Biomass Heating of Greenhouses January 19, 2010
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This narrative is a supplement for the presentation entitled Biomass Heating of Greenhouses. It was developed as part of a North Central Region SARE Professional Development grant.

1) This presentation will cover types of biomass for combustion, types of equipment and two case studies of a greenhouse application. This is the third presentation is the Greenhouse Energy Webinar Series. This was developed by Scott Sanford at the University of Wisconsin.

2) Disclaimer: Any products mentioned in this presentation do not reflect an endorsement of that product. Likewise, a lack of mention does not imply that a product is not recommended. Photo Credit: Scott Sanford unless noted otherwise.

3) Outline - What is biomass; Types of fuels for combustion; What is a boiler or furnace?; Outdoor wood-fired hydronic heaters; Pellet / grain fired boilers / furnaces; Stand alone stoves; Waste vegetable oil use; Case Study of two greenhouses;

4) Biomass fuels is defined as a plant material based fuel. Some examples are wood, grains, cherry pits, grasses, crop fogger, straw and plant based oils. Photos: upper left – ear corn, upper right – wood chips, lower right – Miscanthus giganteus, lower left – round bails of corn stalks.

5) Biomass fuels can be divided into several categories; Those that can be used directly such as wood and grains with minimal processing; Products that are bulky and are best densified to reduce transportation costs and facilitate use such as straw, grasses and sawdust; By-product that can be sometimes used directly or are used as an ingredient in making pelleted fuels such as seed and nut hulls; Processed fuels such as plant based oils such as rapeseed oil and soybean oil. Oils can be used directly, processed to bio-diesel or used as waste oils after a higher value use such as fryer oil. Photo: Miscanthus giganteus which is a warm season grass native to Japan, Taiwan and the Pacific Islands. Grows to 13 feet and can yield 10 to 20 tons of biomass per acre.

6) Material Characterization is important so we understand differences between fuels. Unit of measure is important so we understand how the product is traded and priced. The moisture content of biomass will reduce the net energy content because water must be evaporated before burning will initiate. Low moisture levels result in more net energy. The energy content will vary between material types. Often energy contents listed in literature is the bone-dry energy content and not the as sold energy. Before biomass will burn, all of the water must be evaporated. This requires energy, about 1050 Btu per pound of water. There are two types of heating values published, Low Heating Value (LHV) and High Heating Value (HHV). LHV is the net energy after the moisture is evaporated. HHV is the net energy if the moisture is condensed after combustion to recover the heat of evaporation. Few biomass boilers or furnaces are designed to condense the combustion moisture so the LHV should be used for calculations. Size and shape of the fuel may affect the types of combustion equipment that can be use. The ash content is an indication of the inorganic material in the fuel and the amount of ash that will need to be

disposed of. Chloride content of the fuel is important because at high temperature the chloride is corrosive and can shorten the life of a boiler.

7) There are several types of wood fuels available. The energy content of wood will vary by % moisture, density and % ash. Cord wood has been the popular what to handle wood but there are other wood industry by-products that can also be used for fuel. Green mill residue is the bark and sawdust from processing logs into lumber. It is high in moisture, usually greater than 20%, and is typically stored in piles outside. Dry mill residue comes from planning of kiln-dried lumber and furniture making. It has the advantage of low moisture (less than 10%) but is in high demand for animal bedding and fuel pellet manufacturing so the price may be higher. Wood chips from whole trees, urban forest trimmings and logging residue (tops & limbs) can also be used for heat production but is typically high in moisture (~50%) so the net energy content is lower. For large ranges of greenhouses who can invest in the specialized equipment, wood chips or green mill residue may be cost effective. For smaller growers, cord wood or wood pellets will likely be more cost effective.

