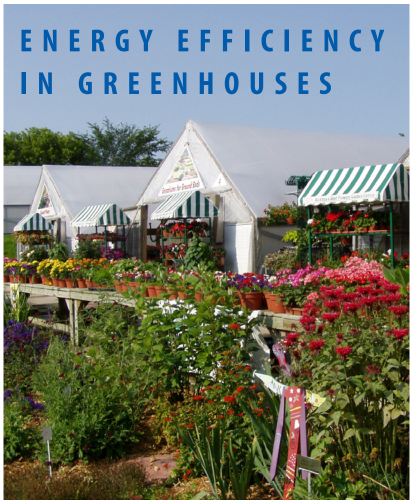

A3907-05

Biomass heating in greenhouses—Case studies

Scott Sanford

There are several options for reducing greenhouse heating costs, including energy conservation measures, fuel switching, and changes in production methods. Fuel switching can be economical if the cost savings per unit of energy is great enough to cover the investment in equipment needed to make the change. Given concerns about global warming and a desire to buy local, some growers may find biomass energy to be an economical alternative. There are numerous types of biomass fuel (figure 1) and several types of heating systems that can meet the needs of greenhouses. With all of these variables, it can be difficult to know which heating system or combination will fulfill your heating needs and give you the best return on your investment.

Figure 1. **Some common types of biomass fuel**

This publication explores some biomass heating options for two types of greenhouses and serves as a companion to *Biomass Energy for Heating Greenhouses* (A3907-04). Case Study 1 explores biomass heating options for a small freestanding greenhouse used to grow spring bedding plants, and Case Study 2 looks at a large commercial greenhouse used to grow and sell both spring and fall plants.

Figure 2. **Freestanding, gothic-style greenhouse (30 x 96 ft.)**

These case studies compare the different types of biomass heating systems and a conventional propane heating system. However, it's a good idea to also compare energy conservation options such as double-wall glazing, higher-efficiency conventional heating systems, and thermal (night) curtains to make sure you are investing in an option that will provide the highest return on your investment. Should you decide to invest in a biomass-fueled heating system in the future, investing in energy conservation measures first may save you money by reducing the size of the heating system needed.

Case study 1

A small greenhouse for spring bedding plants

The greenhouse used for this case study is a gothic-style located near Madison, Wisconsin. It measures 30 x 96 feet and is 13 feet high with a 3-foot sidewall (figure 2). It is covered with double poly film on the roof and sides and 8-millimeter double-wall polycarbonate on the end walls.

The greenhouse is used from February 1 through June 30 to grow bedding plants and vegetable transplants. The average set-point temperature is 70°F during the day and 60°F at night, with a 12-hour day length. The current heating system consists of two propane-fired power-vented unit heaters with input ratings of 200,000 British thermal units per hour (Btu/hr). These heaters are 78% efficient, so their heat output is 156,000 Btu/hr—78% of the heat content of the fuel input. According to the greenhouse heat-loss model, heating with these two power-vented unit heaters will require 1,592 gallons of propane for an average spring growing season. At a cost of $2.00 per gallon, the overall cost of heating with only propane would be $3,184.

Heating requirements

A greenhouse heat-loss model developed by the University of Wisconsin for auditing greenhouses was used to calculate the amount of heat needed to maintain a set-point temperature. In a typical greenhouse, 80% of the heating occurs at night. In the case of this greenhouse, the daytime heating needs are, on average, fully met by solar radiation—except in February. The average daytime heating requirement for February is 12,795 Btu/hr, about 10% of the overall daily heating requirement. The heat-loss model uses monthly weather data, so table 1 shows an average of the monthly heating requirements.

Table 1. Average nighttime heating requirements, by month

Month	Per night[a] (Btu)	Btu/hour (approximate)
February	1,643,818	136,985
March	1,119,650	93,304
April	732,940	61,078
May	343,839	28,653

[a] Assumes a 12-hour night.

