Harvard Forest Old and New Wood Heating System: Basic Facts[1]

Historical System: From its construction in 1940, Shaler Hall and part of the Archives building were heated by a HB Smith coal burner (2.88 mBTU) that was converted to wood sometime during WW II. A back up heating system was created by adding an oil burner in 1968 in Shaler Hall and another in 1972 when Torrey Lab was built. Shaler Hall, Torrey Lab and the part of the Archives heated by this system totaled 33,723 sf[2]. The wood boiler, which is assumed to have been 30% efficient[3], was fed 3 times per day (7:30, noon and 3:30) with 4' logs, and oil burner ran overnight/weekends during heating season as well as on extreme cold days.

New System Overview: After 8 years of planning and fund raising, we purchased 3 Froling FHG Turbo 3000 Wood Gasification boilers (0.17 mmBTU, total .5 mmBTU) to replace the Smith wood boiler. For back up, we purchased a Ray-Pak propane-fired secondary boiler (1.5 mmBTU/hr). Beginning on 10/10/13, we fired up the first of the new wood boilers and converted over to the new district heating system. This system provides heat to Shaler, Torrey and the Archives as well as two additional buildings: Community House and the renovated Pole Barn. These buildings total 41,255 sf[4] , a 120% increase in the district heating system scope.

New System Layout and Operation: The heating plant is located in a boiler room in the Pole Barn. It contains the boilers and their associated thermal storage tank, pumps, and controls. The 3 biomass boilers are connected in parallel to a large heat exchanger and are equipped with individual circulating pumps and thermostatic diverting valves that ensure that the boilers are protected from overly cold return water during start-up. In addition, the boilers are protected by a 'thermal dump' system that operates automatically in the event of either power loss or pump failure by diverting excess heat into a passive heat-dump system. To conform to the Commonwealth of Massachusetts' Boiler Board's requirements[5] the boiler side of the heat exchanger is at atmospheric pressure and the other side of the heat exchanger, which is connected to a 2500-gallon thermal storage tank, is maintained at about 25PSIG. There are variable-speed circulating pumps on both sides of the heat exchanger to transfer heat into the thermal store. The heat exchanger creates a significant inefficiency in heat transfer between the biomass boilers and thermal store, but is currently an unavoidable impediment.

In addition to the biomass boilers, the system is equipped with a 1.5 mmBTU Ray-Pak propane boiler that is designed to provide whatever heat the biomass boiler cannot supply during cold weather or overnight, when the boilers are not fired. The propane boiler is fitted with a modulating valve that can direct heat to either the hot water being supplied to the buildings or into the thermal store to increase its temperature. This arrangement allows the very high output of the propane boiler to be used efficiently and minimizes short-cycling. Hot water is supplied to the buildings by main circulating pumps in the boiler room. The individual heat loads in the buildings are controlled with variable speed pumps and mixing valves. Each of the separate loads in the Torrey Lab, Archives, Shaler, Fisher Museum and Community house has its own control valve and circulator. In both Shaler and Community house, it is also possible to make domestic hot water with residual heat from the central heating system.

The heating system as a whole is controlled by three programmable logic controllers that monitor temperatures and flows. These controllers set the position of the various control valves and also set the speeds of the variable speed pumps for the various parts of the system. The master controller is located in the biomass boiler room in the pole barn and communicates with slave controllers in Torrey and Shaler via high speed internet connections. Critical data from the control system is transferred to the Harvard Forest biomass monitoring system.

Monitoring system: The new heating system is controlled by a programmable logic controller that also collects data on system temperatures, water flow and control operation. Temperature and flow data are transferred to a Campbell

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[1] Acronyms used: thousands of British Thermal Units (mmBTU); Metric tons of carbon dioxide equivalents (MTCDE); Green house gases (GHG)
[2] Included Shaler Hall/Fisher Museum (28,154 sf), John Torrey Labs (4,714 sf), Archive (855 sf, 3 of 10 bays). Total 33,723 sf.
[3] Evaluation of Efficiency Differences Between Existing Harvard Forest Heating System and New Biomass District Heating System, Wilson Engineering Report to USDA Forest Service Wood Education and Resource Center, 5/9/10
[4] Includes historic system plus Community House (4,592 sf), Pole Barn (2,340 sf). Total 40,655 sf.
[5] Scott Nichols, Tarm USA, Inc. http://www.woodboilers.com/

Scientific CR1000 datalogger that also reads critical system temperatures for specific locations in the biomass boiler room. The datalogger also records the amount of propane used by the Ray-Pak boiler. In addition to collecting data, the datalogger also computes BTU usage and sums it on an hourly basis. The data from this system are available as either an Excel spreadsheet or as an ASCII comma delimited data file.[6]

The 3 Froeling FHG boilers are also monitored by 'BoilerScope', a proprietary monitoring system developed by DCM logic. This system provides on-line information about the status of the boilers and graphs their performance. These data may be downloaded. Access to this system is via a password-protected account. HF will provide passwords to interested parties.

