EXECUTIVE SUMMARY

This report summarizes the feasibility of a multi-fuel, auger fed biomass boiler at Clearbrook Farm. The purchase and installation of a corn boiler is supported by the analysis. Even if buying renewable solid fuels as commodities at current pricing, the system will have an attractive payback period of approximately 6 years and avoid roughly 17 tons of CO2 emissions annually (equivalent to approximately 43,500 miles of average passenger car travel.)

The plan for Clearbrook Farm to produce their own grain corn as fuel is sound even with relatively conservative assumptions regarding organic production costs ($500-600/acre) and yields (100 bu/acre) resulting in a $6.50/bu cost of fuel to the farm. For an installed heating system cost of $9,157 and 3 month use (Mar-May) resulting in $1,514 savings annually, the payback period is 6 years. Given the proven ability of the owners to successfully grow a wide variety of crops, it seems likely that they will surpass the agronomic assumptions in the analysis.

To fully displace their annual propane demand of 7,000 gallons (644 million BTU), Clearbrook Farm would have to grow approximately 2,100 bushels using about 21 acres at yields of 100 bu/acre (suggesting 1 acre of fuel corn is equivalent to 333 gallons of propane.)

INTRODUCTION

Clear Brook Farm is a diversified organic farm in Shaftsbury, Vermont that was started in 1994 and run by Andrew Knafel and Matthew Patterson (photo above). The farm grows about 25+ acres of mixed vegetables and berries and 10 acres of sunflower seeds that are converted to bio-diesel in collaboration with nearby State Line Farm. Along with the produce part of the operation, the farm has 11 greenhouses comprising 25,000 sq ft. These greenhouses are used to produce bedding plants in the spring, greenhouse tomatoes in spring and summer, and greens in the fall/early winter. All of the farm's agricultural products are marketed through their farm stand, 2 farmers' markets and a winter community supported agriculture (CSA) share program. The farm employs up to 20 people at the height of the season and 4-5 part-time through the winter.

This study was funded jointly by University of Vermont Extension and the Vermont Agency of Agriculture, Food and Markets as part of the Renewable Energy for Agriculture Grant Program (REAP). This grant was awarded to assess and implement renewable energy heating systems in Clearbrook Farm's greenhouses.

Clearbrook Farm currently uses about 7,000 gallons of propane a year to heat all the greenhouses. The majority (90%) of fuel usage takes place over an 8 week period starting in Mid-March. The rest is used to heat cold sensitive crops grown in the greenhouse for the winter CSA. Most of the propane is used by individual furnaces in each greenhouse and some is used for soil heating in the tomato greenhouses.

Clearbrook Farm is interested in either a centralized wood/corn heat system that would heat up to 5 greenhouses or a portable unit that could be moved between various greenhouses to offset a more limited amount of propane. Clearbrook is considering the possibility of growing their own shell corn for whatever system is selected. This would offer the benefits of on-farm fuel production as well as a good rotation crop for vegetables.

The greenhouse layout at Clearbrook Farm is presented in the pictures shown as Figure 1 and Figure 2 along with the site plan provided as Figure 3. House #1 and the Display House have been noted by Andrew and Matt as the most likely candidate spaces for heating by the alternative fuel boiler. The display house was recently constructed and is in need of heat and House #1 is somewhat deficient in heating input capacity for more versatile use. The 40' alley between the two rows of houses is a critical feature for the operation, allowing tractor and truck access to all houses. The boiler and hopper will be located outside, on the south end of the candidate houses to allow for ease of fuel delivery and maintenance

Figure 1 A view looking southeast showing the display house under construction and also houses #1-5. The display house was completed in the Fall of 2009.

Figure 2 – A view looking east showing the 40' alley between the two rows of greenhouses and showing houses #6-8 on the right. The area just beyond the gravel fill would likely be the location of the boiler.

