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Renewable Energy Systems for Greenhouse Heating: Six Case Studies

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Biodiesel Production from Waste Vegetable Oil for Greenhouse Heat
Cate Farm - East Montpelier, Vermont

Richard Wiswall and Sally Colman own Cate Farm in central Vermont. They produce vegetables, herbs and flowers on 22 acres, and bedding plants and greenhouse tomatoes in seven 21’ by 96’greenhouses. Biodiesel made from waste vegetable oil is used to heat the greenhouses as well as power two diesel tractors and one car.

When he decided to switch to an alternative fuel, Richard had the choice of converting vegetable oil to biodiesel that could run in his existing equipment or modifying the existing equipment to use straight vegetable oil. The number of locations where he required the fuel made it simpler and more cost-effective to transform the waste oil so it could be burned in existing equipment rather than changing and maintaining multiple pieces of equipment.

Making biodiesel is not as complex as rocket science, but some knowledge of chemistry is helpful. There are several different options for the ingredients and procedure (see the references at the end of this section). Richard uses a base of oil (triglyceride) combined with methanol in a reaction catalyzed by lye (sodium hydroxide) and heat. This process yields glycerin (a byproduct) and methyl esters (the biodiesel).

A 55-gallon metal drum is used for mixing his biodiesel batches. In the drum, Richard drilled two holes to draw off its contents: one opening at the bottom (for glycerin) and one midway up the barrel with a small pump (for methyl esters). An electric hot water element and thermostat are used to heat the ingredients inside the barrel; a paint mixer attached to a small motor mixes them.

Making biodiesel begins with collecting fryolator oil from area restaurants. Non-hydrogenated oil is best, with canola and soy most sought after. Oils changed weekly at the restaurant are preferred to often-reused oils. Richard has established reliable weekly pick up schedules with restaurants throughout the year. It’s important to arrive reliably on a regular schedule throughout the entire year to satisfy the restaurant’s needs- otherwise they may return to their more familiar waste haulers.

Once the restaurant oil arrives at Cate Farm, it sits in the sun or on heated concrete slab in plastic jugs while the particulate matter settles out. Once particulates have settled, Richard pours 40 gallons of the oil over a screen into the 55-gallon drum.

He mixes the oil slightly and draws off a sample to take a titration for determining how much lye to add (see resource list for titration instructions). The greater the amount of free fatty acids in the waste oil, the more lye is required as a catalyst. The oil is then heated to 130 degrees.

Meanwhile, Richard mixes lye with 8 gallons of methanol in a container separate from the oil drum. He is extremely cautious with the methanol, wears protective clothing and eye protection and measures it in the open or in a well-ventilated shed. The lye dissolves in the methanol to produce sodium methoxide.

Finally, Richard adds the lye/methanol mixture to the heated oil and mixes it for one hour, then allows the mixture to sit overnight. The next day he can draw biodiesel from the top 4/5 and glycerin from the bottom 1/5. The biodiesel might sit for awhile before pumping to settle out any residual glycerin. If Richard wants to use it in his diesel vehicles instead of the furnaces, he will wash it with water mist to further remove any impurities. The glycerin goes to the compost pile for now, but with more processing, could be burned or made into soap as other options.

Cate farm has seven greenhouses with oil fired furnaces, as well as oil furnaces in the house and shop. There are several different brands such as Sundair and Sebring, but all have Beckett oil burners. In order to successfully use biodiesel in these units, Richard takes a variety of precautions.

To prevent any residues from entering the burner and clogging the nozzle he adds a 5-micron spin-on cartridge filter in the fuel line, right before the burner. Then he removes the air tube and spray paints the inside with high-temperature silver paint.

This compensates for the lower luminosity of the biodiesel flame compared to heating oil, thus 'tricking' the cad cell into thinking there's a brighter heating oil flame and not shutting the burner down. To make a fine mist of biodiesel that burns well, Richard increases the burner oil pump pressure from 100 psi to 150 psi, and then compensates for that added pressure by installing a small nozzle and adjusting the air bands to get the proper air intake. These steps may require the assistance of an oil burner technician.

In the greenhouse, 275-gallon fuel tanks hold the biodiesel and are kept inside to make sure the fuel flows well when it's cold outside. At the end of the heating season, Richard makes sure to leave the tanks full so as to minimize the potential for fuel breakdown due to exposure to oxygen. Next year, before starting a furnace for the first time, he drains off the bottom gallon or so of fuel from the tank in case any residues have settled out.

Oil furnace with a Beckett burner in a tomato greenhouse.

Richard runs straight biodiesel (B100) in his tractors all season long. Over the winter, he needs only one tractor for limited use and he switches to regular diesel to avoid any low temperature operating problems. Come April, when tractor use increases, he switches back to B100. However, he runs B100 in his home and shop furnace all winter long without problem since the fuel tanks are inside.