Comparison of Fuel Usage and GHG emissions. Between 2006 and 2012, an average of 60 cords of wood (421 total) and 11,020 gal. oil (77,143 total) were used to heat these buildings. During that same 7 year period, the total GHG emitted by wood was 175 MTCDE per year (1,228 MTCDE total). For oil, the GHG emissions were 112 MTCDE/yr. (786 MTCDE total). The total average GHG emissions for the 7 year period was 288 (total 2,014). Averaged over the total square footage of 33,723 sf , GHG emitted was 0.0085 MTCDE/sf. As we are still in the "shake down" period of the new system, we do not have analysis of data to share. Note as of 1/11/14, we have used 75,388 lbs of wood or 38 cords.[7]

Research related resources: There are 3 eddy flux towers (EMS, NEON, hemlock) with initial data going back to 1989, meteorological station data from 1964. An array of >100 long-term plots to measure forest growth and carbon dynamics; the 35-hectare big grid forest plot in which all stems are mapped and remeasured every five years (Harvard Forest-Smithsonian Institute collaboration).

Potential research areas/questions: What is the carbon and GHG emission accounting for a small scale biomass heating plant? The Manomet report and other studies have argued that large-scale heat and energy production with biomass is not carbon neutral due to the initial reduction in carbon sequestration associated with harvesting. These and other studies suggest that small scale systems, with increased efficiencies may be carbon neutral. The installation of this system with the wood source coming from Harvard Forest lands provides the opportunity to examine in detail all relevant aspects of carbon uptake, storage and release associated with small-scale heat production. Also, does the purported increase in boiler efficiency lead to significant improvement in overall heating efficiency (i.e., a decrease in wood use/area of building?

Next Steps for System Improvement: We will continue detailed system monitoring for system optimization and seek to improve system efficiency by careful system tuning. For instance, we have begun turning off the propane system on weekdays between 8am and 3:30 pm, the beginning and end of the crews' work day. We used to turn off the oil burner in a similar manner in the previous system. We have added a 4th firing at night and also have 3 firings on the weekends to reduce propane use. We will also seek permission to pressurize our system by the MA boiler board.

Comparison of Fuel Production: For the first 70 years since Shaler Hall was built, fuel production involved a 10 step process from the initial felling of a tree by chain saw to feeding 4 foot lengths of split wood into the boiler [8]. It took 12.25 hours of labor to harvest and fire one cord of wood. With the relocation of the boiler to a safe and more convenient location as well as investment in modern processing equipment, we have reduced that to 8 steps and most importantly, the production time by over 50%[9]. It now takes 6 hours to harvest and fire one cord of wood.

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[6] This information will be available on the Harvard Forest web site harvardforest.fas.harvard.edu during the first half of 2014.

[7] Note each boiler holds up to 7.4 ft^3 whole wood, in 20" lengths. A cord of wood is 128 cf and there are 17.3 firings per cord. As of 1/14/14, the average weight of a one boiler fire box of wood weights 110. lbs. This includes a range of moisture content (12-20%) and wood types (primarily red maple and red oak). Thus, an "HF" cord weighs between 1900-2000lbs. This figure assumes 1950 lbs.

[8] *Historical cord production*. Steps 1& 2. Fell trees with chain saw & haul by tractor/skidder to access point – 1 hr.; Step 3. Cut logs into 4' lengths – 1 hr.; Step 4. Hydraulic splitter used to cut into usable diameter firewood - 2 hrs.; Step 5. Stack on pallets (2 pallets/cord) -1 hr.; Step 6. Moved 2 pallets (i.e. 1 cord) by tractor to rear of Shaler basement scuttle - 0.25 hr,; Step 7. Two staff threw 1 cord through scuttle into Shaler basement - 3 hrs.; Step 8. Restack cord in basement - 1 hr.; Step 9. Load 1 cord (6 carts @ 20 cf per load) for transport to boiler – 1hr.; Step 10. Transport cart to boiler, feed 1 cord (6 carts) to boiler - 2hrs.

[9] *Time per cord*. Step 1& 2. Fell & haul trees – 1 hr.; Step 3. Cut to 12' lengths - 0.25 hrs. Step 4. Load logs into wood processor – 0.25 hr. Step 5. Processor cuts wood to 20" and splits it - 1 hr. Step 6. Stack wood on pallets (4 per cord) 1 hr.; Step 7. Use tractor to deliver cord (2 pallets) to building – 0.5 hrs.; Step 8. Push 2 pallets into biomass room, fuel for 6 boiler firings - 2 hrs.