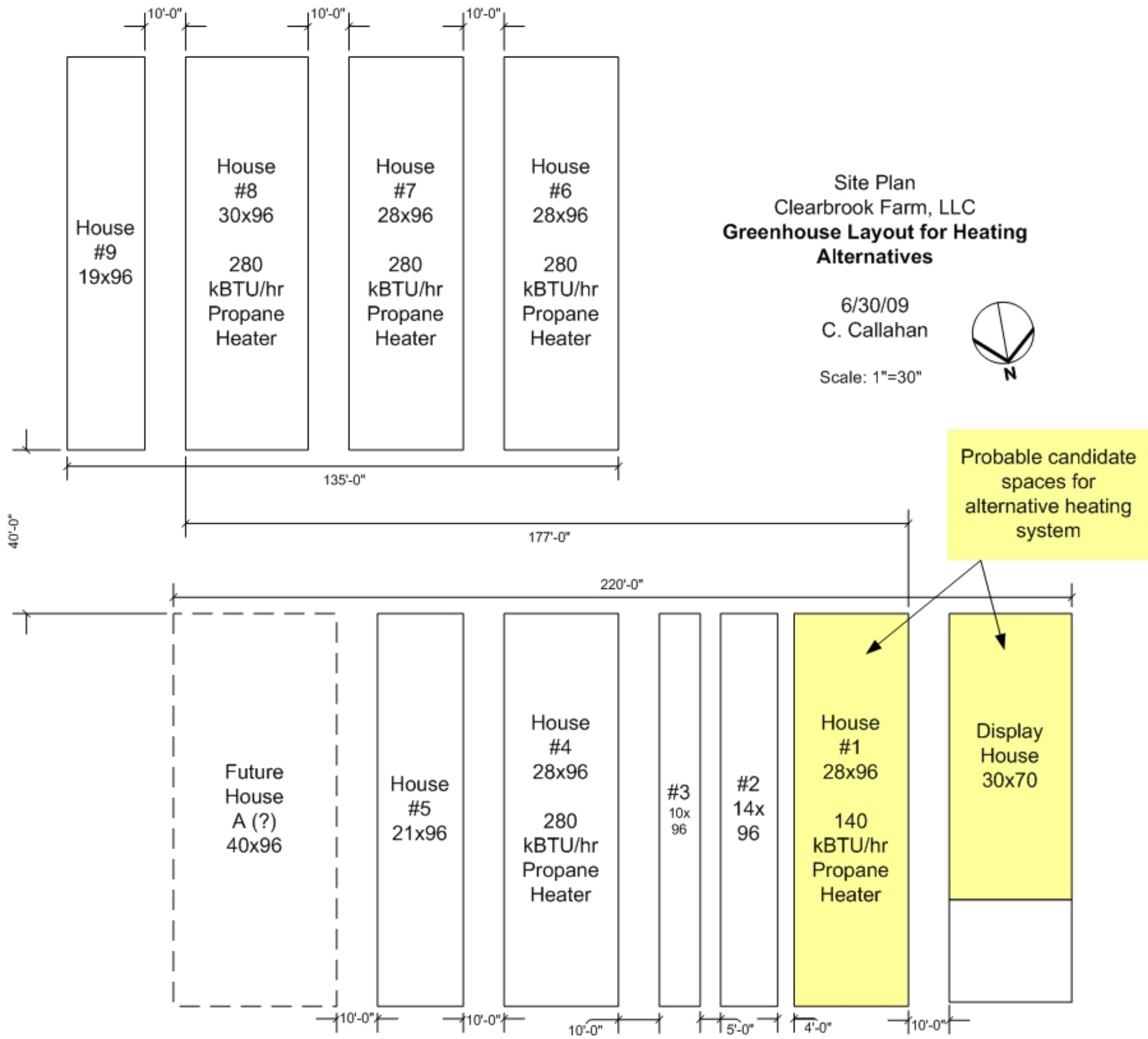

Figure 3 – Site plan view of Clearbrook Farm's greenhouses and new display house. House #1 and the Display house have been noted by Andrew as the most likely candidate spaces for heating. The display house was recently constructed and is in need of heat and House #1 is somewhat deficient in heating input capacity for more versatile use. The 40' alley between the two rows of houses is a critical feature for the operation, allowing tractor and truck access to all houses. The boiler and hopper will be located outside, on the south end of the candidate houses to allow for ease of fuel delivery and maintenance.

DISCUSSION

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

BOILER SIZING & COST

The sizing of the heating system for a greenhouse is influenced by the size of the house (exposed area), materials and method of construction (envelope), desired inside temperature and outside temperature at time of use.

For each of Clearbrook Farm's houses, a heat loss estimate was performed as shown in Table 1.

Andrew and Matt decided to focus the installation of an alternate-fueled boiler on the newly constructed retail Display House and House #1 which sees the majority of the growing each year (March-May and sometimes into June).

As noted in Table 1, the combined heat load for these two houses is 319 kBTU/hr (base) to maintain an inside temperature of 60 °F.