The usable heat output from a stove, furnace, or boiler system was estimated by comparing the heating required and the system output. During periods of warmer temperatures, a biomass furnace or boiler may output more energy than is needed if the unit is not thermostatically controlled. The excess heat is considered unusable and is assumed to be vented. During periods of lower temperatures, the furnace or boiler won't always have enough capacity to maintain the set-point temperature. All biomass heating units should have a backup system; most growers use the existing heating system. The thermostat for the propane unit heaters currently in use would be set about 5°F below the set point of the furnace thermostat so the propane heaters would provide only supplemental heating during cold periods when the biomass furnace or boiler isn't able to provide enough heat.

Heaters in greenhouses are sized to maintain an indoor set-point temperature at some minimum outdoor design temperature. For this study, an outdoor design temperature of -20°F was used to size the heaters. Table 2 shows the heater output required to maintain a set-point temperature of 65°F at several outdoor temperatures.

Table 2. Heating required to maintain indoor set-point temperature of 65°F at various outdoor temperatures

Outdoor temperature	Heating requirement (Btu/hr)
-20°F	244,600
-10°F	215,800
0°F	187,000
10°F	158,300
20°F	129,500
30°F	100,700
40°F	71,900

Biomass heating options

Option A: A residential or shop pellet stove to supplement the heating

The pellet stove has a rated output of up to 70,000 Btu/hr (~85,000 Btu/hr input) and would be operated mainly at night. The unit would be set near an end wall and rely on existing horizontal circulating fans to move the heated air around the greenhouse. The unit does not have thermostat control, so the grower would have to estimate the heat setting using the forecasted temperature for the evening.

The installed cost is an estimated $4,350, which includes the stove ($3,500), chimney pipe ($550), and brick pad and labor ($300). The stove has an expected efficiency of 80%.

Option B: A pellet furnace with thermostat control and an input rating of 10,000 to 165,000 Btu/hr (8,000 to 132,000 Btu/hr output)

This type of furnace has a high-volume blower (1,400 cubic feet per minute) to distribute the heated air. A short section of duct would be attached to the outlet to direct the air down the greenhouse horizontally. The furnace would be placed at one end of the greenhouse near one of the existing unit heaters. The controller automatically ramps the output up and down, allowing the furnace to be used during periods of lower heat demand without overheating the greenhouse.

The installed cost of the furnace would be $6,030, including the furnace, 14-bushel-capacity fuel bin, thermostat control, chimney, brick pad, and labor. Bagged fuels are used in these calculations, but a bulk storage bin could be installed to reduce the fuel cost and handling. This furnace has an expected efficiency of 80%.

Option C: An EPA-qualified outdoor wood-fired boiler (OWB), with forced-air heat exchangers in the greenhouse to distribute the air

According to independent tests, one boiler that would fulfill the heating need has an output of 160,000 Btu/hr (average over an 8-hour burn). The boiler would be placed outside the greenhouse, and PEX tubing would be run to two water-to-air heat exchangers in the center of the greenhouse. One exchanger would be set on each side of the center aisle, and they would face opposite directions to promote a circular airflow. The heat exchanger fans and circulator pumps would be connected to a thermostat, so when the thermostat calls for heat, the circulator pump and heat exchanger fans switch on.

The installed cost is estimated at $13,050, including the boiler ($10,175), heat exchangers ($1,600), piping and pumps ($775), and concrete pad and labor ($500). According to EPA data, the average efficiency of this boiler is 75%, which does not account for heat loss from the boiler and piping to the greenhouse, or for the amount of wood burned during the day when there is little or no demand.

Option D: The same system as Option C but using an unqualified OWB

A typical, pre-2008 OWB is an example of an unqualified OWB; it does not meet the Phase 2 emissions limits of the EPA's program.

The installed cost would be $11,635, with the boiler cost of $8,760 and all other costs the same as Option C. The estimated efficiency of this type of boiler is 40%.

Figure 3. T-shaped, gutter-connected greenhouse (33,012 sq. ft.)

Heating options analysis

Given the output capacities of heating systems used in this study, Option A can provide 100% of the heating requirement down to an outside temperature of 40°F, and Option B can provide 100% down to about 20°F. Options C and D can provide 100% down to about 10°F. According to 30-year averages, the average minimum temperature for Madison in February is 14.3°F, so looking at monthly heating requirement averages, Options C and D should be able to provide 100% of the heating needs. In reality, there will be many nights (and some days) when the heat loss will be higher than the capacity of the biomass heating system. Propane heating will provide 45% of the heating for Option A while supplemental propane heating on nights cooler than 20°F, and it will provide an estimated 25% of the heating for Option B and 20% of the heating for Options C and D on nights cooler than 10°F.

