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Lessons Learned: Developing and Demonstrating a Rotary Kiln Mobile Pyrolysis Reactor

In 2014 the Utah Biomass Resources Group (UBRG) received a grant from the US Department of Transportation's SUN Grant program to scale-up the mobile pyrolysis technology developed by Amaron Energy of Salt Lake City. This $493,000 grant also includes a sub-award to the Chemical Engineering Department at the University of Utah to conduct research on upgrading an important byproduct of the pyrolysis process: bio-oil. Dr. Eric Eddings leads a team that is working to convert the bio-oil into a product that can be utilized by blending with petroleum products for heat production.

Amaron's pyrolysis kiln is built around a 15 foot long, 24 inch diameter tube. This rotating metal tube is heated from the outside with gas burners to temperatures of 400 to 600 degrees Celsius. The tube is in constant motion and this (*continued on page 4*)

> *"Careful feedstock preparation and screening are key to the pyrolysis operation."*
>
> *- Darren McAvoy,*
> *Forestry Extension Associate*
> *Utah State University*

Feedstock being fed into the mobile pyrolysis unit (top); finished product, biochar following pyrolysis (bottom).

In This Issue

(A) endemic, (B) epidemic, and (C) post-epidemic interior Douglas-fir stand conditions following Douglas-fir beetle infestations.

Potential Wildfire Hazards Linked to Douglas-fir Beetle

Utah State University MS Forest Science student, Andrew Giunta investigated the relationship between bark beetles and wildfires in the Central Rockies. Giunta was particularly interested in the forest conditions in endemic (occurring when infestations occur in small groupings of trees), epidemic (occurring when infestations are widespread), and post-epidemic phases of Douglas-fir forests following Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) infestations. The changes in fuel loads, needle moisture content, and stress responses across infestation phases were measured to determine to what extent beetle infestations impacted wildfire risk.

Methods

Ground, surface, and aerial fuel loads were measured from twelve study sites located throughout central and eastern Utah. Each study site consisted of one stand in each infestation phase: endemic, epidemic, and post-epidemic. Giunta used this information to estimate canopy cover, canopy base height, and fuel loads and to identify differences between these three phases had on fuel loads and wildfire probability.

NEEDLE MOISTURE

Wet and dry weights were measured from clippings collected from a recently infested Douglas-fir stand in the Caribou-Targhee National Forest. Samples were carefully selected to be representative of all infestation crown classes from the study area (green; green-infested; yellow; red). The difference in wet and dry weight was used to identify the variances in needle moisture between crown phases associated with DFB infestations.

TERPENE EMISSIONS

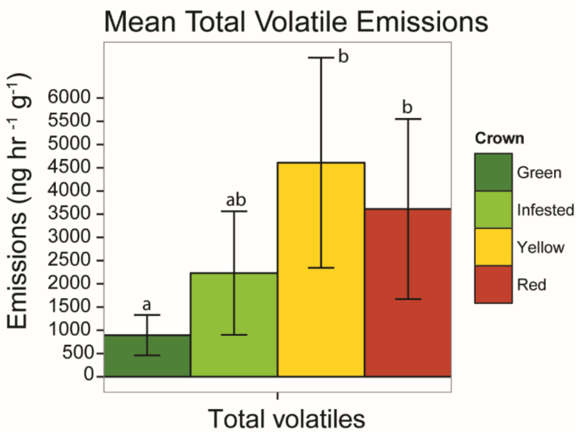
Stress responses of infested trees were measured through the collection of volatile emissions from a single branch enclosed in a Teflon bag. Terpene emissions from each branch were measured via a portable volatile collection system. Biweekly data was collected and shipped to the Rocky Mountain Research station where emission compounds and rates were quantified. These samples were also weighed to obtain a fresh mass weight where volatile emission rates were standardized.

Results

The fuel load analysis showed no significant differences in the surface fuels layer among the infestation phases. However there was a significant increase in the loading and depth of litter between the epidemic and post-epidemic phases due to needle loss associated with the transition between phases. In the aerial fuels layer, the stand level crown base heights in the post-epidemic stands were significantly lower. The canopy bulk density in the aerial fuels layer was significantly higher in endemic stands than post-endemic stands.