8) Cord wood or wood logs is a popular fuel especially if a wood lot or hedge row is available for harvesting locally. The unit of measure for wood is the “Cord” which is a volume of stacked wood filling 128 cubic feet or a pile 4 foot wide by 4 foot high by 8 feet long. This is sometimes referred to as a full cord. A face cord would be a stack of 16-18 inch long logs, 4 foot high by 8 feet long corresponding to one third of a full cord. Wood as harvested will have a moisture content of about 50%. To get the most net energy, the wood should be split and air dried for 1 or 2 years (summers) to reduce the moisture to about 20%. Wood species such as oak will not dry unless split because the bark holds the moisture in the log. The energy content will vary by tree species as well as moisture content. The average energy content for deciduous trees is about 22,300,000 Btu per cord at 20% moisture with a range from 14.7 MBtu to 30.7 MBtu per cord. The principle difference in the energy content is variation in wood density between species. Air dried Basswood weighs about 2100 pounds per cord, while Hickory weighs 4160 pounds per cord. All wood nets about 7000 Btu of energy per pound at 20% moisture.

9) Cord Wood – Many people view wood as low cost especially if they have a wood lot and don’t have to pay for the wood. But it doesn’t magically get from a standing tree to a split log without some labor. Typically a piece of wood will be handled 3 to 6 times to get it from the wood lot to the stove. Harvesting includes cutting up in lengths, loading/transporting, splitting, pile/stack and loading into the stove as needed. To burn the moisture content should be about 20% or lower. This is accomplished by allowing to air dry for 1 or 2 summers after being split. Wood like Oak will retain moisture under the bark unless it is split. Wood can not be automatically stoked or loaded into boilers so labor will be required as needed. The unburned material left after combustion is ash that will need to be removed from the boiler frequently and disposed of. Outdoor wood boilers are being regulated by many states and municipalities due to high emissions from older models. We’ll discuss this more in a later slide.

10) Wood chip can be advantageous if there is a local supply of low cost wood scrape. The largest disadvantage of wood chips is the typically high moisture content that reduces the net energy yield. Wood chips can be handled in bulk which reduces labor costs. Handling can be done with dump trucks, loaders, augers and conveyor. If using green chips, they can be piled

outside reducing storage costs otherwise a covered bunker may be necessary to maintain the net energy content.

11) There are several types of grains that can be used for fuel. Corn has been the most popular and is readily available in most areas. Grains are traditionally sold in bulk by the bushel or ton or in 50 pound bags. The traded moisture content for corn is 15.5%. This doesn't burn well so some retailers are offering corn for stoves at 12% moisture. It is usually cleaned to remove fines and sometimes a light coat of oil is applied to reduce dust. The energy content will vary with the moisture content. Corn will net 6810 Btu per pound at 15% moisture and 7130 Btu per pound if dried to 12% moisture. Some of the advantages of corn fuel: readily available, no processing required and its an annual crop that is mechanically harvested and handled. Biggest disadvantage is that when corn burns it produces clinkers and slag which is ash that metals and then solidifies into a mass. Clickers may need to be removed manually from the stove on a daily basis depending on the boiler firepot design. Corn needs to be dried after harvest and stored in a dry location for proper combustion. Wood pellets are used to get corn to start burning as it doesn't ignite easily. Wood pellet stoves can be stopped and re-ignited when needed to match heating needs, corn, being difficult to re-light, is normally burned continuously. Higher moisture corn may flame out at lower feed rates.

12) Different grains have different densities and storage moisture levels. Rye, which is often used as a cover crop, makes a very good fuel.

13) Heating values are often over stated in equipment literature or on-line estimation tools. Many times the bone-dry heat values are used when referring to grains for fuels. Corn at 15% moisture (by weight) means in one pound there will be 0.85 pounds of dry corn and 0.15 pounds of water. Water requires about 1050 Btu per pound to evaporate. Therefore the heat value can be calculated as 0.85 pounds of corn times 8250 Btu/lb minus the energy to evaporate the water (1050 Btu/pound times 0.15 pounds of water) which will equal 6855 Btu per pound of 15% corn will be available after combustion. Boilers are not 100% efficient so there will be further losses to transfer the heat from the fire pot to the air or water. Typical efficiencies will be 80%.

