore alternative heat distribution systems including in-ground PEX tubing, bench mat heating, and hydronic air unit heaters. Heating the ground and root zone of crops allows for the heat to be delivered just where it is needed in the early growing season and results in more efficient overall use of the fuel. Later in the season when humidity control is the primary heat need, the air heaters can be used in combination with ventilation fans to "pump" moisture from the crop canopy.
- **Chimney** Design– The most successful installations have either used forced draft exhaust (e.g. using a blower) or have used very straight and tall chimneys to support better combustion air delivery and exhaust removal.
- **Ignition Controls** – Appliances installed early in this project required manual ignition of the fire. This was later addressed with better appliances that offer propane backup burners that also serve to start the biomass fire.
- **Ratings** – Both biomass appliances and associated hydronic air heaters are sometimes rated higher than the performance experienced in this project. The heating appliances are sometimes rated based in input BTU/hr (i.e. how much fuel is burned) and not by what can be delivered (i.e. how much heat is provided to the space). Additionally, the use of different fuels can result in different heat output rates and efficiency. Hydronic unit heaters are sometimes rated for steam and their ratings will be reduced when using lower temperature hot water. The manufactures often have rating information by water temperature, available upon request.

- **Insulation** – Several farmers found a dollar saved on hot water piping insulation is a dollar lost due to increased fuel consumption. There are number of insulated PEX tubing options; our farmers preferred the solid EPS insulated option over the foil wrap insulated option (see Figure 27). Other farmers noted that they will be adding insulation to plumbing in general, especially runs within buildings.

Testimonial

- **Jericho Settler's Farm** – Mark Fasching and Christa Alexander – "We have found we only need to heat very minimally for winter greens production. Furnace seems to be most cost effective for heating soil for spring tomato production - so far two very different spring weather patterns have resulted in large difference in fuel use between the two springs. Greatly improved winter greens production capacity for deep winter harvest of quality greens. Increased tomato season by 1.5 months - also grow early cukes, zukes, and squash which alone more than pay for the fuel cost of winter and spring heating. Easy to use - we have found wood pellets burn cleaner than dry corn and result in less furnace clean out time/effort."
- **River Berry Farm** - David Marchant – "Both the Maxim and LDJ worked rather well this year (2015). No major issues only had to replace one auger motor in the LDJ. We mixed corn and wood in the LDJ and it really worked quite well. The Maxim had no issues at all this year. We put antifreeze in the system and were able to turn it on in the spring and nothing was frozen or broken. Saved a lot of time. Wish we had a large bulk bin where fuel can be blown in. The impact on the business, to be honest, has been a wash. Lots of time spent with the units. When Propane is in the $2.50 range there is some savings in fuel. Unless you get credit for less carbon emissions doesn't seem worth it. It would have been much more effective to have put the energy and money towards curtains and high efficiency heaters. Although I am sure there are issues with that as well. Not to be negative as I really enjoy learning about the solid fuel units. It is nice to know that there are ways to heat greenhouses besides using fossil fuels."
- **Clear Brook Farm** – Andrew Knafel – "Honestly a lot of work and focus to make it work well. I wish there was a cheat sheet on pellet rate and air speed, I have no idea when to tinker with that... honestly too many things going to have to lots of fine tuning on any one system on the farm."
- **New Leaf CSA** – Elizabeth Wood – "I've generally been happy with and have recommended the corn stove, or at least the idea of getting corn or pellet fueled heaters to other growers. I do find I need a propane back up in case it goes out or for really cold weather. And going to get corn is an extra trip. But it is great to rely less on fossil fuels and more on locally grown energy. The price of propane can't stay cheap forever and I will be very glad to have the corn stove when it goes up."
- **Lewis Creek Farm** – Hank Bissel – "A year ago, I would have been saving a lot on fuel cost. I'm not sure I saved too much this year. Well, it's certainly a simple system to run. It gave me heat in my winter storage and packing areas that I did not have before and that certainly eliminated some losses from freezing in the storage. I still have a lot of heat loss from the long runs of feed pipe. In some cases just the pipe running through a storage room kept it above optimum temperature. I only had foam sleeves on the pipes. I need much more."

