EXECUTIVE SUMMARY

This report summarizes the feasibility and initial performance of a gasifying cord wood boiler system for heating two plastic-covered metal-hoop greenhouses totaling 4,382 sq. ft at High Ledge Farm in Woodbury, VT.

Paul Betz, owner and grower at High Ledge, intends to purchase cord wood cut and split and delivered at a price of $210/cord. With an installed heating system cost of $21,826 and 3 month use (last week of March through May) the system will result in $1,915 savings annually compared to the use of propane fuel purchased for $2.56/gallon. When fueled by renewable cord wood at current pricing for wood and propane the system will have a payback period of 11 years and avoid roughly 6 tons of CO_2 emissions annually (equivalent to approximately 14,441 miles of average passenger car travel.)

INTRODUCTION

High Ledge Farm is a small, family farm growing 2.5 acres of vegetables for fresh market. The farm sells every Saturday, May through October, at the Montpelier Farmers' Market and has a 25 member CSA (Community Supported Agriculture) for their local community. High Ledge also maintains just over 4,000 sq feet of greenhouse space for bedding plant production and for growing greenhouse tomatoes and winter greens. Paul and his wife Kate also work off the farm.

Figure 1 - Paul Betz, Owner/Grower at High Ledge Farm in East Calais, VT with his Central Boiler E2300 boiler. The North House is in the background.

This study was funded by University of Vermont Extension. This grant was awarded to plan, implement and assess a renewable energy heating system using local wood for fuel at High Ledge Farm.

The farm typically uses about 800-1000 gallons of propane each year to heat two greenhouses (approximately 92 million BTU/year energy and $2,560/year cost[1]). The first greenhouse is the South House (21'x60', double polyethylene, air-inflated greenhouse cover, with poly end walls and no knee wall insulation) which is used for growing bedding plants and ornamentals on benches and hanging baskets.

[1] *Assuming 92,000 BTU/gal propane and$2.56/gal propane.*

The second is the North House (22'x60', same construction as the South House) used for summer production of tomatoes and (unheated) winter production of leafy greens, both grown in the ground. Paul currently does not have perimeter insulation nor is he using any soil heating. Both of these improvements are planned over the next year.

Paul was interested in installing an alternatively fueled heating system following a devastating propane tank failure that led to a fire which destroyed almost all the farm's buildings including his greenhouses in the spring of 2009 just prior to the start of the growing season.

Cord wood is an attractive fuel for Paul since he has ready sources from wood lots on the farm, and neighbors that are loggers. The fact that he could provide the fuel himself or from his local community is important to Paul from an energy security perspective. The relative safety of the fuel is also a huge consideration to the farm family.

DISCUSSION

The following sections provide background information on the boiler system cost, savings, and payback.

BOILER SIZING & COST

A Central Boiler EClassic 2300 boiler (http://www.centralboiler.com/e-classic.html) was chosen as the heating unit by Paul. This is an advanced outdoor cord wood boiler with a small propane supply for ignition and backup. The boiler is rated for 200 kBTU/hr input. The cost was $12,400 in September 2009. The propane back up assures that no crops will be lost if nobody is at the farm to keep the furnace loaded with wood. It also makes it easy to ignite the wood. This boiler is certified to meet EPA Phase II requirements of emitting less than 0.32 pounds of particle pollution per million BTUs of heat output. This certification is required by Vermont law for any outdoor wood boiler purchased and installed after March 31, 2010[2]. A list of compliant units can be found at this link: http://www.epa.gov/burnwise/owhhlist.html.

Because the boiler produces hot water, Paul purchased and installed two hydronic unit heaters (one in each house) to allow the greenhouse air to be heated upon demand, which is essential to crop production. These are similar to propane unit heaters commonly used in greenhouse production that have a fan on the back of a heat exchanger. The difference is that the heat source is hot water, not combusted propane. The heat exchangers are from Modine (Model HBS121SO1, cost $840 each). Although the units are rated for121 kBTU/hr when operated on 2 psi steam (220 °F), they are derated when operating on hot water at other temperatures. In Paul's case, the hot water is expected to be 160-180 °F which results in a 15-30% derate according to the manufacturer. This is an important factor to consider when sizing the heat exchangers.