It is unlikely that both spaces will need the maximum heat input at the same time due to their different intended uses. The boiler will be used early in the spring to heat House #1 (when heating demand is highest) and only later used to hear the Display House (when bedding plants are on display).

It is also important to note that 10 °F is an assumed *design* temperature, one that is possible but is rarely seen in the period during which the spaces will be heated. The 40 year average temperatures for March, April and May are 29, 42, and 59 °F respectively.

In order to maintain an inside temperature of 60 °F at these average temperatures would require 198, 115, 6 kBTU/hr heat addition respectively to both the Display House and House #1.

Thus, a boiler with an output rating of approximately 160 kBTU/hr will provide a majority of heating coverage.

An American Royal 200 kBTU/hr (input) corn boiler was selected for installation at Clearbrook. This boiler can be fueled by multiple solid fuels (e.g. corn, wheat, rye, cherry pits, & wood pellets). Others who have installed these boilers also provided anecdotal feedback that the exhaust from the smoke stack is quite clear when burning corn. The cost of this unit was $3,200 although it had a normal retail price of $6,400. The price reduction was due to an overstock.

Andrew and Matt decided to also purchase two 195 kBTU/hr hot water / air heat exchangers to serve as hydronic unit heaters. These were also available from American Royal for a price of $599 each.

A 3.5 ton grain bin was purchased to store fuel in. This cost $2,000 installed on a concrete slab.

To connect the boiler to the heat exchangers, Andrew and Matt decided to use a superinsulated PEX pipe called LogStor. This costs about $18 per linear foot, and 70 feet was used resulting in a total cost of $1,260.

Various other costs were also incurred during installation. A complete cost summary is provided in Table 2.

Current Fuel Usage			7000	gal propane over 2 months				
			644	MBTU				
			447	kBTU/hr avg				
Heating Conditions			60	deg F inside temp				
			10	deg F outside temp (design temp for peak load during growing season)				
			0.8	U-value (BTU/ft2/hr/F) [from J. Bartok, 2006]				

House	W ft	L ft	H peak ft	A_Exp ft2	Typical Use	Existing Heater kBTU/hr	Estimated Peak Load kBTU/hr	Plus Margin kBTU/hr
Display House	30	70	20	4100	Year	None	164	197
House 1	28	96	12	3876	Mar-Jun	140	155	186
House 2	14	96	12	2835		175	113	136
House 3	10	96	12	2616		175	105	126
House 4	28	96	12	3876	Apr-May	280	155	186
House 5	21	96	12	3313	Apr-May	350	133	159
Future House A	40	96	12	4958		None	198	238
House 6	28	96	12	3876	Apr	280	155	186
House 7	28	96	12	3876	Apr	280	155	186
House 8	30	96	12	4048	Apr	280	162	194
House 9	19	96	12	3167	Apr-May	175	127	152
						2135	1622	1946

Total current simultaneous peak use (based on equipment)			1260 kBTU/hr
Total current simultaneous peak use (based on heat loss estimate)			782 kBTU/hr
Total planned / future simultaneous use at peak load plus	20%	margin	1946 kBTU/hr

Table 1 – Greenhouse heat load calculation summary. The Display House and House #1 are the intended target spaces for heating by the corn boiler.

Initial Costs	**Amount**	
Boiler - American Royal Multifuel	$ 3,200	200 kBTU/hr (2009 model, marked down from $6400)
Hot water / Air Heat Exchangers (2)	$ 1,198	195 kBTU/hr
Super insulated hot water piping	$ 1,260	70 feet at $18/ft
Circulator Pump	$ 199	
Other plumbing materials	$ 300	
Grain bin	$ 2,000	3.5 ton bin, installed
Installation Labor	$ 500	
Construction rental - backhoe	$ 500	
Total	**$ 9,157**	
Estimated life	20	years
Ammortized cost	$ 458	per year (without cost of capital)

Table 2 – Cost summary table.

Figure 4 – American Royal Corn Boiler – Picture from manufacturer's website: http://www.americanroyal.net/page/page/3075421.htm. Per phone conversation with manufacturer's representative, the boiler is rated at 200 kBTU/hr input with 150-175 kBTU/hr output (i.e. 75-88% gross efficiency). The efficiency of the unit will vary based on input fuel.

Figure 5 – LogStor pre-insulated PEX tubing was used to connect the hot water boiler to the hot water / air heat exchangers. Pictures downloaded from http://www.classiccomfortohio.com/images/pex-flex.jpg and http://www.timbersedgeheating.com/logstor.htm.