- **Wood's Market Garden** – Jon Satz – "It does not make my immediate life any easier. Hoping it is a good long-term thing. It requires a lot of time, it emits a lot less carbon, it can be a royal pain at the wrong time of year. We are considering a potential shift over to wood chips from pellets. Feeling it is not worth the added investment presently."
- **Berry Creek Farm** – Gerard Croizet – "I like the wood pellet furnace it works well and I feel better using biomass fuel, even better than when I make my own biodiesel which I was tied to doing, and I can spread the ash byproduct on my hay field. If I had to change thing? The manifold for the underground pipes works well but the plumber didn't like it: not enough space to work and it must be a metric size we had to order specific connections. For the heat exchanger attachment to the existing oil furnace it is the cheapest and easy way to do. But if my blower broke I will not have a backup. I think I may get a separate Modine type hydronic heater in order to have two separate systems. Otherwise it is a good system, I love the radiant heat specially this year I will not have been able to plant my tomatoes so early without it."
- **High Ledge Farm** – Paul Betz – "It is more work, but I feel like it allows me to debate less about how much fuel I use, and feel less guilty about it. I'm not leaving the window open, but its locally derived, and renewable, not extracted, and I like that. Quality, quality, quality of wood is the key. Splitting smaller than last season as well; no real big "all-nighters" made the wood easier for the boiler to reignite and get to work sooner."
- **Intervale Community Farm** – Andy Jones – "Love the biomass. Doesn't smell as good as biodiesel, but still a lot nicer to think of farms and forests supplying us instead of Exxon Mobil BP Shell. I don't think that at our scale with our equipment there is a dollar savings with biomass, but it is a good sustainability offset. There is probably more benefit during times of much higher propane cost. Good for sustainability, carbon footprint, and building relationships with other Vermont businesses (Energy Co-op of Vermont and Boivin Biofuels.)"
- **Gildrien Farm –** Jeremy Gildrien – "The custom larger hopper is a waste of money, I wish I had bought a silo instead. Positive results, we are able to heat much more and better than without it."
- **Burnt Rock Farm** – Justin Rich – "The unit worked great, no complaints there. The heat exchangers are fairly noisy, but that is more of an observation than a complaint. Pellet prices increased substantially year-over-year. Given that propane prices tanked and pellet prices spiked this year, the direct cost savings burning pellets is probably the worst it's been in the last 10 years. A grower who gets a good bulk discount on LP could have possibly heated more cheaply with LP than pellets this year. I know that's only part of the point of these units, but it's a pretty important point. We never get the good LP prices at our farm, so it's a decent savings, especially since our LP heater is not a super high-efficiency unit. LP will rise again, and hopefully the 10% pellet price increase isn't seen again. But it seems wishful thinking to assume that pellet/corn providers wouldn't keep an eye on LP prices when setting their own. I like being able to heat the GHs with a product from another farmer, so the corn has worked out well. I am sure I could tweak the controller a bit, but as set up, it actually burns a little better with a ~3:1 corn:pellet ratio. The corn generates a bit more ash, especially if it's burning continuously (that could be a feed rate and/or air control issue, but I haven't fussed with it). The dealer has been

very responsive and reliable with corn deliveries, and I like that he takes his bags back. I've got some big piles of pellet bags awaiting an ag-plastic-recycling day somewhere. I have a few ideas in my head around setting up a sweet potato curing facility down by the greenhouses, to utilize the boiler in the fall. Probably won't happen this year. Bulk delivery, or at least 1 ton sling bag deliveries would be very welcomed, as loading 40lb bags is not time-neutral. On the colder nights when the boiler was running full-bore to heat 2 GHs, the boiler would use ~300-325lbs of corn or pellets. That amounts to ~$35-$40 worth of corn/pellets, which is far less money than I've burned on a cold night with propane. In a year with prices where they are for the various fuels, the boiler is still better for us than LP, but not as much as it would be in a year with "typical" LP prices. ”

Photos of Project Sites and Participants

Figure 3. Becky Madden, Intervale Community Farm (Burlington). LDJ Amaize-ing Blaze corn furnace.

Figure 4 - Justin Rich, Burnt Rock Farm (Huntington), walking through the manifold plumbing inside the greenhouse.