A rough estimate for Cate Farm's biodiesel material costs (not including labor) is about $0.85 per gallon. The methanol is the most expensive ingredient and it costs $3.80 per gallon. Richard makes about 20 gallons of biodiesel per hour, and he produces a total of 2000 gallons per year. Including labor for pick-up, handling and processing at $20/hour, the actual cost of his on-farm biodiesel is $ 1.85/gallon. Compared to purchasing 2000 gallons of No. 2 heating oil at $3.85/gallon, his annual savings is $ 4000.

The fuel is kept in a minimally heated storage shed until needed. Drums are moved to the greenhouses by tractor or hand truck, and transferred into the fuel tanks with a rotary hand pump. About 75% of the bio-diesel is burned in the greenhouses in winter and spring, the rest in the two tractors and car.

Waste Vegetable Oil for Heating Greenhouses
Old Athens Farm – Putney, Vermont

Mike Collins and his wife Rebecca Nixon own and operate Old Athens Farm, located in southeastern Vermont. Fresh market organic vegetable and berries are grown on 2 acres, and their 10,000 sq. ft. of greenhouses produce tomatoes, cucumbers, lettuce, eggplant, and other crops. Sales are to local farmers' markets and wholesale accounts.

The three greenhouses require heating from late winter through late spring, at different times depending on the crops they hold. In the past, over 3,000 gallons of number 2 heating oil was required, but over the years Mike has worked to reduce his heating costs by installing alternative energy systems, including a homemade wood boiler. In 2005 he started using waste vegetable oil as a fuel and by 2008 it was his primary heat source, and he burned approximately 4,000 gallons.

In 2005, Mike purchased two Clean Burn CB 3500 waste oil furnaces (www.cleanburn.com) for about $5,000 each from Sandri Oil (www.sandrisunoco.com) in Greenfield, MA. These units retail for about $7,600 now. They are rated at 350,000 BTUs maximum and are designed to burn waste motor oil but have performed satisfactorily with waste vegetable oil, although they require frequent maintenance to keep them running consistently.

"If you get one of these units I wouldn't throw out your old heater," says Mike, "You might need it as a back-up." Installing the units cost about $1,000 each for the plenum to distribute the hot air, the stove pipe stack, copper fuel line, and fittings.

After he collects the waste vegetable oil from local restaurants, mostly in 5-gallon plastic jugs, Mike pours it into 275-gallon plastic totes and allows it to settle outdoors. Later he pumps oil from the top of these totes into 55-gallon drums, leaving behind the sludge that can cause problems in the heating system. These drums are later moved inside and the oil is allowed to settle once again before being pumped into the 275-gallon 'end tank' that feeds the furnace. The sludge is burned in Mike's wood-fired boiler that is used to provide ground-heat.

The Clean Burn system delivers oil under pressure from the tank to the burner, unlike conventional fuel oil furnaces. A pump sucks on top of the end tank sucks up oil and pushes it at

8.5 psi through the fuel line to the furnace. There is a screen on the pick-up, then a stainless steel filter, and another filter in the pump. Mike says some sludge still comes through the line once in a while. He cleans the filters about twice a year; more often if any waste oil is poured directly into the end tank without settling. A vacuum gauge in the line after the filter tells if it's getting clogged.

Once the oil gets to the burner, a compressor forces it through a nozzle and a spinner head that vaporizes it for combustion. A squirrel cage blower moves air into the combustion chamber and provides a forced draft. You can adjust the amount of air going into the chamber and thus the flame length. "You want it about 30 inches long, all the way to the back of the burn chamber without touching the back of it" says Mike, "but you don't want the flame to sparkle with unburned material, so you might have to make it a little shorter and hotter. The manual tells you how to make these adjustments."

One problem Mike has had with these units is clogging on the inside of the burner as a result of the 'shellac' that forms from the waste vegetable oil, gunking everything up. After the system went down several times, usually in the middle of the night, Mike now performs preventative maintenance by cleaning the spinner head and nozzle every week, or after 75 hours of operation. He scrapes off the gunk with a knife and washes parts in hot water, which takes about an hour.

The nozzle and fan inside the burner tend to gunk up and must be cleaned regularly.

Mike also keeps spare burner nozzles on hand. This has avoided sleepless nights tending the furnace, although once the pump itself failed and there was nothing he could do about that on short notice.

Most of the waste vegetable oil is collected during the growing season, as part of Mike's vegetable deliveries, so extra trips are avoided. The oil comes from restaurants within a 10-mile radius of the farm. Mike only works with restaurants that change their fryolater oil frequently, so it is relatively clean, and that use unhydrogenated oil, so it remains a liquid at relatively cold temperatures, down into the 20's F. However, when the oil is that cold it is dense, so an electric barrel heater is needed in order to move it around.

Collection of the waste oil takes about 100 hours of additional labor and management per year. The heaters require about 2 hours of maintenance each week during the peak heating season. This results in extra labor costs between $1,000 and $2,000 annually depending on hourly labor rate. "Right now I don't have to pay for the oil, but I figure it costs me about 50 cents a gallon to handle it, and another 50 cents a gallon in system maintenance."

