Biochar Applications to Manage Mine Revegetation and Repurpose Beetle Kill

A Study for the Western Alliance for Restoration Management
and the Sustainable Development Strategies Group

Produced by Nathan Gore: Master in Environmental Management (MEM) Graduate

Project Partners

Luke Danielson, J.D

Dr. Jennie DeMarco

Ellen Ross, MEM

Biochar Applications to Manage Mine Revegetation and Repurpose Beetle Kill
Project Primer Produced by Nathan Gore

Executive Summary

The purpose of this environmental management project is to address two massive scale issues that are prominent in our region. One of these issues is the widespread beetle kill of native trees. The other is mined land degradation of soils and water qualities throughout Colorado and the Western United States. Additionally, there is also an opportunity to sequester considerable reserves of carbon that are otherwise likely to enter the atmosphere. Addressing these issues are priorities of considerable importance, with efforts overlapping in numerous industries.

The issues of beetle kill, mine reclamation, and carbon emission can all be categorized as wicked problems, as they occur at tiering, global scales, create impacts across numerous sectors, that require interdisciplinary understanding, and require considerable economic investment. These aspects make them quite daunting for environmental managers; however, developing innovative management strategies that lead to incremental progress is not impossible.

This report summarizes contemporary literature and original laboratory research on biochar's applicability as an alternative management option for beetle killed forests and an organic soil amendment to improve the quality of degraded mined lands. The report also elaborates on the market feasibility of using biochar for extended management strategies, as well as the unique benefits that it can bring to both forest management and mine reclamation. This project initially was conceived to help the Monarch Ski Area repurpose deadwood that is now annually burned on site. Instead, the material could be used for biochar stocks which could then be sold to the many local mining restoration projects for the restoration of soils and water.

Contents

1: Introduction and Needs Assessment

There are great needs to repurpose beetle killed deadwood in the Gunnison Basin, in Colorado, and throughout the West. The Colorado State Forest Service releases an annual report entitled: *Report on the Health of Colorado's Forests*. Recent surveys, published in January 2017 and 2018, presented the following statistics: One in 14 trees in Colorado forests have been killed by bark beetle infestations, leading the number of impacted trees to reach 834 million as of 2018. This is an increase of 30% since an inventory in 2017. Additionally, the continuing spruce beetle epidemic has killed trees across 1.8 million acres of Colorado forests (Colorado State Forest Service, 2017, 2018). Additionally, the spruce beetle was Colorado's most widespread and damaging forest insect pest for the seventh consecutive year (Colorado State Forest Service, 2018). A total of 206,000 acres with active infestations were observed in high-elevation Engelmann spruce forests (Colorado State Forest Service, 2018). There are several reasons why the wicked problem of beetle kill is problematic. First, this amount of standing dead biomass creates an enormous danger of massive wildfires such as the ones that devastated parts of Colorado in the summer of 2020 (National Geographic Area Coordination Centers, 2021). Secondly, the carbon embodied in this wood will enter the atmosphere, rather than be sequestered. Recent studies have even concluded that wood burning may create more carbon emission than gas, oil, and even coal (Laganière et al., 2017). Today, these forests of standing dead are commonly managed through controlled burns and sanitation and salvage methods (USFS, 2018).

There is a need for innovative solutions to manage this important and critical problem more efficiently and in a way that does not produce further greenhouse gas emissions and contributions to climate change. Climate change has been found to promote the bark beetle's capacity for forest degradations, as increased average temperatures will have expanded the climate limitations and thus the geographic ranges where the beetles can survive. In short, beetle kill often results in large scale wildfires, and it can be managed by controlled burning methods; however, both wildfire and burning releases carbon dioxide (CO_2) and greenhouse gases (GHGs) which contribute to climate change and further exacerbate future potential beetle kill (Carswell, 2012; Cudmore et al., 2012).

In addition, the state of Colorado and the Gunnison Basin have a second major issue: mined land restoration. In the state of Colorado, more than 23,000 abandoned legacy mines have been left unattended after the mine has either shut down or the responsible manager has left the site after extraction (Colorado Geological Survey, 2017). This is a critical problem in high alpine headwaters regions such as the Gunnison Valley. Pollution such as acid rock drainage from these sites has been found to impact approximately 1240 miles of streams throughout the state of Colorado, which nearly equates to the distance between Miami, Florida and Toronto, Ontario. (EPA, n.d.).

The legacy sites require intensive restoration projects to restore heavily degraded ecosystems to a condition consistent with acceptable environmental quality. Colorado's Western Slope is home to many of these mines; the Gunnison Basin is full of them. Current approaches to restoring these sites are just scratching the surface of the problem.