GRAIN CORN PRODUCTION and OTHER SOLID FUELS

GRAIN CORN PRODUCTION COSTS

Andrew estimates organic production costs of between $500 to $650 per acre of grain corn for use as fuel. Clearbrook will grow the corn on relatively limited acreage (i.e. ~ 1 acre). Although there would be lower production costs on higher acreage, $650/acre will be used for consideration of this opportunity.

GRAIN CORN YIELDS

Yields of grain corn nationwide have risen steadily despite occasional poor production years. The current national average is near 160 bushels/acre as shown in Figure 6. It is not, however, uncommon to have yields near or above 200 bushels/acre. Andrew estimates he can achieve at least this level of yield, but the cost/benefit analysis below assumes a lower yield of 100 bushels/acre as a conservative figure.

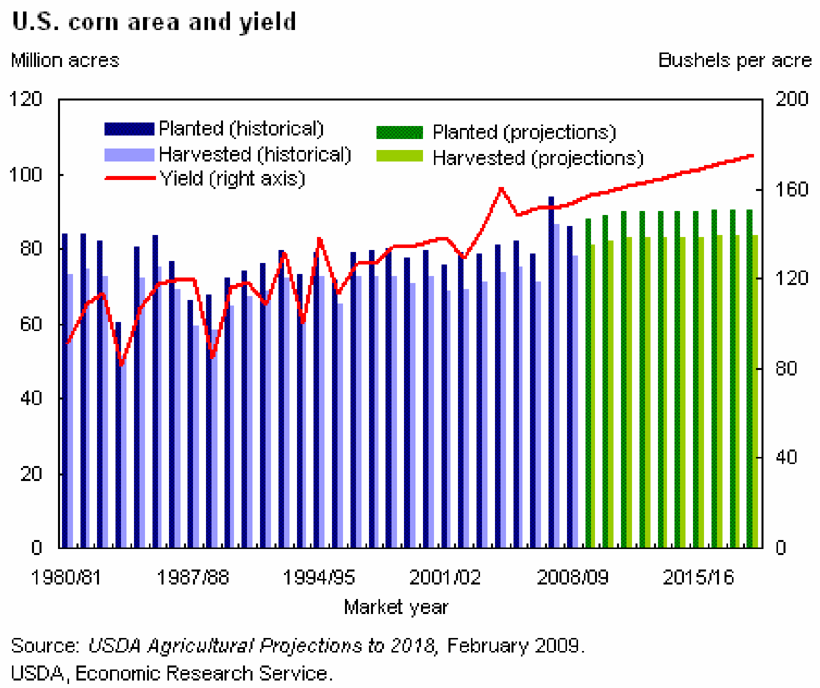

Figure 6 - Historical national averages for corn yields (red line). Downloaded from http://www.ers.usda.gov/Briefing/Corn/2009baseline.htm.

GRAIN CORN PRICING

Combining the above assumptions of $650/acre organic production cost and 100 bu/acre yield results in a cost of $6.50 per bushel. Organic production costs of $500 per acre and yields of 180 bu/acre are probably attainable, which would result in costs of $2.78 per bushel. Grain corn prices for conventionally produced crops have risen in the past 3 years for a variety of reasons, but remain near $4 per bushel as shown in Figure 7.