The oil to be fed into the heater must stored be inside so it is warm enough to flow easily. Mike keeps about 900 gallons of oil inside during the heating season.

Assuming that the waste oil costs $1/gallon to deal with, and that it replaced 3,000 gallons of fuel oil, Mike's savings in winter 2005-06 was about $3,600 compared to paying $2.20/gallon for No. 2 oil. In winter 2007-08, with the cost of fuel oil at $4.00/gallon, the savings was about $9,000. The additional cost of the oil furnaces also has to be considered, amortized over their life expectancy of more than 10 years, but "the payback is pretty quick" says Mike.

The wood-fired boiler that's used to provide hot water for heating the soil can also be used to heat a couple of the greenhouses in an emergency. In addition, Mike keeps a back-up fuel oil furnace in another greenhouse.

One constraint to this system is the limited availability of high quality waste vegetable oil in many communities. Mike works closely with just a few small family restaurants, and they are dedicated to managing and saving their oil for him to use as fuel, in part because of their good relationship as buyers of his produce. In the beginning though, restaurants have to be trained about the quality and handling of waste vegetable oil to be used as fuel.

"This system is worth it for me because I have a reliable supply of good oil based on solid relationships" says Mike. "But you need to think twice about it because the supply is limited and demand is growing. Grease-car hippies and others are after it. It's pretty depressing when you go to pick up your oil and someone's stolen it."

Waste Wood Chips for Greenhouse Heat
Stow Greenhouses - Stow, MA

Fred Green is the owner/operator of Stow Greenhouses in Stow, MA, which has 35,000 sq. ft. of greenhouse space that is used to produce cut lilies for the wholesale market, year-round. The greenhouse must be maintained at 65 degrees F, and additional energy is needed to melt snow off the gutter-connected roof in winter to keep it from blocking sunlight. Prior to converting to a biomass heating system, the operation used 30,000 gallons of heating oil annually.

Asiatic and Oriental lilies are planted and harvested all year long at Stow Greenhouses, for sale to the wholesale cut flower market.

It became clear to Fred that the rising price of heating oil posed a risk to the profitability of his business long before oil prices hit their historic high levels. Back in 2004, when he started investigating alternative heating system options, he got the idea of using waste wood from a nearby nursery operation. The nursery owner was allowing his commercial customers to dump wood chips they collected from their jobs at no charge, so they didn't have to pay to take them to landfills. The nursery would then sell these chips to an electric power plant.

Clearly there was a good supply of waste wood and wood chips in the western suburbs of Boston, but Fred had to decide not only what equipment would be used to burn the wood, but also what was needed to handle it. He visited a dozen different commercial wood burning installations in the eastern U.S. and Canada to get a better understanding of his options. Despite the rigor of his initial research, there was still a lot of trial and error until a satisfactory system was in place.

The first unit that was installed at Stow Greenhouses in 2005 was a 1.5-million BTU unit from Advanced Recycling Equipment, which was designed to burn sawdust but appeared suited to wood chips as well. The system presented several problems that Fred worked to resolve, before finally deciding to sell it.

This 2 million BTU Advanced Recycling unit that Fred bought for $100,000 proved problematic, since it was really designed to burn sawdust, not waste wood chips. He eventually sold it.

First, the hot-water heat exchanger wasn't big enough, so even at full capacity it was necessary to burn oil as well as wood chips to maintain the greenhouse at the proper temperature in the dead of winter. A larger heat exchanger fixed that problem, but then there were problems with the 45-foot belt conveyor that fed chips into the boiler. The belt wasn't designed for the weight of the chips, and as a result it tore due to the friction between the belt and rollers. Sometimes chips would wedge in between the roller and the belt, causing it to jam.

Purchasing a screw auger from a company that sells used saw mill equipment solved that problem. However, the irregular shape of the chips Fred was using – especially longer pieces of branches that made it through the processing stage – caused another problem. These would cause the flow of chips to 'bridge' and create a dam that shut down the supply to the boiler, causing it to shut off. Eventually Fred settled on a rail-type system to deliver the chips into the furnace.

Fred decided to set up a system that would handle the fuel he had. He purchased a used Conifer furnace manufactured by Hern Iron Works (www.herironworks.com/conifer.html) which makes a range of furnace sizes. Fred got the 3 million BTU model 49-S for about $17,000, and connected it to a Kewanee wood-fired boiler (Kewanee is no longer in business but used models are available, as are new parts at: www.ciciboilers.com/parts_kewanee.htm) and a 3,000 gallon water tank.

Buying used components, and then making several modifications to the furnace, like adding a new door for about $1,000 and replacing the internal 'steps' that guide the flow of fuel, Fred was able to set this system up for about $30,000. He also installed up a fan to pull rather than blow air through the furnace, since that does a better job of forcing oxygen through the chips, leading to better gasification. And, he installed a special 'screw' that is used to force chips into the furnace in the event that a bridge forms at the end of the auger.