The needle moisture content analysis indicated green and green-infested crowns had significantly higher moisture content than yellow and red crowns. As expected, red crowns held the lowest foliage moisture content.

The stress response analysis indicated that yellow and red crowns produced higher levels of volatile terpene emissions than green crowns. Higher emissions are associated with a higher level of foliage flammability and an increased risk of wildfire. During the epidemic phase, yellow and red crowns have the lowest foliar moisture content. For these reasons, stands in the epidemic phase are at an elevated risk of crown fire while needles are still retained in the canopy.



Mean total volatile terpene emissions for each crown class based on all sample periods.

Douglas-fir beetle infestations facing Douglas-fir forests across the Intermountain West have the potential to influence the way fire impacts these forests. Giunta found the most significant changes occurred in aerial fuels during the epidemic phase of an infestation. This period can last anywhere from 2 to 5 years. During this time, foliage transitions from the green to the red crown phase and the tree undergoes the highest level of moisture loss and a marked increase in terpene emissions. These conditions contribute to an elevated risk of crown fire until the stand transitions into the post-epidemic phase and needles are lost.

Giunta plans to defend his MS Forestry Science degree in the fall of 2015. His adviser is Dr. Mike Jenkins.

-Bethany Unger, USU Forestry Extension Intern

First look at mechanically disturbed site, Range Valley Ranch, Utah.

14th Annual Timber Harvest Tour

On Thursday, August 13, 2015 USU Forestry Extension co-hosted the fourteenth annual Timber Harvest Tour on the Tavaputs Plateau, Utah. Landowner Mike Siaperas of Range Valley Ranch helped to co-host the event and 46 people spent the day observing the results of the last five years of labor on the 600 acre property. Siaperas intends to shape the property into prime mule deer habitat where disabled youth can visit and hunt.

Siaperas' methods for creating mule deer and wildlife habitat have evolved over time. Operating a bulldozer to improve wildlife habitat is how he spends his free time – and he enjoys every minute of it. Wildlife Biologist, Nicole Nielson with the Division of Wildlife Resources manages the adjacent Cold Spring Wildlife Management Area. She and Siaperas collaborate and modify their restoration efforts based on the lessons they've learned over time. To create the opportunity for aspen regrowth and regeneration, Siaperas uses a bulldozer to mechanically remove overgrown areas and a track hoe with a thumb to stack the debris for very efficient burning later. The Timber Harvest Tour participants got a front row view of their collaborative work. And the results of their efforts look good.

The final result is a carpet of aspen—many thousands of stems per acre are sprouting up wherever he has done this treatment. Some of his first attempts did not fare so well, but he quickly learned to modify his methods for the best results. For example, he found that the sweet spot for depth of the dozer blade to generate maximum aspen suckering was around 10 inches; too deep and roots are damaged, not deep enough and there Isn't enough root stimulation to send them into vegetative suckering. The pyrolysis machine was in full operation for the tour. More can be read about that on page 1 of this newsletter. Co-hosts for the tour included the Division of Forestry, Fire and State Lands and the Intermountain Chapter of the Society of American Foresters.

-Darren McAvoy, USU Forestry Extension Associate

Participants at the 14th Annual Timber Harvest Tour, Range Valley Ranch, Utah.

Mobile pyrolysis unit in full operation at Timber Harvest Tour (top); Bio-oil (one of three potentially valuable products, biochar, syngas, bio-oil) produced from mobile pyrolysis (bottom).

(*continued from page 1*) allows the feedstock (wood chips) to be rapidly heated. The extreme heating of such small particles in a low oxygen environment quickly transforms the wood into three potentially high-value products biochar, bio-oil and syngas.

Over the past year, Amaron has conducted four demonstrations of this technology in three states as well as countless days of testing at the Amaron shop in Salt Lake City.