14) Densification of bulky materials into pellets or cubes has many advantages. One of the main advantages is that it facilitates handling and reduces transportation costs. If we tried to burn straw, for example, we would have trouble designing a feed system for small boilers that could be automatic stoking and it would be bulky for transporting and storing. Making it into pellets, increases the energy density and allows ease of use. Pelletizing also allows the use of products that would separate if used in a bulk mix. Pellets can be made from many different by-products and low value materials. For example a recipe might include straw, nut hulls, and urban wood waste. The combination is endless and varies with location. Pellets can be handled with conventional grain handling equipment and need dry storage. They are used in stoves, boilers and furnaces that automatically meter (stoke) the pellets into the fire box with an auger. The auger speed can be controlled by a thermostat to maintain the air temperature or the boiler water temperature. The pellets burn very efficiently with low emissions or smoke. Boiler efficiencies typically range from 80% up to 90+% for high efficiency units. The only disadvantage is that the pellet cost is higher per ton than cord wood and has a higher energy input because of the pelleting process.

15) Pellets for residential or commercial units will be about ¼” in diameter by up to 1.5” long. For industrial boilers that use coal, a briquette or cube can be used. These are about the size of a small nugget of coal so they can typically be mixed with the coal for a stoking boiler.

16) Wood is the most commonly used material for pellets. They are typically made from sawdust, a by-product of the lumber or furniture industry. Wood pellets are sold in tons for bulk delivery or 40-50 pound bags. The maximum moisture and ash content will vary with grade. There are four grades of pellets with the main differences being the maximum ash and moisture content. Typically wood pellets will have an energy content of about 8000 Btu/lb but that can vary as the standard for the grades of pellets does not specify an energy content. The URL at the bottom of the slide will link you to the standard for the grades of pellets which is overseen by the Pellet Fuels Institute.

17) Biomass pellets can be made from many different materials. These are some of the things that have been used to make pellets. The pellets are sold in bulk by the ton or in 50 pound bags. The moisture content of biomass pellets is generally higher than wood pellets and usually falls into the “Utility” grade because of the moisture content. Energy contents range from about 7200 to 8000 Btu/pound with higher energy contents when wood residue is included. The one disadvantage of biomass pellets is high chloride contents which cause corrosion at high temperatures in boilers or furnaces. The Pellet Fuels Institute standard states a maximum of 300 ppm of chloride but many biomass fuels will exceed this level.

18) There are many possible sources for locally derived fuels. The type of boiler or furnace will affect the fuel choices that can be used. Photo: Corn – upper left, wood pellets upper right, lower left – pellets made from prairie grass, lower right – mix of rye and vetch that was grown as a cover crop on an organic farm.

19) What is a boiler versus a furnace? A boiler heats a fluid that is contained in pipes and can be pumped to multiple locations. The fluid can be water, glycol/water solution or steam. A furnace heats air that is blown through ducts to the needed location. There are both boilers and furnaces available for combusting all types of biomass.

20) Boilers have several advantages over a furnace. One boiler can heat multiple greenhouses and can be used for under-bench / floor heating or water/air heat exchanger or a combination. The boiler can be located outside the greenhouse in a central location and the heat piped/pumped to the desired location. This maximizes greenhouse space and allows for a central storage system/location for the fuel. Another advantage of a boiler is the heat transfer fluid, usually water or a water/glycol (antifreeze) solution can be heated and stored in an insulated tank.

21) A furnace heats the air directly which reduces heat exchanger losses associated with an extra heat exchanger in a boiler system. Furnaces are generally located in or adjacent to the greenhouse which may take up growing space. Since there isn’t any piping there are not water or antifreeze leaks from the heating system to worry about. Depending on the greenhouse and furnace size, it may be necessary to use multiple furnaces in one greenhouse. This may be a challenge for controlling set point temperatures unless the furnaces can be operated from the

same controller. If furnaces are in multiple locations then there will need to be multiple fuel storage areas or bins and may require labor to re-fuel.