The 3 million BTU Conifer furnace heats water in the Kewanee boiler; valves are set to control how much of the hot water is sent to heat the greenhouse or stored in the 3,000-gallon reservoir.

Metal rails, bottom left, move chips that are dumped in the bin forward toward the furnace, where a smaller rail system then carries them into the furnace for combustion.

There are challenges with using waste wood versus purchasing a supply of relatively uniform wood chips from a sawmill. You have to be able to deal with branches, stumps, construction debris and other contaminant such as plastic and metal trash that can come with your 'free' fuel supply. Fred's processing system separates out the worst of the contaminants, but he needed a combustion system that could handle irregular-shaped pieces of wood and a small amount of other debris.

Fred holds the type of long wood chip that used to cause 'bridging' on his roller delivery system. Now that he uses metal rails to move chips this is less of a problem.

Keeping the furnace running, and running hot, is important to getting clean combustion and avoiding the small amount of smoke that's created when the furnace is cold and then re-started. At full-bore the temperature inside the furnace is about 2,000 degrees F, which is hot enough to cause near-total combustion and thus a minimum of pollution, including particulates. (Particulates are a big problem with some outdoor wood boilers that do not operate consistently at high temperatures.) When demand for heat is low in the greenhouse, Fred likes to keep the furnace operating at no less than 1,000 degrees in order to avoid any smoke. The problem is – what to do with all that heat?

The 3,000-gallon tank of water is Fred's latest innovation. By connecting it to the boiler and his hot-water heating system, he created a large reservoir for excess heat that is not needed in the greenhouse during the day, but will be needed at night. Fred also uses some of this excess heat to run a large steam sterilizer that treats his coir potting medium so it can be re-used again and again to grow the lilies. Further, to control Botrytis in the greenhouse, Fred has plenty of heat for driving off humidity when necessary. When there's simply too much heat that can't be used, the reservoir simply boils off water that is later replaced. Says Fred: "it's unbelievable that people are paying 4 and 5 dollars a gallon for oil, and we have so much heat we can't get rid of it."

It's true that Fred has a seemingly endless supply of free fuel – but it comes with a price. He's got to process the chips by separating out the trash and grinding before storing the finished material to keep it dry. He allows landscapers, arborists, phone line and power line crews to drop off their wood chips for free, but he doesn't demand that the chips be of any particular quality. "You get all kinds of junk in with the chips – tools, barrels, trash – but we don't look a gift horse in the mouth." The unprocessed chips are bucket-loaded from the designated drop-off area to a nearby location where large objects are removed before they are run through a Sundance hammer-mill grinder. Fred got bought this $75,000 unit used for a fraction of that cost on e-Bay. It can re-grind 30-40 yards of chips an hour, and works well with the bucket loader.

Hammermill grinder and poly-covered storage that are used to process and store the wood chips.

For the first 3 years of using waste wood chips as a fuel, Fred didn't bother to grind it, he just used a screen to remove the larger pieces. But that left a lot of unusable material due to its size or shape, and some long but thin pieces of wood would get through the screens and later jam the delivery into the furnace. So now, he grinds everything that will be burned. And if a small amount of plastic debris gets into the chips, it's no big deal, given the high temperature that the furnace operates at.

Dry wood chips generate more BTUs per cubic foot than wet chips, and they make less smoke. "We didn't keep the chips dry the first winter, and that was a big mistake" says Fred. He set up a 28x80 wood structure covered with a layer of clear poly to store the chips and keep them dry. It holds 1,200 cubic yards of chips, which is enough to get through the coldest months, but only about half of the 2,500-3,000 yards that will be burned annually. The remainder is stored under plastic tarps. When there's an excess Fred can sell the chips to landscapers.

Moving the chips has also involved a learning curve. "First we had a 30-hpNew Holland with a bucket, but the front axle broke; then we had a 50-hp Kubota, but the pistons on the bucket went and the tires came off the rims, and we finally realized that tractors were not designed for this type of continuous 'front end' work so we bought a 50-hp Cat loader for $38,000 and it has worked well. Burning is easy, boilers are easy – handling all those chips is a challenge."

Outdoor Wood Boiler for Greenhouse and Farmstead Heat
Blais Farm – Springfield, VT

David and Jennifer Blais grow 38 acres of vegetables, strawberries, flowers and herbs along the Connecticut River in Springfield, Vermont. They market through their farm stand and to nearby supermarkets, other farm stands, and a wholesale distributor. Blais Farm has four plastic-covered Quonset-type greenhouses used for bedding plant and greenhouse tomato production, totaling 8,000 square feet. Since 2003, these structures as well as a 600 square foot barn (used for equipment storage and vegetable packing) and a 1,200 square foot home have been heated with an outdoor wood boiler (OWB). Prior to that, they used about 2,500 gallons of #2 heating oil annually to heat these structures.

Outdoor wood boilers burn firewood and are located outside of the structures they are heating. The formal name for an OWB is "outdoor wood-fired hydronic heating appliance." They are also known as outdoor wood furnaces and water stoves. Conventional OWBs consist of a firebox surrounded by a water jacket, a weatherproof cabinet and a short smokestack.