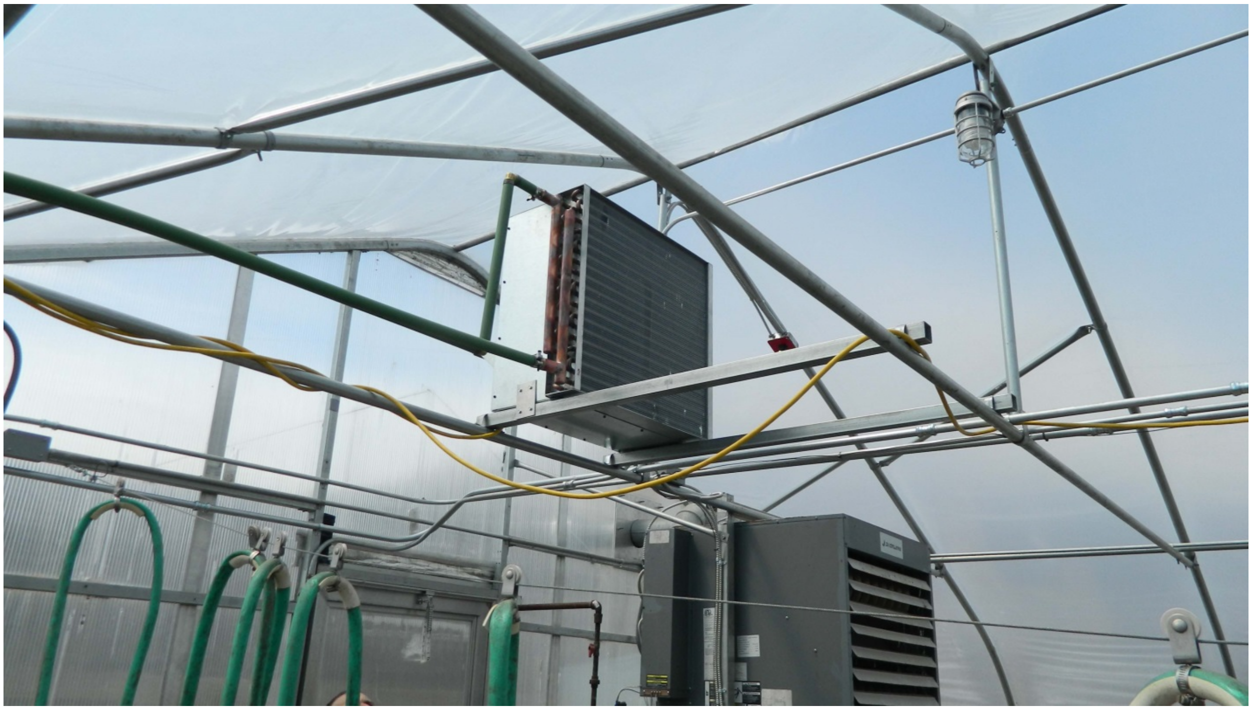

Figure 5 - Hydronic air heater at Burnt Rock Farm (Huntington).