Feedstock Preparation Issues

Many issues stemmed from the way the feedstock was prepared for pyrolysis. In short, we learned we must oversee the preparation, or better yet, have the equipment and ability to prepare the feedstock ourselves. It is not practical to just order chipped, ground, or shredded feedstock because as it stands now, feedstock preparation has a direct effect on the production capabilities of the pyrolysis machine. Initial testing of the equipment was done with lab-chipped wood; this product was very clean, consistent, and shredded into small, even pieces. This was fine for laboratory testing, but this highly consistent, lab-chip product is not usually possible to obtain in the field.

Feedstock Handling Challenges

To accommodate the realities of using less refined material, Amaron installed a dump valve on the pyrolysis machine which drops the filtered feedstock into the reactor in small, manageable batches. Amaron tested this system with a rough-ground feedstock of pinyon and juniper and discovered that to operate effectively with this material, they needed to constantly monitor the feedstock as it entered the machine. This allowed the operator to remove over-sized pieces that could potentially damage the unit.

New Factsheet

Selecting Trees for High Elevations

Individuals living in alpine areas need to consider the impact of elevation when selecting, cultivating, and caring for trees. Alpine sites are typically cooler with shorter growing seasons, have increased precipitation and available water, increased soil moisture, and decreased evapotranspiration and heat stress.

High elevation sites also face extremely low temperatures, variations in the timing of frost, short growing windows, and persistently frozen soil.

Please see the most recent Utah Forest Factsheet for specific species recommendations when planting at high elevations, or visit USU Tree Browser treebrowser.org for other recommendations.

The angle of repose measures the steepness of an angle when loose pieces start to naturally tumble down a slope. Inside of a rotary pyrolysis kiln, the angle of repose is the critical angle the turning tube is positioned which allows the feedstock to tumble down the slope and be pyrolyzed. Amaron discovered they needed a steeper angle of repose in the machine. To fix this they welded a series of fins inside of the rotating tube (similar to those inside of a clothes dryer), which insured the material would tumble instead of slide inside of the tube.

Quenching

When biochar leaves the reactor, it is in a constant state of glowing combustion. Because of this, biochar may combust when exposed to oxygen. Char was prematurely exposed to oxygen following a couple of the demonstrations and this resulted in a few near-mishaps with smoldering char. Amaron added a char-quenching station to their componentry which insures the char will not combust.

Feedstock Preparation Costs

In some cases the cost of preparing the feedstock was substantially greater than the cost to pyrolyze it. Perhaps the ideal business model would include the ability to chip and grind each feedstock according to the specifications preferred by the machine, and the biochar desired by the customer.

-Darren McAvoy, USU Forestry Extension Associate

Firing up the Engine

By the time Eric Eddings and Kevin Whitty finished modifying their black 1986 Chevrolet pickup to run on wood chips for a new undergraduate class, it looked like a shiny black, souped-up roadster – but with a touch of post-apocalyptic grunge from a “Mad Max” movie.

Eddings, a University of Utah Chemical Engineering Professor and the College of Engineering’s Associate Dean for Research, is an expert on combustion and fuels who also loves restoring cars. His colleague Whitty, a chemical engineering professor, is an authority on biomass fuels. Ten years ago, the two imagined what it would be like if they combined their interests into one inventive class. After a decade of busy schedules the two finally realized their dream, and the result was the university’s first wood-fired automobile class, a passion project in which 12 students were tasked with converting a truck from a gasoline guzzler into a vehicle that runs on wood pellets.

“We have a process that is called gasification where those wood pellets are partially oxidized, partially burnt … and it produces a gas that is still a fuel because it’s not completely burned to carbon dioxide and water,” Eddings explained. “It is primarily converted to carbon monoxide and hydrogen with some methane and minor hydrocarbons.”