The outdoor wood boiler at Blais Farm is from Central Boiler, Greenbush, MN (www.centralboiler.com). It is one of largest models they make, the Classic CL7260, with a 764-gallon water reservoir and a firebox that measures 72x60x40 inches. It is located well away from the house and road, at the edge of a field by the greenhouses. Insulated underground pipe carries hot water from the furnace to the various structures and into heat exchangers that release the heat.

A system of valves and circulator pumps is used to create 'zones' that direct the hot water to the locations where heat is needed. The house and barn is one zone, and the greenhouses are another, which is then split up into sub-zones to separate the hot water flowing to them. The first greenhouse is started around March 1^{st}, the other are not heated until April 1^{st}. The OWB has automatic controls that regulate the air flow and operation of the optional blower. David programs the water temperature to the hottest level, 195 degrees F, when operating the greenhouses, to provide sufficient heat.

During the height of the heating season, the OWB burns a cord a night on the coldest nights. David loads the boiler full with 1/3 cord of wood at about 4 pm, then again at 10 pm, and once more at about 2 am. Fortunately, this does not go on for too long. "You get a little ugly when you don't sleep at night" says David.

The boiler cost about $9,000 and the total system cost was $25,000. David bought the system from a local OWB distributor who was not able to provide much technical assistance, so he had to design his system and install it himself, working with a local plumber. They made a series of changes to the system over time to make it work better. “It was ‘farmed-up’ so it still needs improvement” says David.

Hot water from the OWB is delivered to heat exchangers in the greenhouses.

In hindsight, David would have used a better-insulated underground pipe even though it costs more. He used pipe with an R-40 insulation value from the furnace to the greenhouse, and that works well, but the pipe that runs from the furnace to the house is only R-12, and that results in a 20-degree drop in water temperature over that run. The heat loss from that R-12 pipe sometimes melts snow at ground level even though the pipe is buried 4 feet deep. David plans to dig up that pipe and replace it.

Other improvements to his system would be larger circulating pumps to move the hot water more effectively, and a better system of heat exchangers in the greenhouses.
Because David works a logger in the winter, he has access to low-cost wood as scraps left over from his logging jobs or unwanted logs purchased directly from landowners for $10-$20 cord. Otherwise he has to buy logs, which have increased in price a lot in recent years. When he bought the OWB several years ago, a truckload of logs, about 7 to 8 cords, was $400-$500; now the cost is about $1,200.

David has what is needed to process his low-cost logs into fuel, including a skidder, log splitter, chain saws, dump truck, and some extra farm labor. He uses 40 to 50 cords of wood a year in the OWB.

David feels that his OWB burns pretty clean because he runs it hot, and he tends to burns a 50/50 mixture of hardwood and softwood. The unit smokes when it is first started up but not after that unless it is fed with green hemlock or pine. David does not like to use really dry wood because it burns too fast.

According to the EPA, many older models of OWB emit high levels of fine particulates in the smoke they generate, even when operated properly. If OWBs are used to burn wet or treated wood, scrap, or garbage, they generate even more smoke and emit additional toxic chemicals. Short chimneys and reduced draft of OWBs can also cause smoky conditions near ground level. These factors raise concerns about health risks from OWBs.

As a result, many states have regulations associated with OWB use, so be sure to check with your state before buying and installing an OWB. A standard method to test and evaluate the emissions and efficiency of OWBs was established in 2007 by the U.S. EPA, and many new boilers have been designed to burn more clean and efficient. Outdoor wood boilers with emissions equal to or less than 0.60 pounds of particulate per 1 million BTU of fuel burned qualify for the EPA Outdoor Wood-Fired Heater program, see www.epa.gov/woodheaters.

When the system was first installed, heating oil cost $2.20/gallon, so 2500 gallons cost $5,500. Estimating David's wood cost at $50/cord in materials and labor, and assuming 50 cords were consumed, his annual fuel savings was $3,000. At that rate the payback was just over 8 years on the OWB heating system. This past year, heating oil cost $4/gallon, so David's annual fuel savings was $7,000. Payback on the heating system would be 3 ½ years at that price.

"This system is not the future," says David, "it's a band-aid until something better comes along. But it's helped keep us in business. I wouldn't do this if I didn't have a skidder, and the bobcat do the logging jobs. And I'm not sure I want to be splitting 40 cords of wood and feeding the boiler when I'm 70 years old!"

Wood Gasification and Hydronic Heat for Greenhouses and Farmstead
Vermont Herb and Salad Company - Benson, VT

Heather and Jared McDermott are owner/operators of Vermont Herb and Salad Company in southwestern Vermont. They grow organic salad greens, spinach and culinary herbs that are marketed to regional distributors, grocery stores, and some restaurants.