22) Outdoor wood-fire boilers (OWB) or hydronic heaters have been popular in some areas for heating mainly because cord wood is considered cheap fuel especially if you own a wood lot. However high emission rates and poor firebox management have lead to OWB being banned or restricted in many municipalities.

23) These are certainly and option for many greenhouses but my first concern is that we properly account for the true cost of cord wood because many times when we add up all of the costs, it's really not any cheaper. Some of those costs include labor and equipment (Truck, trailer, chainsaw, splitter, tractor) to collect the fuel, labor to fuel the boiler and disposal of the ash. Other issues: There were no efficiency standards for outdoor boilers until 2008 and many of the OWB were simply a box you throw wood in to burn it. Based on EPA testing many of the pre-2008 OWB had efficiencies of 20 to 50% with an average of about 40%. The voluntary EPA standard is being phased in and many states are restricting OWB sales to only models that qualify under the new standard. These boilers can be used with under bench or floor heating or a water to air heat exchanger can be used to distribute the heat into the greenhouse. Fuel can be scrap wood such as pallets or building waste as well as logs.

24) EPA instituted a voluntary program to reduce the emissions from outdoor wood boilers (OWB) by 90% or more. The other benefit of this program is that as the emissions are reduced the efficiency of the OWB will improve. Many states are requiring that any new OWB sold in their states must meet the new standard which will provide further incentive for manufacturers to make improvements. The voluntary program was instituted in two phases. The first phase (orange tag) qualified boilers that had 70% less emission in a standardized test while the second phase (white tag) qualified boiler with 90% less emissions. A list of qualified boilers can be found on the EPA's web site. Information on the program and a list of qualifying boilers can be found at the links listed.

25) Pellet boilers are a great option for a grower that doesn't have a wood lot or have labor to harvest wood. Pellets can be delivered in bulk so there is no handling. The fuel is metered into the boiler's firepot and ash is removed by an auger on the opposite side or drops into an ash pan. The boiler maintains the heat transfer fluid at the desired set point temperature by varying the rate the fuel is metered into the firepot. Manufacturers are offer boiler capacities from 750,000 Btu/hour to 10,000,000 Btu/hour. Having multiple boilers would be recommended for large greenhouses so they can be staged during the spring and fall when the weather isn't as cold and to provide a backup boiler.

26) This is a small pellet/corn furnace that would be suitable for a greenhouse up to 3000 square feet and provide 70-80% of the heating needs. This one has a 14 bushel hopper so it doesn't have to be refueled everyday except during very cold weather. This type is also available as a boiler. An important point to make sure the combustion air flow rate can be adjusted for the fuel(s) being used to get proper combustion. Ask about adjustments before you purchase a boiler or furnace. If you are burning corn or a fuel that produces clickers, you should contact some users

to see what there experiences have been. Some boilers and furnaces do a better job of dealing with clickers than others.

27) This is a photo of a high capacity furnace. Boilers are manufactured in higher capacities than furnaces.

28) One recommendation is that you maintain you current heating system as a backup for cold spells and break-downs when installing a biomass heating system. They are reliable but when a repair part is needed it likely won't be available locally and may take several days to weeks to get repair parts.

29) Pellets fueled boilers and furnaces have many advantages over cord wood. The fuel is uniform in shape and heat content and a variety of material sources can be used. The burn rate can be accurately adjusted by varying the feed auger speed. They have low emissions and efficiencies from 80% up to 90+% for a few high efficiency models. They will add minimal labor requirements because they have automatic stoking and ash removal.

30) How is the heat distributed? With a furnace ducts and fans are used. A poly-tube distribution system may not be suitable depending on furnace outlet air temperature unless cooler greenhouse is mixed with the heated air from the furnace before it enters the poly-tube. A boiler provides additional flexibility because the heat can be pumped through pipes to multiple locations using insulated pipes similar to the photo. The heat can be introduced into the greenhouse through a water to air heat exchanger (radiator) or piped for bench-top, under-bench or floor heating. These methods will reduce heating needs by creating a micro climate where the plant is located instead of heating all the air in the greenhouse. Plants with warned roots grow faster and produce more fruit. If using floor heating, there will be a need for water to air heat exchangers or unit heats because the floor can not transfer heat into the greenhouse fast enough on cold nights. The photo shows insulated supply piping that could be used between a boiler and a greenhouse.