In the Anthropocene, our current time in history where humanity predominantly dictates the state of nature, numerous issues in land degradation deserve critical attention. Bark beetle infestations kill massive expanses of forests throughout Colorado and the Western United States. It is estimated that bark beetles have killed roughly 1.8 million acres of forest land in Colorado alone, and about 85.5 million acres of coniferous forest in the Western United States (USFS, 2020; Colorado State Forest Service, 2018). These forests of standing dead trees result in dangerous fuel buildup which presents the risk of massive scale wildfires and climate change driving CO_2 emissions (California Department of Fish and Wildlife, 2020; Cudmore et al., 2012). Concurrently, mining related issues broadly include deforestation, the mass uplift of soils and the degradation of vital biotic communities, as well as water and air pollutions (Sahu & Dash, 2011).

There may be an innovative solution to both beetle kill fuel buildup and the issues of soils and waters impacted by mining. Research shows that part of the solution could be biochar: a material produced by incinerating biomass such as beetle killed trees, that has many properties for restoring degraded soils (Hawken, 2017; Ronsse et al., 2013) This soil amendment is found to promote nutrient buildup for revegetation, carbon sequestration, and the concentration of heavy metals to catalyze their removal (Ippolito et al, 2019; Lal et al, 2018; Ippolito et al, 2017; Anawar et al, 2015; Lehmann & Joseph, 2009). When added to topsoil, biochar can massively sequester carbon, and its production can be an alternative to controlled burning; thus, furthering emissions offsets. Sequestration and repurposing the beetle kill can serve to mitigate the positive feedback loop of climate change which drives further beetle infestations (Cudmore et al., 2012). Many lands formerly mined are often devoid of nutrients due to heavy erosion or the piling of waste rock, making soil amendments a common management prescription (Shrestha and Lal 2006). Biochar has also been found to aid in the buildup of nutrients in depleted soils and increase the soil’s water retention capacity (Anawar et al, 2015; Novak et al., 2016). The containment and restoration of acid rock drainage is another immensely difficult and resource intensive issue for environmental managers and mining reclamation professionals to address; however, recent studies have found that biochar’s adsorptive qualities can aid in these projects as well (Wibowo, 2019). With the abundance of local beetle kill and no shortage of legacy mines in need of reclamation, Colorado’s Western Slope is an ideal setting to implement biochar strategies for both beetle kill management and mined land restoration.

High elevation alpine ecosystems are among the most difficult areas to revegetate following disturbances. Extreme and variable temperatures and precipitation allow for only a limited suite of specialized species to survive in such areas (Urbanska et al., 1997). The difficulty of revegetating any alpine ecosystem prompts the need for an innovative solution such as soil amendments (Henry & Bergeron, 2005).

Found in the headwaters of the Gunnison River about 42 miles east of Gunnison, at about 10,500 feet in elevation, the Pitch Mine Reclamation Area in Saguache County, Colorado, is an alpine area that experiences severe seasonal weather and difficulty in revegetation due simply to its environment (see Figure 2). Ongoing reclamation activities at this site include revegetation and reforestation activities, erosion controls, and extensive water quality protection activities and monitoring (Homestake, 1991).

Also, in Saguache County is the inactive Los Ochos Mine, located within the Cochetopa Valley desert. This legacy mine was a pioneer site for the United States’ uranium boom which resulted in extensive extractions and modifications to the sagebrush steppe ecosystem (Danielson & Hartson, 2018). Today, the fragile ecosystem is littered with barren expanses and around 718,900 cubic yards of contaminated waste rock piles scattered throughout 92 acres of Bureau of Land Management (BLM) open space designated through the closure plan (see figure 2) (Danielson & Hartson, 2018). Further descriptions of the Pitch Mine Reclamation Area and the Los Ochos Mine can be found in sections 8.1 and 8.2 respectively. The need for extended restoration action is the result of historical mining activity and the environmental conditions of the mines that make native ecosystems difficult to establish in the first place.

In theory, beetle kill sourced throughout Colorado or locally at Monarch Pass could serve as the feedstock for producing large quantities of biochar for prolonged restoration projects. The addition of soil amendments produced from local feedstock will most likely help to build soil and improve soil and water health, effectively restoring the degraded ecosystems from the bottom-up. To truly understand the feasibility of using the beetle kill for a long-term biochar operation to restore the Pitch Mine site, extensive testing needs to be conducted to study biochar's applicability for restoring soil and water quality at this specific location.

Figure 1: Overview of the Pitch Mine Reclamation Area in 2018.
(Photo sourced from Google Earth***)***

Figure 2: Ruins of the Los Ochos Mine and Mill. Barren uplift is a legacy of the mining operation. (Photo by Nathan Gore)

2: What is Biochar?