Their farm is 100 acres, with about 80 acres in woodland. There are two 30’ x 90’ heated greenhouses that are used for starting seedlings and winter greens production, as well as four 30’ x 100’ unheated greenhouses used for in-season production of leafy greens. There is a 500 sq. foot packing house, a 1000 sq. foot storage area, and a residence just under 2000 sq. feet in size. All heated areas are now fueled by wood from the farm’s woodlot.

At the core of the heating system is a Sequoia Paradise model E3400 outdoor wood furnace. It has a 320,000 BTU/hr. rating, with a forced downdraft gasification design. The firebox is 44" deep x 48" tall x 32" wide, holding 39 cubic feet of fuel. The unit stands 60" wide x 72" long x 94" tall, has fiberglass insulation and holds 210 gallons of water. (Sequoyah Paradise, Mauston WI, www.wdheat.com/index.htm). The purchase price was $11,500.

Before installing the furnace and the rest of the heating system, the McDermotts renovated the old dairy barn on the property, which is adjacent to the heated greenhouses and also holds the storage and packing areas. Renovation included pouring a new concrete floor at ground level, for about $4,000, and making improvements for better accessibility and handling cord wood such as installation of a garage door.

The furnace is located inside the renovated barn and is vented outside with metal-bestos pipe; as it would be in a conventional basement installation to heat a big house. “What we initially did after that is a little unique.” says Jared, “We connected the unpressurized hot water in the furnace to a set of large tanks, which then collect and exchange heat with a pressurized hot water system. The pressurized system delivers hot water to our greenhouses, packing area, and home, where it is released by air-to-air heat exchangers or radiant floor heat.”

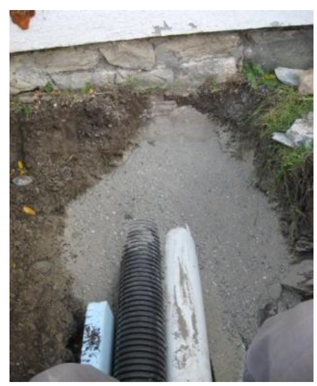
The 215-gallon water reservoir of the furnace was plumbed into 4 unpressured 275-gallon steel tanks totaling 1,100 gallons of hot water storage. All the tanks were connected, so they were really one large thermo-accumulator, allowing the furnace to run all day long even when the greenhouses are not calling for heat.

Initial system with tanks

"We initially thought we wanted around 1000 gallons of water to accumulate heat for a 300,000 BTU/hr. system. But that turned out to be a bad move. When heating is needed, the houses need it most of the time. Additionally, we found that the volume of hot water storage was not enough to really provide adequate overnight heating.

Revised system with tanks replaced by heat exchangers.

The desire to store hot water during the day eroded our ability to simultaneously heat the houses early in the morning and early in the evening when the sun went down. So we ended up taking the hot water storage tanks out all together. In place of them we now have two heat exchangers ($350 each) which serve to connect the low and high pressure systems. We load the fire box at the end of the day and it carries the load through the night."



Pex

The pressurized, heated water is then delivered to different heating zones through insulated Pex tubing. The diameter of the tubing varies depending on the amount of heating that is needed: 1.25-inch tubing runs to the greenhouses, 1-inch to the residence, and 0.5-inch to the packaging facility.

"We built the piping system ourselves since insulated Pex tubing was back-ordered and we didn't want to wait. We used regular Pex for the unpressurized side, but purchased Pex with an oxygen barrier for the pressurized side of the system to reduce the amount of air getting into the system which could cause corrosion. Then we used R-10 foil wrap to cover each pipe individually. That provided a thermal break between the two pipes, to separate the hot and colder water and avoid any heat exchange.

"We wrapped the two pipes together with R-20 foil wrap and slid them inside 4-inch drain pipe. That was easier than I thought, but wrapping the Pex itself was a challenge since it isn't flexible when it is cold. All the pipe was then buried 3 to 4 feet deep and enclosed in 2 inch blueboard (R8). So far, we've had no noticeable temperature drop in the 100 feet of distance from the tanks to the house, which is the longest run."

Two Dayton 104,000 BTU/hr. water-to-air heat exchangers release heat into each of the greenhouses. They have 1/3 h.p. motors running the fans, and cost $600 each. Unlike combustion heaters, they can run continuously without problem, so their relatively low BTU/hr. rating for a 2500 sq. ft. greenhouse is a bit deceptive. The heat exchangers run off programmable thermostats that can be set for different nighttime and daytime temperatures.

"So far, in both greenhouses we can easily maintain 40 to 50 degrees above outside air temps. For our crops under low light condition, we need to maintain 50 to 55 degrees as a minimum air temperature. We don't really want a lot of heat during the winter because the crops just stretch and get small leaves, but more heat once in a while does help reduce humidity to manage diseases. Before we turn on the furnace at night, the humidity can be about 95%, then it goes down to 55% after the system runs all night. We do have an older 150,000 BTU/hr. oil backup furnaces in one of the greenhouses, just for emergency purposes."