The product of this gasification process is synthesis gas or “syngas,” a carbon-neutral fuel that will power the truck instead of gasoline. In order to do that, Whitty, Eddings and the students built a gasifier that sits on the bed of the truck. Modified 55 gallon drums were used — one for the hopper and gasifier that will contain and burn the wood pellets, and another for a heat exchanger that cools the gas. The Utah Biomass Resource Group loaned Whitty and Eddings the original Dragon Wagon for preliminary testing and gasifier exploration. After much tinkering and testing, they came up with their own methodology and successfully demonstrated the ability of wood-fired fuels to be used in this capacity.

The newly-created fuel then goes through a second heat exchanger to take out water, and a third barrel is used to filter out particulates such as ash. The gas is then clean enough to go through PVC pipes to the truck's engine.

Work on the gasifier and truck was funded by a donation from Washakie Renewable Energy, along with equipment donated by Opto 22. The project was being carried out at the university's Industrial Combustion & Gasification Research Facility in Salt Lake City. The facility's director, Andrew Fry, also taught the class with Eddings and Whitty, and the trio received help from two visiting scholars from Hungary, Zsolt Dobo and Helga Kovacs.

Whitty said wood-fired fuel is not a new process. "It's actually been around since the 1800s. London used it for town gas. A lot of people in World War II were doing this exact type of project — converting their cars to operate on wood — because in Europe a lot of petroleum was going into the war effort."

> *"We have a process that is called gasification where those wood pellets are partially oxidized, partially burnt … and it produces a gas that is still a fuel because it's not completely burned to carbon dioxide and water."*
>
> *- Eric Eddings,*
> *College of Engineering*
> *University of Utah*

Running cars on wood chips is not practical, however. It's messy and not efficient, but it is considered a sustainable fuel like other forms of agricultural waste where it is replenishable. Despite that, the professors realized the one-year class would be an innovative way to teach students the gasification process as well as working together on a big project, one of the most important skills in the workplace. Along the way, they also learned about project management, scheduling, budgets, adversity and computer-aided design.

"For undergraduate engineers in particular, a lot of their courses are often fairly prescribed," Eddings said. "But this is one really large project where they work in teams . . . and they're learning if one team falls behind it impacts everyone else. That is very much a mirror of what life will be like when they get out into industry."

Eddings and Whitty's Treemobile, powered by gasification of wood pellets; see it out on the road at treemobile.chemeng.utah.edu

The students finished converting the truck near the end of the 2015 school year, and are now making tweaks to take it to the Miller Motorsports Park in Tooele to see how fast it can go. Their goal: to beat the world record for a wood-gas vehicle set in 2011 on the Bonneville Salt Flats when a truck reached 73 mph. They hope to drive it on the track sometime next month.

Regardless of how fast their truck goes, Whitty says they plan to continue teaching the class. Future students can improve the design of the gasifier by making it smaller, more efficient and more powerful.

"We will start from where we left off with this. We are not going to build a whole new car," he said. "But we could teach this class for 20 years." You can view the class progress at treemobile.chemeng.utah.edu.

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Logan River Taskforce Publishes Riparian Plant Guide

Work to restore the Logan River is currently underway, and the Logan River Taskforce is leading the charge. This taskforce was formed in response to flood mitigation actions carried out by Logan City during the summer of 2014. These actions included channelizing sections of the Logan River and removing trees and vegetation from the riverbanks. Such actions occurred despite public outcry over the work. As a result, the Logan River Taskforce was formed and awarded a $600,000 grant from the Utah Division of Water Quality and a $400,000 city match to undertake substantial river restoration between First Dam and Cutler Reservoir.

Part of these funds were used to create the Logan River Riparian Planting Guide, published in October, 2015.

The purpose of the guide is to educate Cache Valley citizens with riverfront land about the benefits of fostering a healthy riparian buffer. This pocket-sized guide is a useful and practical resource for anyone with streamside property interested in bank stabilization and improving the health of the Logan River. This free guidebook can be obtained by contacting USU Forestry Extension or Logan City.

Stacked charcoal pit ready for covering with leaf pile. Credit: Doug Page.