31) Here are some examples of water to air heat exchangers. They can be located overhead or under bench. They contain fin tube heat exchangers and a fan to move air over the fins.

32) This is an example of a bench-top heating system. The heat is supplied by piping running along the greenhouse wall (supply and return pipes). The heat transfer fluid will flow through each tube from the supply line to the return line. The plant pots or trays are set directly on top of the bench-top piping. With bench top or under-bench heating, the plants may return more water because of increased evaporation.

33) Biomass boilers operate most efficiently if they can burn continuously, but usually as the sun comes out the boiler is regulated so that the damper will close. One method to even out the peaks and valleys of heating is to have a hot water storage tank that the boiler heats. The heat for the greenhouse is then drawn from the hot water tank instead of directly from the boiler. This allows for fewer damper closings and less emissions. If the tank is large enough it may allow the use of a smaller boiler because the heat can be stored during the day for night use.

34) Wood chips are plentiful in many areas and can be purchased at a relatively low cost . The capital investment for wood chip boiler system may be higher and due to the number of moving parts (augers and conveyors) the maintenance costs may also be higher than a pellet boiler or outdoor wood boiler. Chips are supplied by the tractor trailer load so adequate space is required to store chips. These boilers are ideally suited for industrial application such as several acres of greenhouses. As more biomass systems are installed and the demand for wood fuel increases, it will be important to assess the availability and cost of the supply before investing.

35) A residential or shop stove can be used to supplement the heating of a greenhouse. They are lower cost, $1500 to $4500 installed, easy to install and payback fast. The disadvantages are the hoppers may be too small to last all night at a high burn rate and they may not be thermostatically controlled, which can lead to overheating. They are typically located next to an end wall due to venting requirements making it more difficult to distribute the heat generated efficiently. Pellet stove heating capacity are approximately 30,000 to 70,000 Btu / hour, far below the heater size to provide 100% of the heat except for a small greenhouse. Note the pictured stove has an ad hoc hopper extension – an old milk filter frame.

36) Here is an example of a larger stand alone pellet stove in a greenhouse.

37) The table in this slide is a comparison of different fuels based on current prices (June 2009) and typical boiler efficiencies. The cost per million Btu only includes fuel cost and does not include capital recovery, maintenance or labor. Electricity is the most expensive heating source followed by heating oil and propane per million Btu. Note that the low efficiency outdoor wood stove is the same cost per million Btu as heating oil and propane. The least expensive heat source is natural gas with the high efficiency outdoor wood boiler being the second least expensive heat source. Therefore, investing in a biomass boiler will only be justified if displacing propane, heating oil or electricity.

38) Sizing a biomass heating system. Question: What percentage of the heating do you want to replace? 100%, 80%, 50%??? It turns out that the closer it is sized to 100% the longer the payback. The optimal size will depend on the cost of the biomass boiler or furnace and the cost difference per million Btu between the biomass fuel and the fossil fuel being replaced. It is likely between 50 and 80%. Biomass heating systems are design to run continuously and not be started and stopped like a gas or oil heating system. Therefore the equipment capacity can be sized smaller and still meet the average heating needs.

39) Waste Vegetable oil is also a possible energy source depending on your location. Restaurants typically have to pay to dispose of fryer oil so it can often be gotten for “FREE”. In some areas there is competition for the oil from folks running cars on biodiesel. The oil isn’t free, even if you don’t have to pay for it because you’ll have time and travel expenses to collect it. You’ll need a suitable location to store the oil until used and the oil will need to be processed before using.