Figure 2 - One of Paul's two hydronic unit heaters.
Also note the insulated piping coming out of the ground from the other house.

[2] For more information visit www.VTwoodsmoke.org. The current VT regulations are available at http://www.vtwoodsmoke.org/OWB_Ph2_Reg.pdf

Paul also installed a 250 gal hot water storage tank with the thought that it might save him from having to load the boiler through the night. He fabricated it from an oil tank and insulated it with blue board before paneling it with rough sawn pine. Balancing direct heating through the unit heaters and storage of hot water proved trickier than initially expected. Paul plans to revisit this portion of the system and perhaps make some design changes next year

Figure 3 - Homemade insulated hot water tank (beyond the wooden crate) with the other hydronic unit heater overhead.

One unexpected bonus of making a switch to hot water heating was the incorporation of a plate heat exchanger to heat water used to water plants using the hot water from the boiler. Paul notes a reduction in thermal shock experienced by the plants when using warmed water. An adjustable mixing valve is used to set the desired water temperature.

Figure 4 - Water heating system for plant watering.

Circulators are required to move the hot water from the boiler to the greenhouse, and cooled water back to the boiler for re-heating. Paul's system employs 4 circulators to provide the necessary flexibility of heating different areas separately. Each circulator cost approximately $220 (mixture of Taco model 009's and Grundfos UPS26-99FC's). The Grunfos circulators Paul selected offer an additional benefit of multi-speed selection to vary flow based on season, etc.

Figure 5 - Circulators mounted on the boiler. Grundfos is red, Taco is green.

To connect the boiler to the heat exchangers, Paul opted for a relatively inexpensive, pre-fabricated, insulated PEX product (Thermal Barrier Underground Pipe from Farmtek). The cost was $6.95 per linear foot compared to $18.00 for a higher insulated type that other growers have used (e.g. LogStar was used at Clearbrook Farm). Paul has noted that this is an area that could be improved in his system. He wishes he had installed a better insulated piping product to reduce heat loss to the ground between the boiler and the greenhouses.

Figure 6 – A less expensive, less insulated flexible PEX product is shown on the left (FarmTek – Thermal Barrier @ $6.95/ft) and a more expensive, better insulated flexible PEX product is shown on the right (LogStor @ $18.00/ft). The cheaper option uses a foil bubble wrap with a manufacturer claim of R-value =1.1 per layer and the more expensive option uses expanded polyurethane foam with an R-value of 6 per inch.) In defense of the foil bubble wrap, it appears this is a poor application for the product. According to its manufacturer, it is intended to be a single layer radiant barrier, not a multi-layer insulation against conductive losses. The latter is what is needed to prevent underground losses.

Other miscellaneous parts of the system such as a cement pad, clamps, valves, brackets, etc. added up to $3,518.

Installation labor was $3,500. Paul estimates he spent 40 hours of his own time, used plumbers for about 30 hours of labor, and had some hired hands for another 10 hours.

A cost summary is provided in Table 1.

Initial Costs	**Amount**	
Boiler - Central E Classic 2300	$ 12,400	200 kBTU/hr (input)
Heat Exchangers	$ 1,678	2 x 120 kBTU/hr unit heaters
Pumps	$ 880	4 circulators
Other parts & materials	$ 3,518	Pad, tank, propane hook-up, plumbing
Installation Labor	$ 3,350	Grower and hired help
Total	**$ 21,826**	
Estimated life	20	years
Ammortized cost	$ 1,091	per year (without cost of capital)

Table 1 – System Cost Summary and Estimated Amortization with a 20 year life.

COST/BENEFIT ANALYSIS and PROFORMA

Expected fuel costs are $210/cord for wood with an assumed moisture content of 15%[3]. Compared to $2.56/gal propane this represents a savings when considered on a per BTU basis. Cord wood at this price (and assuming 15% moisture) equates to $12.35 per million BTU whereas propane at the price noted equates to $34.77 per million BTU (retail, not pre-buy).