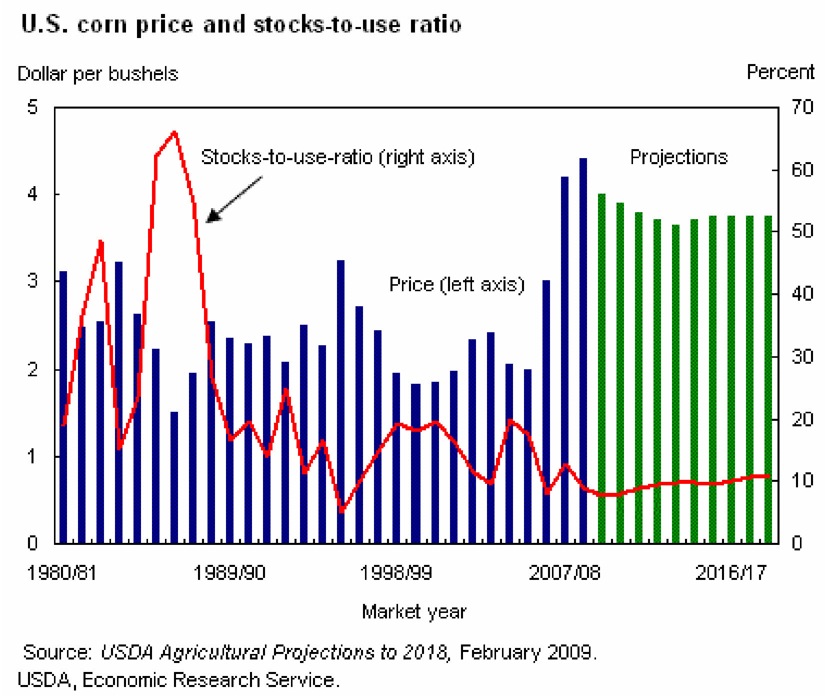

Figure 7 – Historical national averages for corn price. Downloaded from http://www.ers.usda.gov/Briefing/Corn/2009baseline.htm.

COST/BENEFIT ANALYSIS and PROFORMA

Fuel production costs have been summarized above. 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 Clearbrook will heat House #1 and the Display House. Table 3 summarizes the heating degree days for the area using three different inside temperature setpoints; 50, 60, and 65 °F. Clearbrook intends to maintain approximately 60 °F in the spaces being heated during March, April and May. The resulting heating degree days are 979, 555, and 159 respectively (as highlighted in Table 3). Heating degree days are a cumulative measure of the difference between the assumed inside temperature and that outside. The data in Table 3 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 a overall heat loss coefficient (UA) of 0.8 BTU/hr/°F/ft^2. Multiplying this by the exposed heat loss surface area (top, sides and ends) of the greenhouse 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 result is provided in Table 4 with the results for House #1 and the Display House highlighted.

	Heating Degree Days Burlington, VT - 40 yr average		
	HDD50	HDD60	HDD65
January	942	1252	1407
February	895	1175	1315
March	687	979	1130
April	296	555	695
May	38	159	256
June	11	67	132
July	1	22	52
August	4	30	73
September	34	149	243
October	126	335	483
November	425	714	863
December	799	1094	1249

Table 3 – 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. Clearbrook intends to heat the Display House and House #1 only during March, April and May (highlighted).

	Millions of BTU's to maintain 60 deg F			
		HDD 60 deg F		
House	**UA** BTU/hr/F	**March** 979	**April** 555	**May** 159
Display House	3280	77.1	43.7	12.5
House 1	3101	72.9	41.3	11.9
House 2	2268	53.3	30.2	8.7
House 3	2093	49.2	27.9	8.0
House 4	3101	72.9	41.3	11.9
House 5	2651	62.3	35.3	10.1
Future House A	3967	93.2	52.8	15.2
House 6	3101	72.9	41.3	11.9
House 7	3101	72.9	41.3	11.9
House 8	3239	76.1	43.1	12.4
House 9	2533	59.5	33.7	9.7

Table 4 – Greenhouse heat loss factor, heating degree days (60 °F basis) and heat load summary. The corn boiler will be used to heat House #1 and the Display House only (highlighted).

The remainder of the cost benefit calculation is a matter of converting the BTU's of heating required to bushels of corn and comparing this to the equivalent cost of propane to do the same amount of heating. The cost of heating with corn needs to account for the amortized cost of the boiler and associated plumbing as shown in Table 5. This is a single case assuming $650/acre production costs and 100 bu/acre yields. This table was constructed as an MS-Excel spreadsheet and any figure in blue is adjustable by the user to explore various scenarios. Even with conservative cost and yield assumptions, the corn boiler system is predicted to save the farm $1,514 annually with a payback period of 6 years (estimated 20 year life).