Making Charcoal The Age-Old Way

They say eventually things will come back around. Perhaps that is some of what is happening in the modern biomass industry: a rediscovery of an ancient product. Currently there is a fair amount of experimentation surrounding something called "biochar." Biochar is the new version of what has been known for thousands of years as "charcoal" or perhaps more accurately a by-product of charcoal production: i.e., it was "charcoal dust." Biochar is typically the broken, granular form of charcoal, something that in the past was considered a waste product made during the production of the larger, more valuable charcoal pieces that could easily be handled. I won't go into how biochar is produced today, there have been numerous articles written on the subject recently, both in this Newsletter and elsewhere. Needless to say methods have changed. What I will do is describe how charcoal has been produced for thousands of years with limited technology. Perhaps there are a few lessons that can be learned by looking at this age-old method.

Mankind has been producing charcoal for somewhere between 6,000 and 8,000 years. Since this dates before recorded history, no one knows with certainty. Charcoal was likely discovered by accident as a product of incomplete combustion in a wildfire or wood cook fire. Charcoal has one-third the weight of wood and one-half its volume for the same heat production capacity, and thus is much easier to transport and store. As time went by, many uses for charcoal were discovered, perhaps the most important of which was that (until the discovery of coal), it was the only fuel that burned hot enough to smelt metals, which in turn allowed for the Industrial Age.

The connection to forestry should be obvious: it takes wood to produce charcoal, it takes a forest to produce wood, and it takes a little thought and planning if you don't want to deplete your resources and go out of business.

The basics of charcoal production are fairly simple: burn wood in an oxygen-restricted environment and extinguish the fire before the carbon is consumed. The nearly pure carbon that is left is charcoal.

The pit is inspected during ignition. Credit Sonia Page.

The first steps in the process were to clear a relatively level, protected area (30-40 feet in diameter), harvest and haul wood from the surrounding forest (20-40 cords for each charcoal pit), and season the wood prior to starting the construction of a pile to be burned. The pile was known in the charcoal business as a "pit." Traditionally charcoal was made by making a tight pile of seasoned wood, then covering the "pit" with a layer of leaves followed by a layer of soil. The leaves kept the soil from filtering between the wood before it could be ignited. The soil allowed control of the amount of oxygen that reached the fire so that a smoldering, oxygen-restricted fire could be maintained.

The construction of the charcoal pit required careful attention: form a chimney in the center, tightly pile the wood around the chimney with the outside sloping inward so that the leaves and dirt can be laid on the sides and top of the pit, drop small kindling wood and embers (followed by more kindling wood) down the chimney and…wait. Small openings were created around the base of the pit to allow air to "draw." The fire was allowed to "catch," then the chimney was sealed, and the base vents were covered or left partly open to control how fast the pit burned.

From the time the pit was ignited until it was "raked out," it required monitoring 24 hours a day, with no breaks, lest a vent develop and the charcoal be consumed, leaving only ash as a virtually worthless product. After roughly a week of burning, all vents were sealed, thus halting the burn, and the pit was left to cool for another week, time enough to insure the fire was completely extinguished. The pit was then opened and the charcoal was raked out, separating the larger charcoal product from the soil that had covered the pit and would have become mixed with the product. The charcoal product was then moved by wagon to cooling sheds for a period to further insure the material did not reignite. Once the charcoal was completely cool and safe for transport, it could be moved into a storage barn for later use or transported to the end user.

There are currently only a few sites in the U.S. where charcoal is still produced in this traditional way, one of them is at

Hopewell Furnace National Historic Site in southeastern Pennsylvania, managed and maintained by the National Park Service.

Twice a year in May and August a team of Park Service volunteers builds a small demonstration pit and makes charcoal this age-old way. At the suggestion of my friend and charcoal mentor Dr. Tom Straka, Forestry Professor at Clemson University, my wife Sonia and I joined the team to get some hands-on experience. What we found was a dedicated team of 50 volunteers who get together each year for the two events. They gave us a warm welcome and a lot of good local advice. While there was plenty of work during our week at the site, there was also plenty of comradery, not to mention the vast array of early American history within a short distance of Hopewell.