In order to determine the benefit of the entire system, one first needs to assume a period of use in order to aggregate fuel consumption. This is done using an assumed inside temperature setpoint and historical outside temperatures for the period during which Paul will heat his greenhouses. Table 2 summarizes the heating degree days for the area using three different inside temperature setpoints; 50, 60, and 65 °F. Paul intends to maintain approximately 60 °F in House #1 and 65 °F in House #2 from the last week of March through May and perhaps into June. The resulting heating degree days are 241 (25% of March), 561, and 213 respectively (as highlighted in Table 2) for a total of 1,015 HDD's/yr. Heating degree days are a cumulative measure of the difference between the assumed inside temperature and that outside. The data in Table 2 are based on averages of 40 years of weather data.

To determine the energy required to keep a space at the desired inside temperature, one needs to know the heat loss characteristics of the space. A basic model is used here, in which the greenhouse is assumed to have an overall heat loss coefficient (U) of 0.8 BTU/hr/°F/ft^2. Multiplying this by the exposed heat loss surface area (top, sides and ends) of the greenhouse (2,165 ft^2 for House #1 and 2,217 ft^2 for House #2) and then by the degree days for a certain inside temperature (converted to degree hours by multiplication) results in the amount of energy required to maintain that inside temperature. This is how an estimate of 85 million BTU/yr for the aggregate heating load was derived.

[3] Measurements made at High Ledge showed moisture contents of 11-18% when wood was covered with recycled tin roofing and 15-25% when wood is stored uncovered. Paul generally uses covered wood.

	Heating Degree Days Montpelier, VT - 40 yr average		
	HDD50	HDD60	HDD65
January	1009	1341	1507
February	876	1150	1287
March	677	966	1114
April	300	561	703
May	50	213	342
June	9	57	113
July	1	14	33
August	3	27	65
September	36	156	255
October	157	417	601
November	446	750	906
December	844	1155	1319

Table 2 – Summary of heating degree days based on 40 year average data compiled hourly. The three columns of HDD's are calculated with different base temperatures of 50, 60 and 65 °F respectively.
Paul starts growing toward the end of March, so only a portion of the full HDD's for that month have been used in the calculations.

The remainder of the cost benefit calculation is a matter of converting the BTU's of heating required to cords of wood and comparing this to the equivalent propane to do the same amount of heating. The cost of heating with biomass needs to account for the amortized cost of the boiler and associated plumbing as shown in Table 3. This table compares wood at $210/ton to propane at $2.56/gal. This table was constructed as an MS-Excel spreadsheet and any figure in blue is adjustable by the user to explore various scenarios. The wood boiler system is predicted to save the farm $1,915 annually with a simple payback period of 11 years (estimated 20 year life).

		Amount	
Initial Costs			
Boiler - Central E Classic 2300	$	12,400	200 kBTU/hr (input)
Heat Exchangers	$	1,678	2 x 120 kBTU/hr unit heaters
Pumps	$	880	4 circulators
Other parts & materials	$	3,518	Pad, tank, propane hook-up, plumbing
Installation Labor	$	3,350	Grower and hired help
Total	**$**	**21,826**	
Estimated life		20	years
Ammortized cost	$	1,091	per year (without cost of capital)
Operating Costs			
Cost of cord wood		210	$/cord
Moisture content		15%	
Ideal energy content		25,000,000	BTU per cord (dry)
Energy content		21,250,000	BTU per cord (actual)
Energy cost (gross)	$	9.88	per million BTU input
Boiler efficiency		80%	
Energy cost (net)	**$**	**12.35**	**per million BTU output**
Propane Unit Cost	$	2.56	per gallon
Propane Energy Content		92,000	BTU/gallon
Energy cost of propane (gross)	$	27.82	per million BTU input
Propane furnace efficiency		80%	
Energy cost of propane (net)	**$**	**34.77**	**per million BTU output**
Period of Use & Heat Load			
Inside temperature		60	°F
Degree Days			
March (start 3/21)		241	degree days
April		561	degree days
May		213	degree days
Total		1,015	degree days
Greenhouse UA's			
North House		1,732	BTU/deg/hr/F
South House		1,774	BTU/deg/hr/F
Total		3,506	BTU/deg/hr/F
Energy Used		**85**	**million BTU per year**
		5.0	cords of wood (net)
		1161	gallons of propane (net)
Ammortized capital cost	$	12.78	per million BTU
Biomass cost	$	12.35	per million BTU
Total biomass energy cost	**$**	**25.13**	**per million BTU**
Displaced propane cost	**$**	**34.77**	**per million BTU**
Incremental savings	**$**	**9.64**	**per million BTU**
Annual savings	**$**	**1,915**	**annually**
		928	gallons of propane
		6	ton CO_2
		14,441	passenger car miles
Payback period		**11.4**	**years**

Table 3 – Calculation of cost and estimated annual savings for cord wood. This is done in MS-Excel with any blue figure being adjustable by the user.