"We also have some bench heating. When we replaced a roof on a barn several years ago, we salvaged the old metal roofing from it. This makes a nice sheet under our radiant bench heating system. It allows water to drain off, but also acts as a radiant reflector to direct the heat to the plants. This system works until about 10-15 °F outside temps and then we need the forced air system."

"In our home we already had a hot water system heating system, so we plumbed straight into the existing system. We did the same thing in the packing house, where we had radiant floor heat; we just removed the heater and connected to the new system."

Jared in front of one of his home-made bench heaters made with salvaged metal roofing and PEX tubing.

“To move water around in our system we chose Grundfos multi-speed 1/10 horsepower circulator pumps (http://www.grundfos.com/web/homeus.nsf). There are two pumps feeding the tanks from the furnace, then each of the three water-to-water heat exchangers has an unpressurized pump feeding it. On the pressurized side, each tank has a circulator pump feeding its zone, so there are eight pumps in total. Because they are multispeed you can adjust for the demand of each heating each zone. These pumps can go from 9 gallons a minute to 30 gallons a minute so they provide a lot of flexibility.”

“One benefit to the unpressurized side is that it can never get too hot; it would just boil over. I tried turning up the aquastat to 190 degrees, but with no real benefit; the tanks didn’t get a lot hotter, like 180 degrees, and stay there. With the aquastat set at 175 degrees the tanks run at 150 to 170 degrees. Turning up the system just seems to use more wood without heating the water up a lot.”

Grundfos multi-speed pumps. The switch on the center left of the black cover allows selection of one of three motor speeds resulting in variation of the flow.

“It was sort of surprising that our water temperatures run a little cooler that you would want in a commercial oil or propane hot water system. We can deal with that because we bought large heat exchangers, so we if we need to move a little more water through the system to get the same amount of heat released, that’s OK. We basically have an endless supply of 150 to 170-degree water.”

“One of the main reasons we decided to put this system in is that we have access to wood on our own property. We recently acquired a neighboring sugarbush of about 80 acres, and it hasn’t been managed in 40 or 50 years, so there’s a lot of wood to be removed for many years.

We already have the equipment like a big tractor, chainsaws and such, and we have family and friends that have experience in the woods as loggers or tree service people – it does take skill, you don’t just go cut wood. So we put a crew together this summer and got about 30 cords organized in the landing area in 4 days. If I had to guess, it might cost us $50 per cord with all our expenses. If we needed to, we could also buy truckloads of logs for about $16/cord locally, and then process them.”

“There is no such thing as seasoned, dry wood when it is left outside. So we have converted an old hay barn to be our wood shed. We store 30 cord in the barn and get it bone dry in 9 months. The barn has excellent access for tractors: Our goal is to never lay a hand on the wood.”

“We have a forklift, so we bring the logs right down to the furnace area; with the concrete floor in the old barn we can drive right inside so we aren’t out in the elements trying to process the wood or load the furnace. We cut everything to about 80 inches so it only needs to be cut once more; we don’t need to split it to load the furnace because it has such a large box.”

“When we were researching furnaces there were a couple of other units we liked, but they all had pretty small wood boxes. Tarm systems had a good reputation, Wood Gun had some really nice central heating systems, and Blue Forge also looked interesting. They were all in the same price range, but they all had small wood boxes; the one we got has a wood box-- and a door-- about twice the size.”

“I’ve heated with wood a long time and knew that I did not want to become a slave to feeding the furnace; that was an important factor. The idea is to load up once or twice a day; we do not need to load in the middle of the night. When it’s really cold we can still load every 12 hours. Since it does have a big burn box it does use a lot of wood when it’s cold out, about half a cord a day. When it’s in the 30s to 40 outside we only load up a little in the morning and then load up more at night to conserve on wood use. “

“We went into this project thinking we could easily modulate the heat to meet our load by using the hot water storage tanks as a buffer. It turns out it is probably easier to modulate your load (i.e. which houses are heated when) to keep your wood boiler running at its peak as long as possible. We’re adding a third heated house this coming heating season at strategic times to keep the boiler running hard, where it likes to be.”

“The furnace is so big and burns so hot that you don’t need to relight it, even after 12-16 hours you can still throw some small branches in and turn on the forced draft fan and it relights. But wood is not oil; oil is easy. It may cost a lot but you just write a check and a guy pulls up in a truck and delivers millions of BTUs to your property and the heat comes on without you even knowing it. We have a lot of wood in Vermont, but it may not be practical for most people.”

“The total cost of our system was about $30,000--not including improvements that made life easier like a concrete floor and a walk-in basement interior. We also paid a lot for metal items, since copper and steel were at all-time highs when we did this project. There were several thousand dollars in copper and steel fittings. There was a couple thousand dollars in Pex tubing and several thousand dollars in plumbing supplies. We also overbuilt the system in some ways but that’s better than wishing you had done it differently later on.”