40) There are two options for using waste veggie oil: it can be converted to biodiesel and burned in a standard oil burner or filtered and burned in a waste oil burner. Converting the oil to biodiesel requires the oil be chemically altered through a process called transesterification. This

is a low temperature process (225F) that requires the addition of methanol alcohol and lye to the oil to replace a glycerin group with an alcohol group on the hydrocarbon. The byproduct is glycerin/lye/methanol mixture which will need to be disposed of. This process requires the handling and storage of hazardous chemicals: Methanol and lye, usually Potassium Hydroxide. One advantage of biodiesel is that it can be burned in a standard oil burner. This can be an advantage is there isn't enough oil to replace 100% of the heating needs or you run out. Oil burner maintenance will be very important with the use of biodiesel as there can be an increase in plugging of the burner jet and soot buildup. To avoid the need to handle hazardous chemicals, the waste oil can be burned in specially designed waste oil burners. The oil will need to be filtered to remove particulate matter and water before being used in a waste oil burner. Many types of vehicle oils can also be burned in these burners (engine oil, hydraulic oil) as well as #2 heating oil. It will be necessary to have a tank and line heater to liquefy the oil as it tends to crystallize or gel. The reduced viscosity allows the oil to be pumped to the burner.

41) Here is a photo of a waste oil furnace in the head house of a greenhouse. The oil supply tank is kept inside (behind owner) so tank heaters are not needed. This could be ducted into a poly-tube air distribution system to provide even heating of the greenhouse. This units are available as furnaces or boilers. Laughing Stock Farm in Freeport Maine did a very nice study on the use of waste vegetable oil which at http://laughingstockfarm.com under energy project.

42) Next we will look at two case studies to show the feasibility and options that might be considered for different cases. The first case is a 30 foot by 96 foot freestanding gothic greenhouse used to grow vegetable transplants and bedding plants in the spring. The double poly film glazed greenhouse is started about the first of February and is used until June with a day-time temperature set point of 70°F and a night-time set point of 60°F. The current heating system is two 200,000 Btu/hr power-vented propane fired unit heaters. The propane cost is assumed to be $2.00 per gallon. Current propane prices are lower than this but $2.00 is the approximate average of the last four heating seasons in Wisconsin. The greenhouse is assumed to be located in the Madison, WI area.

43) The first option is to purchase a residential/shop pellet stove that will be operated mostly at night to supplement the propane heating system. The stove does not have a thermostat so it will operate continuously at a constant feed rate. The 70,000 Btu per hour stove will cost $4350 to install and has an efficiency of 80%. It is assumed that bagged wood pellets will be used at a cost of $210 per ton or $4.20 per 40 lb bag.

44) Option B will use a thermostatically controlled pellet furnace that has a heating range of 10,000 to 160,000 Btu per hour. The heated air will be ducted directly into the greenhouse over the benches. It will be located at one end of the greenhouse. The $6030 installed cost includes a 14 bushel fuel bin. Bagged wood pellets will be used to avoid the expense of purchasing a bulk bin. Pellet cost is assumed to be $4.20 per 40 lb bag. In both Option A and B, fans will need to be used to distribute the heated air in the greenhouse.

45) Option C uses an outdoor wood boiler (OWB) that qualifies under the EPA Phase 2 emission standard. The average capacity over an 8 hour burn period is 160,000 Btu per hour. The heat will be distributed into the greenhouse using two water to air heat exchangers located in the center of

the greenhouse. A pump to circulate the heated water from the OWB to the heat exchangers will be thermostatically controlled. The installed cost of the boiler, piping and two heat exchangers is estimated at $13,050. The boiler efficiency is assume to be 75% based on EPA data. I'm assuming the grower has a wood lot and will harvest his own wood at a cost of $150 per cord assume labor, equipment and repairs.

46) Option D is the same as Option C except the OWB is a non EPA qualifying boiler model with an efficiency of 40%. The installed cost is $11,634.

47) A computer model was used to estimate the monthly greenhouse energy use using monthly weather data. The slide shows the heating need per night and the estimated hourly heating requirement. On average the day time heating need will be met with the solar gain except during the month of February when the average day-time heating need will be 12,800 Btu per hour. Based on the average hourly heating need, options B, C & D should be able to meet the heating requirements on average but some days and nights will require more energy than the average need.