One can consider the variation of payback period based on different fuel costs. This is summarized in Table 4 for the expected system at High Ledge Farm.

Simple payback (years) as a function of fuel costs							
Cost of Cord Wood	Cost of Propane ($/gal)						
	$ 1.75	$ 2.00	$ 2.25	$ 2.50	$ 3.00	$ 4.00	$ 5.00
$ 100	14	12	10	9	7	5	4
$ 200	21	17	14	12	9	6	5
$ 300	42	27	20	16	11	7	5
$ 400	1031	70	36	24	15	8	6

Table 4 – Summary of payback study with cost of cord wood and propane as the main variables.

CONCLUSIONS

In summary, the purchase and installation of a cord wood boiler by High Ledge Farm is supported by the analysis above. Buying cord wood at current pricing results in the system having an attractive payback period.

Paul has had one growing season of experience with this heating system and shares the following advice and lessons learned to date.

First, he recommends paying the premium for insulated piping.

"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 a foot instead, and it's somewhat inferior. 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 entirely. The temperature of the incoming water to the tomato house is decidedly cooler than that in the plant house, which is closer to the boiler. 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 better pipe."

"Also, when considering hydronic unit heaters, remember that the steam ratings differ from the hot water ratings. Secondly, that the hot water ratings are based on 180 °F water which may not be the real temperature given heat losses between the boiler and the house."

"When buying the exchangers, be sure to check the Btu ratings. When they are listed they give the ratings for steam, not hot water. Even then the water temp they use is 200 degrees… this is not the 'at best' 185 degrees your water will be, more likely 175 degrees ,that you will get at the heater itself. The end result is the heat exchangers are a little undersized that I got for the houses. They are good for about 30 degrees lift against the outside temperature. That's Ok if it's 25 degrees outside, but not if it's any colder. I will be most likely changing them as well next year."

Paul installed a 250 gallon water tank in this system anticipating the need to store heat for night time use and to avoid having to feed the boiler constantly. He now thinks he will use that option less. "One thing I will be doing is taking the 250 gallon extra storage tank out for next season. The boiler can recover so fast, it really amounts to extra load, like putting your hands out of a moving car. I will plumb it so I can add it back in if I want later in the season, but I don't think it's really helping anything."

As with many biomass combustion systems ignition is not as simple as a standing pilot or instant ignition propane heater.

"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."

On buying wood, Paul says, "I ended up buying split and delivered, even had the guy stack it, because I can take that as a business expense and save my back and weekends for other pursuits. Although I can buy log length for $100 a cord compared to $210 for cut, split and delivered wood, I was never going to see the labor I put into the processing get recovered as farm profit… it's all just work."

Even paying the premium for the cut and split wood provides savings over propane and ultimately a reasonable payback period on the system. Paul had been buying truck loads of full length logs and then bucking and splitting himself. When he considered the labor involved in that option, he decided his time might be better spent growing. For example, even at $100 per cord for 12 cords of full length logs, Paul estimates he was putting about 90 hours to get it bucked, split and stacked. At a labor rate of $15 / hr that adds $113 per cord for a total cost of $213/cord. Paul determined there is value in buying wood from a neighbor who specializes in the work and has the equipment for efficient processing.

Another recurring theme of biomass heating systems in greenhouses is the need for a good relationship with the manufacturer or their representatives / dealers. Referring back to the ignition challenges, Paul notes, "Be sure you like your dealer; we are working on it, and they are trying, but when I have called the manufacturer, they treated me like I was dumb, and it was off-putting."

In conclusion, Paul would suggest that a clean, outdoor wood boiler is certainly an option for Vermont greenhouse growers and hopes that others learn something from his installation.

"All in all, I'm pleased with the system and see that I have a bit more to do to make it work its best for our farm. It isn't perfect, but neither was propane. Using wood forces you to really think about the whole system and how to weave it into your operation, which is a good thing."