“We are a small business, and controlling our heating costs was important. This system gives us a lot more flexibility; we can pay ourselves to maintain our forest while we’re collecting our fuel. Plus, the cost of buying oil at unpredictable prices can be backbreaking, especially in winter when our cash flow is less. We’d easily be using 1200 gallons of oil each month throughout the 4 months of winter without this system. So at $3.00 a gallon we’d be spending $3600 a month whereas now we’re using about half a cord a day or $750 of wood a month. From mid-October to mid-November and mid-March to mid-April we use half as much fuel, so overall we’re saving about $14,000 a year in fuel costs.”

“We did get some help from grants to cover our costs, and we did a lot of the research ourselves, but we worked with a master plumber and engineer who helped us with our design. We purchased a lot of product from his business so he looked over our plans before we installed anything.”

Wood Pellet Furnace for Small Scale Greenhouse Heat
Your Farm, Fairlee VT

Kevin and Laura Channel are the owner operators of Your Farm, in Fairlee VT. They started this farm only a few years ago; all the land was in hay when they purchased it. Since that time they brought 6 acres into mixed vegetable and cover crop rotation, and they constructed a 26' by 48' greenhouse for starting transplants in the spring and raising greenhouse vegetables in the summer and fall. They market through a CSA, farmers' markets and restaurants.

To heat their new greenhouse they bought a Harman PF 100 forced hot air pellet furnace (Harman Stove Company, Halifax, PA www.harmonstove.com) from Upper Valley Stove Company in Lebanon, NH (www.uppervalleystoves.com). They dealt with the owner directly and found that he was very helpful even after the purchase, for example, troubleshooting over the phone at no charge.

Kevin did the installation on his own with a dolly and a trailer and one other man help. He found the manual to be very self-explanatory on maintenance, but he also benefitted from supplementary tips that the store owner provided such as using a long-handled screwdriver to scrape the burnpot instead of the factory-supplied tool.

Kevin hooked up the direct vent himself and installed baffles. He assembled and attached the blower fan pretty easily. It took a few hours to unload, and install/assemble. He had the plenum fabricated by a sheet metal shop for a couple hundred dollars, and assembled it after the furnace was in place. The vent pipe is double walled and a little more expensive than normal so a short run is desirable.

An electrician hooked up the direct wire and the thermostat, but Kevin says he could have done it himself with the diagram from the manual; the electrician was on site anyway doing some other more professional work at the time.

The furnace is located in a 12' by 16' potting shed that is attached to the greenhouse, sharing an end wall. There is shared air between the greenhouse and potting shed through an 8'W X 7'H opening in the shared wall. However, the furnace is behind the end wall, the plenum protrudes through the end wall 7' high. The blower fan is always kept on "High" setting.

There is an HAF fan that circulates the forced hot air 12’ (3rd bow) from the plenum outlet throughout the house. A second HAF fan is located at the other end of the house. The thermostat is located in the middle of the greenhouse 4’ above the ground. The potting shed is insulated with 2” rigid foam (R-9 or R-11 value.)

During the first season, the furnace we used 2.75 tons of pellet fuel from March 17 through May 30 when it was shut down. Only half of the 26' x 48' house was heated (using a sheet of plastic as a partition in the middle of the house) from March 17 through April 28. Then they took down the partition and heated the whole house.

The second season the furnace was fired up on March 5 and shut it down on May 30 again. They partitioned greenhouse from March 5 to April 1, but cracked the partition at night to let heat into the area where early greens for market were growing in the ground. They used 3.5 tons of pellet fuel during this time period.

Kevin maintains the furnace carefully. “I give the heat exchanger a good cleaning after every ton, about 3 times a heating season, and I empty the ash pan, scrape the fire box and clean out the fines from the igniter box after each ton. This takes 30 to 45 minutes. At the end of the season a more thorough cleaning gets done including cleaning the combustion fan, the complete fire box, auger mechanism and the Sensor (the brains of the furnace). It takes two hours to do that well.”

They used "premium" pellets, brand name "Energex" (www.energex.com) purchased from Upper Valley Stove Co. They come from Quebec or PA. Premium is mostly hardwood and some soft wood pellets. This gives high BTU with hardwood and good high heat exchange with soft woods. It also has less "fines" which can clog up the auger mechanism in the furnace than other brands they tried such as New England Wood Pellets.

The price of wood pellets has been volatile in recent years, along with many other fuels. In 2007 the Channells paid $210 per ton, in 2008 they paid $230, and in 2009 they pre-purchased at $275 per ton due to fuel surcharges, “which will hopefully tail off now that fuel prices are down again” says Kevin.

There system has worked well overall. “The only trouble we have faced is a failed auger motor. The auger feeds pellets as the thermostat calls for heat. So one morning I came in to find the temp at 37 degrees! It was easily replaced in 30 minutes once I did the troubleshooting and retrieved the part. Thankfully it was a sunny day and the stove company had them in stock. This is a common failure with this unit. Keep an extra on hand if you are going to go this route.”

“Down the road I am concerned about the rust building up on the heat exchangers. I’m keeping a close watch on that and the efficiency and durability of the unit in the long run. The manufacturer said this is their first greenhouse application…we’re all holding our breath, but thankful to be using renewable fuels.”