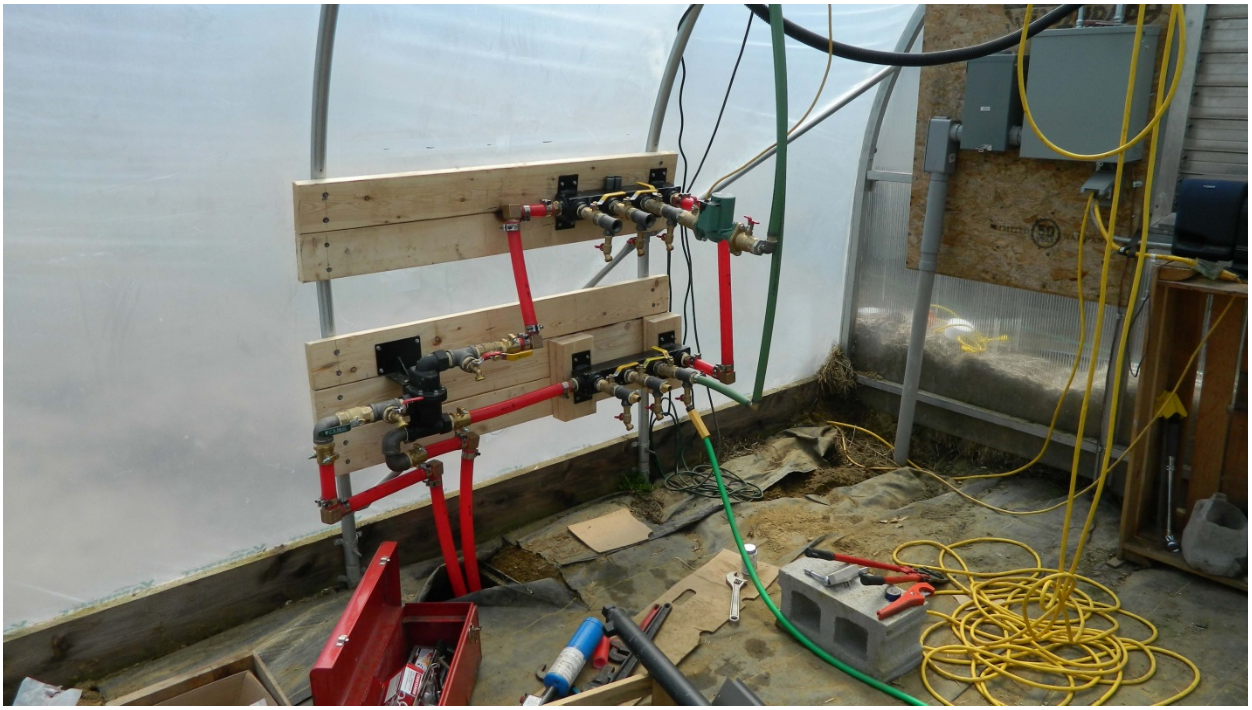

Figure 6 - Hot water manifold inside the greenhouse at Burnt Rock Farm (Huntington).

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Figure 7 - Justin Rich, Burnt Rock Farm (Huntington) with his almost complete boiler system.

Figure 8 -Hydronic air heater (200,000 BTU/hr) at Clear Brook Farm (Shaftsbury).

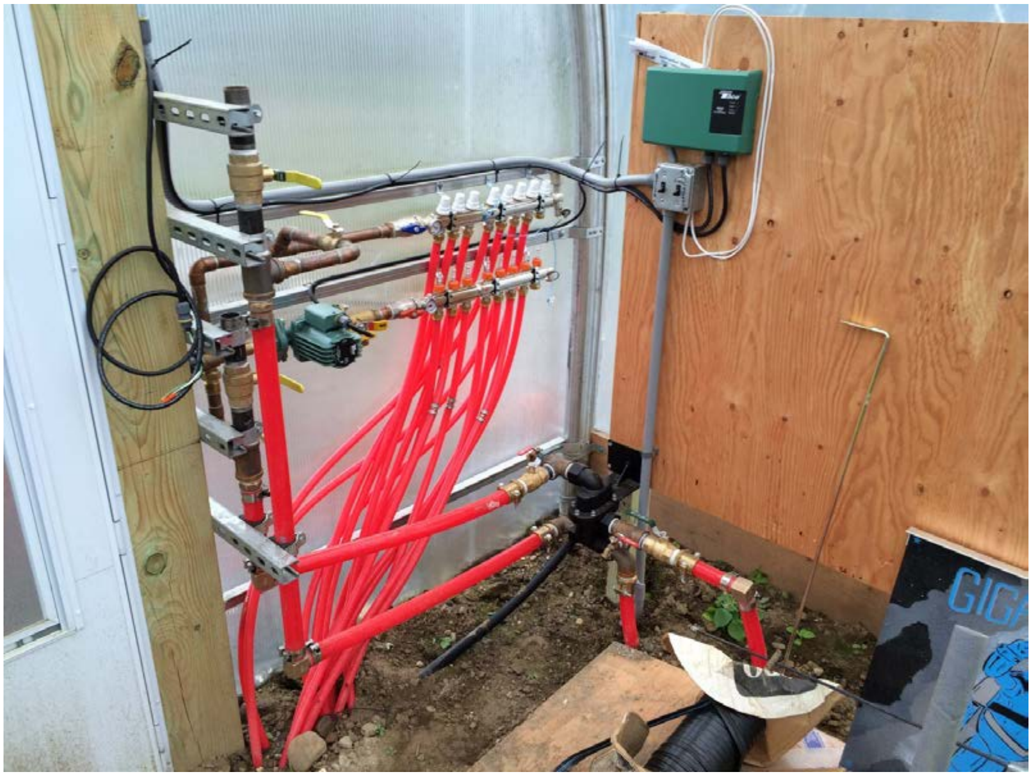

Figure 9 - Hot water manifold at Clear Brook Farm (Shaftsbury).