But Hopewell Furnace NHS is more than just a charcoal producing historical site. It is the site of one of America's early "Iron Plantations" dating back to the 1700s. These plantation communities were centered on an iron furnace and surrounded by the Iron Master's mansion, worker housing, forges, iron ore mines, an office, a store, a gristmill, a sawmill, a blacksmith shop, barns, grain fields, orchards, as well as a large, but defined acreage of forestland. In short, everything the community needed to be virtually self-sufficient.

Since the forest from which wood could be harvested for charcoal (and other products) was limited, consideration had to be given to sustainability of the harvest. Each

Collier Gary Brouse adds kindling to the chimney during pit ignition. Credit Sonia Page.

Upcoming Events

National Extension Forestry and Wood Products Conference

Cocodrie, Louisiana
November 1, 2015

Utah Arborist School

Cedar City, Utah
November 9, 2015
Details HERE

Ponderosa Pine Lumber Grading Short Course

Flagstaff, Arizona
November 20, 2015
Details HERE

Learn at Lunch Webinar: "How to Fit Large Trees into Communities"

Dr. Mike Kuhns

December 1, 2015
Details HERE

2015 Forest Inventory Analysis Science Symposium

Portland, Oregon
December 8, 2015
Details HERE

Long tined rakes were used to rake out the pit. Credit Sonia Page.

year harvestable forest sections were identified and cutting areas were grouped into a pattern that avoided clear-cutting (a technique not favorable for tree regeneration). Sites were protected from livestock, and tree regeneration was encouraged. Much of the regeneration could be obtained from fast-growing sprouts (i.e., coppice forestry). To ensure adequate time for growth, the same area would not be harvested for 20 to 30 years. For charcoal production, smaller trees that could be handled by hand were preferred, leaving the larger trees for more valuable building products. In eastern Pennsylvania where trees grow quite fast, a typical iron plantation required roughly 3,000 acres of forestland for sustainability of harvest and continuity of the furnace and the livelihoods of the plantation residents. The plantation system shared some similarities to the English feudal system.

The iron furnace at Hopewell opened in 1771 and continued to operate with charcoal as fuel until 1883. The federal government purchased the Hopewell property in 1935 to become part of a "Recreation Demonstration Area," part of the Work Projects Administration program. In 1938 the core of the plantation was designated a National Historic Site and the remaining acreage was transferred to the state of Pennsylvania, becoming French Creek State Park.

-Doug Page

Douglas H. Page completed his Master of Forestry Degree at Utah State University in 1981. From there he went on to have a 35-year forestry career that spanned 3 state forestry organizations (Texas, Utah, and Colorado) and two federal organizations (US Forest Service and Bureau of Land Management). He is currently retired and living in Cedar City, staying active in forestry through professional involvement with the Society of American Foresters, volunteering, and consulting.