48) Based on the computer model, Option A can provide 100% of the heating until the outdoor temperature falls below 40°F. It was estimated that this option can replace 50% of the propane use. Options B, C & D can theoretically provide all of the heat down to 10°F. Based on average these option should be able to replace 100% of the fuel but in reality it is estimated at 20% of the heat will be supplied by propane.

49) Based on the options used, option A and B have the shortest payback. Options C & D have a longer payback despite using a value for wood at less than market value of about $200/cord. The payback is very sensitive to the cost of propane in relation to the biomass fuel cost. Six years is likely a longer payback than many would like but we have to consider that petroleum prices are expected to increase when the current economic recession eases.

50) Second Case study is a year round grower / garden center located near Madison, WI. The T-shaped, gutter connected greenhouse covers about 33,000 square feet. The wall and roof are glazed with double poly-film. The heating system consists of in-floor heating with unit heats for peaking on cold nights. The baseline energy cost is $171,162 for 85,581 gallons of propane gas at $2 per gallon.

51) An option to use outdoor wood boilers was considered until it was estimated to require 389 cords of wood. The grower didn't feel he had the labor to procure this amount of wood nor space to store it and he had very limited "free" wood available. Therefore this option was excluded from consideration.

52) Based on the table the average heating requirement for highest heating requirements is 2,600,000 Btu/hour for January. If the heating system is sized for the average then any time temperatures fall below the average temperature the heating demand will exceed the values in the table.

53) If 100% of the heating is to be met, than the heating system will need to be size for the coldest likely temperature even though it may only occur a few hours per year. The recommended design temperature for Madison is -20°F. This value can be found in the standards publication, on the National Greenhouse Manufacturers Association web site under "downloads". Using the computer model, the heating requirement will be 4.2 MBtu per hour.

54) Option A - Meet 100% of heating requirements. The equipment dealer recommended two pellet boiler sizes, a 3.5 MBtu/hr and a 1.5 MBtu/hr. Having two sizes allows the one that best fits the heating requirements to be used; smaller boiler in spring and fall and both boilers during the mid winter period. This allows the operating boiler to run continuously versus going burning out because of low demand periods. It is estimated that 5% of the heating needs will need to be covered with gas heaters. The installation cost is $291,000 which includes bins for bulk pellet storage.

55) Option B uses two pellet boilers (2.5 MBtu/hr and 1.0 MBtu/hr) to meet the average heating requirement. The smaller boiler will be used during the spring and fall and both boilers would be used during the mid winter months. It is estimated that 20% of the heating needs will need to be covered by gas. Bins for bulk deliver are included in the $211,000 installed cost.

56) This is an example of the type of equipment and setup being proposed. The pellets are stored in the white bin and augered to the boiler as demanded. To the left of the boiler is an ash cart that the ash is augered into as it is produced.

57) Conclusions: Either option is a very good investment due to the short pay back time. If energy conservation measures such as thermal curtains were installed before considering a biomass heating system, the capital cost of the biomass system would be reduced and the annual cost of fuel as well. Typically energy conservation measures will have a faster return on investment than switching to renewable energy sources.

58) Here are a few references that may be useful.

Biomass Energy for Heating Greenhouses – looks at the types of fuels, equipment, and consideration for implementing biomass as a heating source.

Biomass Heating in Greenhouses: Case Studies – looks at the biomass heating option, equipment and economics for a 30 x 96 hoop greenhouse and a large gutter connected greenhouse.

Pellet Fuel Institute – They provide educational materials, list of pellet manufacturers and industry standards.

Energy Self Assessment Calculators – One of the calculators allows the comparison of different fuel types.

Focus on Energy – Wisconsin's Energy program – they have factsheets and installer lists for biomass systems.

Burning Shelled Corn – A website developed by Pennsylvania State University with information on renewable fuels.

Wood Pellet Heating - A Reference on Wood Pellet Fuels & Technology for Small Commercial & Institutional Systems, Published by Massachusetts Division of Energy Resources

59) Contact information.