Figure 10 - Maxim 250 outdoor wood pellet/shell corn hot water boiler at Clear Brook Farm (Shaftsbury).

Figure 11 - Elizabeth Wood, New Leaf CSA, with Amaiziblaze 2100 (30,000 BTU/hr) pellet stove used to heat a very small greenhouse for early seedling production.

Figure 12 - Gideon Porth, Atlas Farm (Deerfield, MA) with LDJ corn boiler.

Figure 13 - Jeremy Gildrien, Gildrien Farm (Leicester) with Maxim 250 and larger fuel hopper.

Figure 14 - Two chimneys on this greenhouse at Harlow Farm (Westminster); one is for the original propane heater and one is for the new LDJ biomass furnace.

Figure 15 - Hot water distribution manifold with early cucumbers in the background at Jericho Settlers Farm (Jericho).

Figure 16 - A nearly completed Maxim 250 outdoor biomass boiler at Jericho Settlers Farm (Jericho).

Figure 17 - Testing basic emissions and boiler thermal efficiency at Jericho Settlers Farm (Jericho).

Figure 18 - Tomatoes benefiting from underground heat at Jericho Settlers Farm (Jericho).

Figure 19 - Luke Joanis and LDJ furnace at Cedar Circle Farm (E. Thetford). This unit was later moved to Walker Farm in Dummerston.

Figure 20 - Dave Marchant (left, blue jacket) hosts a twilight meeting at River Berry Farm (Fairfax). The unit in this picture is an LDJ furnace providing air heat to this bedding plant house. This unit has operated for 7 heating seasons.

Figure 21 - Dave Marchant (Fairfax) at a later twilight meeting showing bench heating mat heated with hot water from the Maxim 250 outdoor boiler. A hydronic air heater, also fueled by the Maxim, is visible on the far end of the greenhouse.

Figure 22 - Dave Marchant (Fairfax) shows the manifold for distributing hot water from the Maxim 250 boiler to both ground heat (under tomatoes in foreground) and to the greenhouse next door.

Figure 23 - Participants at a field day at River Berry Farm (Fairfax) get up close to the Maxim 250 outdoor biomass boiler in operation.

Figure 24 - Dave Marchant (Fairfax) points out the hydronic air heater in the greenhouse.

Figure 25 - The McDermotts from Vermont Herb and Salad used as large cord wood gasifier to heat two greenhouses for growing leafy greens through the winter.

Figure 26 - Paul Betz with Central Boiler eClassic 2300 cord wood boiler, used to heat two greenhouses (Woodbury).

Figure 27 –A less expensive underground insulated PEX tubing option (left) is wrapped in foiled bubble wrap and has space between the insulation on the pipe as well as the outer wall. Cost is approximately $7.00/ft. The solid EPS insulated PEX tube (right) is more expensive at $11.00/ft but has demonstrated reduced heat loss and pipe to pipe heat transfer. Water infiltration is a concern on the foil wrapped version on the left due to the open area that exists.

Figure 28 - Mike Collins, Old Athens Farm (Putney) stands next to his flat panel solar hot water heating syetem. While not biomass, solar is an alternative heating source that growers often ask about and this project was intended to generate real-life data for assessing the feasibility of solar to heat greenhouses in our region. In this case the solar system was tied into a small scale wood biomass boiler to heat hot water for the greenhouse and the farmer's residence in the off-season.

Figure 29 - Pete Johnson, Pete's Greens (Craftsbury) with Clean Burn 500, waste vegetable oil furnace.

Figure 30 - LDJ shell corn/wood pellet furnace at Walker Farm (Dummerston).

Figure 31 - Jon Satz, Wood's Market Garden (Brandon), pushing the button for the first startup of the BioBurner BB500.

Figure 32 - Boiler House at Wood's Market Garden (Brandon).

Figure 33 - Jason Martin, Woods Market Garden (Brandon) checks the fuel feed in the day bin.

Figure 34 - John Satz (Wood's), Jason Martin (Wood's) and Scott Laskowski (LEI Products) go through boiler settings during the first startup at Woods Market Garden (Brandon).