Initial Costs	**Amount**			
Boiler - American Royal Multifuel	$ 3,200	200 kBTU/hr (input)		
Hot water / Air Heat Exchangers (2)	$ 1,198	195 kBTU/hr		
Super insulated hot water piping	$ 1,260	70 feet at $18/ft		
Circulator Pump	$ 199			
Other plumbing materials	$ 300			
Grain bin	$ 2,000	3.5 ton bin, installed		
Installation Labor	$ 500			
Construction rental - backhoe	$ 500			
Total	**$ 9,157**			
Estimated life	20	years		
Ammortized cost	$ 458	per year (without cost of capital)		
Operating Costs				
Shell corn production	$ 650	per acre		
Yield	100	bu/acre		
Cost of production	6.50	$/bu		
	232	$/ton		
Moisture content	15%			
Ideal energy content	8,000	BTU per lb (dry)		
Energy content	6,800	BTU per lb		
	56	lb/bu		
	380,800	BTU per bu		
Energy cost of corn (gross)	$ 17.07	per million BTU input		
Boiler efficiency	80%			
Energy cost of corn (net)	**$ 21.34**	**per million BTU output**		
Propane Unit Cost	$ 2.00	per gallon at	92,000	BTU/gallon
Energy cost of propane (gross)	$ 21.74	per million BTU input		
Propane furnace efficiency	80%			
Energy cost of propane (net)	**$ 27.17**	**per million BTU output**		
Period of Use & Heat Load				
Inside temperature	60	°F		
Degree Days				
March	979	degree days		
April	555	degree days		
May	159	degree days		
Total	1,693	degree days		
Greenhouse UA's				
Display House (DH)	3,280	BTU/deg/hr/F		
House 1	3,101	BTU/deg/hr/F		
Total	6,381	BTU/deg/hr/F		
Energy Used (total for House 1 & DH)	**259**	**million BTU per year**		
Ammortized capital cost	$ 1.77	per million BTU		
Grain corn cost	$ 21.34	per million BTU		
Total corn energy cost	**$ 23.10**	**per million BTU**		
Displaced propane cost	**$ 27.17**	**per million BTU**		
Incremental savings	**$ 4.07**	**per million BTU**		
Annual savings if #1 and DH are heated completely with corn boiler	**$ 1,514**	**annually**		
	2,819	gallons of propane		
	17	ton CO2		
Payback period	**6.0**	**years**		

Table 5 – Calculation of cost, savings and payback. This is done in MS-Excel with any blue figure being adjustable by the user.

For example, one can consider the variation of payback period based on different production costs and yields. This is summarized in Table 6 for the system at Clearbrook Farm. The benefit of curtailed production costs and higher yields is evident, though yield appears to be the greater driver in this case.

Payback as a function of							
Cost ($/acre)	Yield (bu/acre)						
	50	65	70	80	100	150	200
650	NA	NA	NA	70.2	6.0	2.7	2.1
575	NA	NA	168.2	9.9	4.3	2.4	2.0
500	NA	18.4	9.5	5.3	3.3	2.2	1.9

Table 6 – Summary of payback study with cost of production and yield as the main variables.

Additionally, it may be of interest to the owner of such a heating system to know when it makes more sense to purchase a different type fuel rather than grow it themselves. Table 7 summarizes the "breakeven energy costs" of replacement fuels when compared to grain corn grown at Clearbrook for $6.50/bu. The cost of $6.50 per bushel being based on $650/acre production cost and 100 bushels/acre yield as assumed above. If shelled corn can be purchased for this price or lower, it makes sense to buy the fuel in. If propane can be purchased for less than $1.57 per gallon, the fuel content and efficiency conversion suggests it would make financial sense to buy propane instead of growing corn for fuel. If switching to a non-renewable, the environmental benefits of a renewable fuel would also be lost. For example propane carries with it a CO2 burden of 12.17 lbs CO_2 / gallon of fuel. In the case of not heating House #1 and the Display House with propane, that equates to 17 tons of CO_2 emissions avoided.

Break even energy costs							
Corn	$	6.50	per bushel @	380,800	BTU/bu	80%	efficiency
Propane	$	1.57	per gallon @	92,000	BTU/gal	80%	efficiency
Wood Pellets (high energy)	$	280	per ton @	16,400,000	BTU/ton	80%	efficiency
Wheat	$	7.93	per bushel @	464,316	BTU/bu	80%	efficiency
Oats	$	3.90	per bushel @	228,384	BTU/bu	80%	efficiency
Barley	$	5.71	per bushel @	334,272	BTU/bu	80%	efficiency

Table 7 – Summary of various replacement fuel costs at levels when it would make sense to switch from self-produced corn at $6.50 / bushel.

CONCLUSIONS

In summary, the purchase and installation of a corn boiler is affirmed by the analysis above. Even if buying renewable solid fuels as commodities at current pricing, the system will have an attractive payback period.

The plan for Clearbrook to produce their own grain corn as fuel is sound even with relatively conservative assumptions regarding production costs and yields. Given the proven ability of Andrew and Matt to successfully grow a wide variety of crops, it seems likely that they will better the assumptions in the analysis.

Two subtle features of this system further support its success. First, the two spaces being heated have varied use schedules which will allow for appropriate sharing of the boiler's hot water. Secondly, there remains a small propane heater in House #1 which will allow some backup should the new corn boiler system require maintenance or adjustment during its first year of service.