A cord of wood cost $150 (assuming you harvest the wood yourself), and wood pellets locally cost $4.60 per 40-pound bag in 50-bag pallet lots ($230 per ton). Access to bulk storage for the wood pellets would reduce the cost to $180 per ton (assuming a 20-ton load) and would save labor. Table 3 summarizes the energy costs and savings for the different options.

Conclusion

The residential pellet stove will have a better return on investment than the OWBs even though the biomass fuel cost for the EPA-qualified OWB is lower. Both the pellet stove and furnace have longer payback periods than would be acceptable to most growers. The lower-emission, higher-efficiency OWB is a better investment than the standard OWB, but both also have longer paybacks than would be acceptable to most businesses. The longer payback period is due to the higher capital cost without a corresponding increase in energy savings.

The payback period is very sensitive to the cost difference between propane and wood pellets. Last winter, with wood pellets selling at $4.00 per 40-pound bag and propane at $2.15 per gallon, the payback for Options A, B, C, and D were 4.7, 4.6, 7.1, and 9.4 years, respectively. In this case, investing in energy conservation projects would be a better investment than installing a biomass heating system. For more information about energy conservation in greenhouses, refer to UW-Extension publications A3907-01 and A3907-03.

Case study 2
Large greenhouse for year-round production and retail

This gutter-connected greenhouse located near Madison, Wisconsin, has a T-shaped footprint that covers 33,012 square feet (figure 3). The greenhouse is glazed with double poly film on the roof and walls and has in-floor heating with unit heaters for peaking on cold nights.

Table 3. Summary of costs and savings for biomass heating options

Heating system option	Capital cost	Biomass fuel amt.	Biomass fuel cost	Propane cost[a]	Fuel cost savings[b]	Simple payback period (years)
A: Residential or shop pellet stove	$4,350	282 40-lb bags	$1,297	$1,278	$609	7.1
B: Pellet furnace	$6,030	355 40-lb bags	$1,633	$796	$755	8.0
C: EPA-qualified OWB[c]	$13,050	6 cords	$900	$636	$1,648	7.9
D: OWB[c]	$11,635	10 cords	$1,500	$636	$1,048	11.1

[a] Assumed cost of $2.00 per gallon.
[b] Savings compared to heating with propane only.
[c] Outdoor wood-fired boiler.

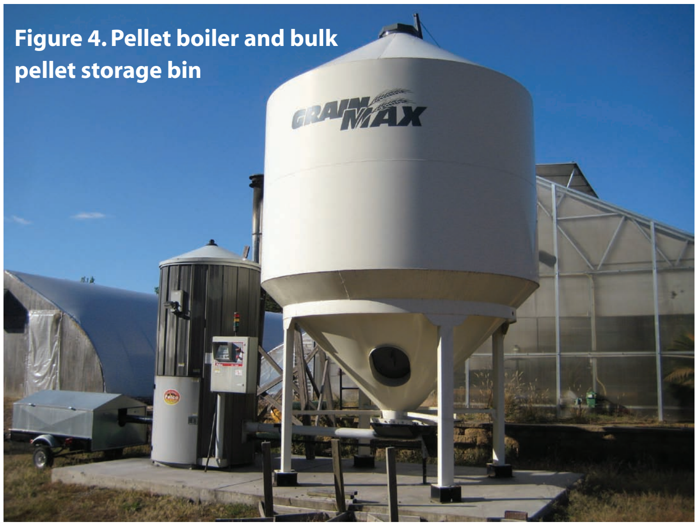

Figure 4. Pellet boiler and bulk pellet storage bin

According to the heat-loss model, the greenhouse will require 85,581 gallons of propane, which, at $2.00 per gallon, will cost $171,162 for an average year. If cordwood were used to provide all of the heat, an EPA-qualified outdoor wood boiler (OWB) with 75% efficiency would require 389 cords of wood. Due to the large volume of wood required and the limited labor available, the greenhouse owner has chosen not to consider cordwood. The owner does have some cropland and would like to consider using corn, small grains, wood pellets, prairie grass pellets, or a combination of the latter two options. Therefore, this case study analyzes commercial-sized pellet boilers and bulk pellet storage bins as propane replacements (figure 4). Wood chips are also included because they are low cost, available locally, and unlike cordwood, can be handled in bulk.