EHS implications: This project removed 100% of all oil tanks (8,275 gal total capacity) from within Zone 1 of the Harvard Forest Public Water Supply well #1. It consolidated scattered workshop spaces into one efficient, well lit, and code-compliant work space in the renovated pole barn. It also removed flammable oil and cordwood stored in the basement of the main building on campus, Shaler Hall. New wood harvesting equipment has effected significant improvements in employee safety during wood processing. A modern propane generator is now sized to cover all basic needs of the main complex that often loses energy.

Alternatives We Considered:

Backup system. We considered pellet back up instead of propane. Concern noted over supply in future years. We also considered using 4 small propane boilers instead of one large one. The problem is small propane boilers only come in condensing mode. Two issues for HF. One is what to do with condensate which is by regulation considered industrial waste and therefore would have to be either treated or stored and hauled away. Significant cost anticipated in hooking the pole barn up to the existing system. We would have had to have engineer review structure of existing system to see if compatible with condensate, always have cost of hauling this away. Second concern was that condensing boilers only work efficiently when the4 supply going out is 180 degrees and the return temperature is around 160. We did not think that likely to happen and so the boilers would not operate efficiently.

Wood System. First, we consulted with BERC who recommended the Shaler complex including Torrey, Archives, Shaler and Community House. We then consulted with VanZelm engineering and they recommended scaling up to cover the entire campus including 5 houses with a chip boiler and chip production facility located north east of the main campus. That was too expensive ($3.xM in 2010). Next we scaled back to the original BERC idea of the core buildings again. We utilized the materials from the VanZelm study to identify the two best vendors to work with (Veissman and AFS). In the end, due to price and product, we chose to work with AFS to create a design/build system. Core consultations with USDA WERC, Wilson Engineering and Harvard EHS GHG coordinator (Gordon Reynolds), Research Designs Inc. and Seaman Engineering helped shape the final product. During the process of considering Veissman and AFS and while we worked with AFS as our selected vendor, we worked through the following ideas. We considered one 600mmbtu boiler to fuel the system. We decided the 25% turn down limit of minimum 125mmBTU would not work well for the shoulder seasons and therefore would increase propane use. Also, we did not want to use that system on the lowest edge possible due to concerns re air quality.

What problems have we had? Once the system was balanced, it seems to be operating quite well. The issue now is how to maximize efficiency, given the choices we have made. Further fine tuning the balancing with AFS will occur over the next few months. We have insulated all the possible pipes throughout the entire heating distribution system. We can replace some more circulators, specifically the Fisher Museum needs heating system needs to be upgraded. We could consider moving away from our existing cast iron conventional radiators and moving to modern flat panel in all buildings. We obviously want to look to remove the heat exchanger as noted above. We need to renovate Community House as it needs major insulation in the basement and replacement windows.

What about the rest of our buildings? 3 bays of the Archive building are propane heat. The Maintenance Garage has an outside wood boiler and back up propane heat. We have converted 5 houses to propane (School, Fisher, Higginson, Benson and Lyford). The 4 residences with newer oil systems (Bryant, Highway and Raup Houses, plus Fisher Cottage) will be converted in due course. This totals an additional ~35,000 sf.

Where are the circulators? Each biomass boiler has its own circulator and there is a variable-speed circulator for the primary loop between the wood boilers and the heat exchanger. There is another variable speed circulator between the heat exchanger and the thermal storage tank. The main system circulator pushes water from thermal storage tank to the "entrance" of each heating loop that feeds various buildings. There are two of these pumps so a spare is always available. These large pumps can supply up to 100 gal/min and are also variable speed. In addition, the Ray Pak boiler has its own circulating pump and diverting valve so that it can supply hot water to both the thermal store and the main supply loop to the buildings. Once water leaves the biomass boiler room, it goes to variable speed circulators for each heating load, i.e. Torrey/greenhouse, Shaler/Archives, and Community House. Note that inside each heating loop there may be several smaller circulators that power each thermostat zone. We upgraded most of the ancient preexisting pumps but not all of them. There are three BTU monitors: system output, biomass boiler output and RayPak output.

There are also temperature sensors on the building heating loops that are used to control the speed of the individual loop pumps.

How do we cope with the below zero days? Propane boiler kicks in to augment the wood system as needed.

What do we do when it is very warm? The theory is that we will keep an eye on the thermal storage temperature and the temperature of the loop between it and the heat exchanger. That will determine whether to fire and when.

How do we determine out how many boilers to light? The crew checks the temperatures: outside, heat coming from boilers, thermal storage and then uses his judgment. In another year or so, we expect to have a protocol to cover this.

What happens when the electricity goes off? The propane generator kicks on and allows the regular heat system to operate.

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