References/Additional Information

Hopewell Furnace NHS: http://www.nps.gov/hofu/learn/historyculture/charcoal.htm

Warwick County Park: http://bit.ly/1ZYyCkM

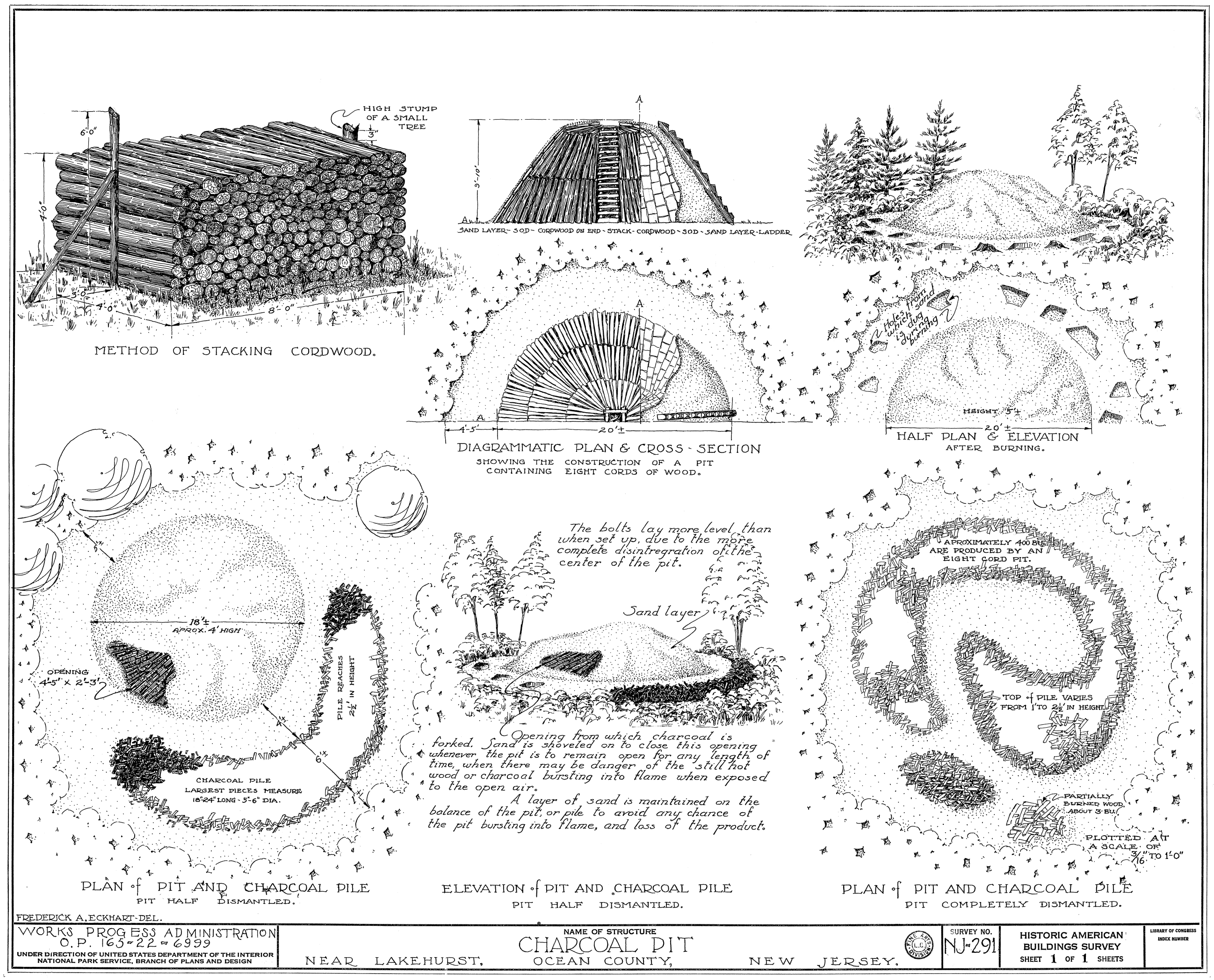
Forest History Today: http://foresthistory.org/Publications/FHT/FHTSpringFall2013/History_Road.pdf

Tooele Kilns: http://extension.usu.edu/tooele/files/uploads/TooeleCountyCharcoalKilns.pdf

Utah Historical Quarterly: http://utahhistory.sdlhost.com/#/item/000000093005350/view/24

Utah Historical Quarterly (web extra): http://heritage.utah.gov/history/charcoal-kilns-winter-2015

See more pictures on the extended web special: http://forestry.usu.edu/htm/utah-forest-news/extended-web-special/



The bolts lay more level than when set up, due to the more complete disintregration of the center of the pit.

Opening from which charcoal is forked. Sand is shoveled on to close this opening whenever the pit is to remain open for any length of time, when there may be danger of the still hot wood or charcoal bursting into flame when exposed to the open air.

A layer of sand is maintained on the balance of the pit, or pile to avoid any chance of the pit bursting into flame, and loss of the product.

Anatomy of a charcoal pit: Credit: Library of Congress.

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Do you have a story idea for the next edition of Utah Forest News? Have feedback about any story in this issue? Send us an email or give us a call!

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