Table 4. Average nighttime heating requirement, by month

Month	Per night[a] (Btu)	Btu/hour (approx.)
September	8,424,853	702,071
October	15,018,403	1,251,534
November	22,012,158	1,834,346
December	29,167,064	2,430,589
January	31,150,243	2,595,854
February	28,137,714	2,344,809
March	21,901,552	1,825,129
April	15,388,874	1,282,406
May	5,862,478	488,540

[a] Assumes a 12-hour night.

Heating requirements

As shown in table 4, the heating capacity needs to be 2.6 million British thermal units per hour (2.6 MMBtu/hr) to meet the average requirements for January, the month with the highest heating requirement (average nighttime temperature of 9.3°F). The greenhouse heat-loss model used in this study accurately predicts monthly heating requirements but not those of a particular day or hour. Any time temperatures fall below the monthly average temperature, the heating demand will exceed the hourly heating requirement shown in table 4.

To meet the total heating requirements of the greenhouse, the heating system capacity must be sized to meet the heating requirements during the coldest temperature. For most of Wisconsin, the recommended outdoor design temperature is -20°F which, for the greenhouse in this study, would require a heating capacity of 4.2 MMBtu/hr. To determine the outdoor design temperature for your location, consult the *American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook—Fundamentals*, Chapter 27, Table 1A, or other climatic data.

Biomass heating options

Option A: Pellet boilers sized to meet the total heating requirements of the greenhouse

The dealer recommends installing two boilers, one with an input rating of 3.5 MMBtu/hr (2.73 MMBtu/hr output) and the other with an input rating of 2.5 MMBtu/hr (1.95 MMBtu/hr output). The maximum combined output of the boilers is 4.7 MMBtu/hr, which exceeds the minimum requirement of 4.2 MMBtu at the outdoor design temperature of -20°F. These two pellet boilers will meet the heating requirements for very cold nights, and the ability to run only the smaller boiler will provide some flexibility for heating during the warmer months of October, April, and May.

This option can theoretically provide 100% of the heating requirements, but this type of boiler is difficult to throttle down during the low heating demand of early fall and late spring. A grower with these boilers would likely use the propane unit heaters about 5% of the heating season so no one has to get up in the middle of the night to light the boiler.

These boilers have automatic stoking and ash removal, so they require little labor. They can burn any type of fuel that can be moved with an auger, which feeds the boiler fuel from a storage bin. Possible fuels include corn, biomass pellets, small grains, and cherry pits. Wood pellets are used for the calculations in this study because they currently have the lowest cost per unit of the fuels that will work in this type of boiler. The wood pellets are delivered in 20-ton loads at a delivered price of $180 per ton. The storage bins should be sized to store about 30 tons so the fuel supply isn't interrupted.

The total cost is $286,000, which includes two boilers ($138,000); bins, piping, design services, miscellaneous costs ($133,000); and labor ($15,000). This type of pellet boiler has an efficiency of 75 to 82% depending on the fuel type and draft control position; an average of 78% is used for this study.

Option B: Pellet boilers sized to meet the average heating requirements of the greenhouse

The dealer recommends installing two boilers, one sized at 2.5 MMBtu/hr input (1.95 MMBtu/hr output) and the other at 1.0 MMBtu/hr input (0.78 MMBtu/hr output), providing a combined output of 2.7 MMBtu/hr to meet the average heating requirements.

This option can theoretically provide 100% of the heating requirements using the monthly average data, but in reality, these boilers will only be able to hold the temperature down to 10°F. There will be many nights with temperatures below 10°F when the propane unit heaters will be needed to supplement the pellet boilers. The propane heaters will provide an estimated 20% of the heating requirement during the heating season. As with Option A, the efficiency ranges from 75 to 82% depending on the fuel type and draft control position; an average of 78% is used for this study.

The costs total $211,000 for the two boilers ($75,000); bins, piping, design services, miscellaneous costs ($121,000); and labor ($15,000).

Option C: A wood-chip boiler sized to meet the total heating requirements of the greenhouse

The wood-chip boiler (figure 5) can handle wood chips (preferably hardwood) between the size of sawdust and 4-inch chips, with a moisture content no greater than 50%. The 135 brake horsepower (4,522,500 Btu/hr output) chain grate boiler is sized to meet the total heating requirements of the greenhouse.

The fuel storage system will hold 3,838 cubic feet, which would be enough to provide 3 days of fuel at the maximum firing rate. The hydraulically driven walking floor in the storage bin meters the fuel to a drag chain conveyor. The wood chips are then transferred to the boiler by a drag chain conveyor or an auger. Multiple feed augers meter the fuel evenly onto the chain grate and can be varied from a few pounds to a few hundred pounds of fuel per minute.

The firebox has under-grate combustion air injection and over-fire air jets to ensure complete combustion of the volatile gases. The boiler incorporates automatic ash removal and a dust collector to remove fly ash. This boiler system has an expected efficiency of 80% based on fuel that will provide 5,500 Btu per pound.

The installed cost is approximately $520,000, which includes the boiler, fuel storage, and a building to house it. The fuel cost is estimated at $6.50 per million Btu and assumes wood chips with an average energy content of 5,500 Btu per pound. It is assumed that propane would be used during the late spring and early fall when heating may only be needed for a few hours per night—accounting for about 5% of the total annual energy requirement.

Heating options analysis

According to the summary of costs and potential savings in table 5, all of these options would be acceptable in terms of an economic return on investment. Option B has the shortest simple payback period despite replacing only 80% of the heating needs. Sizing the heating system to replace 100% of the heating needs increases the system cost for the benefit of a few hours per growing season. If the current heating system is in good working order, sizing the system for 80% of the heating needs would be more cost effective. Option C is the most expensive to purchase and install, almost double the cost of Options A and B, but the fuel is half the cost of wood pellets and is definitely the cheapest. Despite the fuel cost advantage, Option C has the longest simple payback because the capital cost is relatively high compared to the fuel savings.

Figure 5. Wood-chip boiler

Table 5. Summary of costs and savings of pellet boiler options

Heating system option	Capital cost	Fuel amt. (tons)	Fuel cost	Propane cost[a]	Fuel cost savings[b]	Simple payback period (years)
A: Pellet boilers to meet total heating reqs.	$286,000	465	$83,700	$8,558	$78,900	3.7
B: Pellet boilers to meet ave. heating reqs.	$211,000	392	$70,560	$34,232	$66,370	3.2
C: Wood-chip boiler to meet total heating reqs.	$520,000	715	$50,900	$8,558	$111,700	4.7

[a] Assumed cost of $2.00 per gallon.

[b] Savings compared to heating with propane only.

Conclusion

According to the information used in this case study, installing a pellet boiler would be a very good investment, with a simple payback period of 3.2 to 3.7 years. The wood-chip boiler has a reasonable payback period, but the capital cost is almost double that of the pellet boiler. The cost of propane is the key driver in this analysis. The demand for wood pellets has increased recently, resulting in an increase in fuel cost, a trend that is likely to continue. Industry has been increasingly interested in using biomass such as wood chips, and if demand increases, the cost will also likely increase. If this same greenhouse had access to natural gas, the cost of heating would be approximately $94,000 per year (at $1 per therm), $77,000 less than heating with propane only. In this case, converting to natural gas and focusing on energy conservation options would be a better investment.

Final thoughts

Simple payback is a quick calculation that indicates the potential economics of an option, but it does not take into account costs such as ash disposal, system maintenance and repair, and daily labor. A net present value analysis would account for these costs and assess the effect of energy price inflation over the life of the equipment. Your local Cooperative Extension agent or accountant can help you complete a net present value analysis. Long-term energy prices are expected to continue an upward trend, so investing in biomass energy is likely a good investment providing that biomass is readily available in your local area.

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