Biochar is a carbon based solid product produced when organic feedstocks such as wood, manure or leaves are heated in closed containment in the absence of oxygen (Lehmann & Joseph, 2009). Biochar is similar in appearance and physical composition to common charcoal; and is a highly porous, lightweight, and fine-grained material with a high surface area. Biochar is formed by incinerating biomass feedstocks under the process of thermal decomposition pyrolysis (Lehmann & Joseph, 2009). While similar in composition to charcoal, biochar is distinguishable from similar products as it is produced with the intent to improve the qualitative condition of soils. Some of these improvements include but are not limited to: the sequestration of carbon, increasing soil productivity, the filtration of water, and the concentration of water soluble metal contaminants. (Ippolito et al, 2019; Lal et al, 2018; Ippolito et al, 2017; Anawar et al, 2015; Novak et al., 2016; Anawar et al, 2015; Lehmann & Joseph, 2009).

Both the research and the use of biochar for environmental management are relatively recent developments; however, the utilization of biochar to promote the buildup of plant available nutrients and soil organic matter is by no means a new science (Lehmann & Joseph, 2009). Records from the mid-19th century recount observations of biochar being utilized for agricultural soil improvement. An account by Trimble (1851) states: “evidence upon almost every farm in the county in which I live, of the effect of charcoal dust in increasing and quickening vegetation” (Lehmann & Joseph, 2009). The modern day uses of biochar are based on the discovery of ancient Amazonian dark soils, locally referred to as Terra Preta de Indio, where charcoal and ash were used as fertilizers and high levels of organic carbon persist today (Glaser et al., 2001). Amazonian soils that received Terra Preta charcoal treatments prior to the arrival of Columbus in 1492, still to this day retain massive extents of stored carbon and plant available nutrients. These soils have efficiently sequestered carbon and promoted soil fertility for more than at least 500 years (Mann, 2006). These cases and many other early uses of biochar demonstrate the applicability of the product for many uses highly beneficial to treated soils, and as a solution for many difficult to resolve environmental issues. Modern day commercially produced biochar has been found to have great success for environmental projects. The porosity of biochar makes it at an appliable agent for adsorbing metals uplifted from mining activity, which includes but are not limited to Iron, (Fe) Aluminum (Al) Cadmium (Cd), Copper (Cu), Lead (Pb), and Zinc (Zn). Positive fluctuations in pH have also been observed with biochar treatments, which makes the amendment a potential solution for treating acidic waters and soils. (Wibowo, 2019; Ippolito et al, 2017). Furthermore, these adsorptive properties make biochar a potential aid for the cost and resource intensive cleanup of acid rock drainage (ARD), a wicked problem regarded as the greatest environmental issue present in the mining industry (Warhurst, & Noronha, 2000).

Modern day commercially produced biochar can be systematically produced by thermal conversion pyrolysis. The term pyrolysis is derived from the Greek elements pyro "fire" and lysis "separating," as pyrolysis is literally the separation of organic matter through heat (Biochar for Carbon Capture, n.d.). The thermal conversions are performed at temperatures ranging from 300 to 600 °C, and in the absence of oxygen. Pyrolysis for biochar production is generally executed with one of two methods, slow or fast pyrolysis. Slow pyrolysis is the most utilized method for producing biochar as this process yields higher percentages of feedstock converted to biochar as opposed to gases or bio-oils (Kung, 2014; Biochar for Carbon Capture, n.d.).

3: Beetle Kill as a Supply for the Biochar Market

With the massive amounts of beetle kill littered throughout Colorado and the West, there is a great potential to use the carbon stored within beetle killed biomass as the feedstocks for large biochar operations. The coniferous trees subject to beetle kill at locations, such as Monarch Pass, are viable as the feedstock for biochar due to the pyrolysis by which the material is produced. The beetle killed tress, which when still ingrained in the soils are referred to as standing dead, can be refined into biochar so long as the woody biomass holds together in the biochar kilns (Biochar Now, 2018). The capability of the industry pyrolysis kilns would suggest that the most prominent factor influencing an individual tree's potential for use as feedstock is the timeline before it decomposes. Most species of spruce generally decompose within a timeline of 50 to 100 years, giving land managers an ample period to repurpose viable feedstocks (Korneliussen, 2012). Therefore, even after these trees have degraded to the point that they are not valuable for lumber, they can be made into biochar (Lehmann & Joseph, 2009).

While different factors such as air and soil moisture can influence the rate of decomposition, one could use normal decomposition time to gauge the lifespan that a standing dead could be used for biochar. Additionally, both hardwood and softwood forest resources impacted by wildfire are also viable for biochar production through patented pyrolysis systems such as those used by the Biochar Now LLC Company (Biochar Now, 2018). With pyrolysis technology and a market built on proven biochar successes in the agriculture and mining sectors, the beetle ridden forests of Colorado could serve as massive feedstock reservoirs for extended biochar restoration strategies.

4: Mine Reclamation for the Biochar end Market

A product of Colorado's rich mining history, more than 23,000 inactive mining operations now lie abandoned as hazards to both the surrounding environment and communities that rely on the land's resources (Colorado Geological Survey, 2017). There are an estimated 500,000 abandoned mines in the United States (House.gov, 2016) and there are undoubtedly some millions of abandoned mines scattered throughout the world. Each area presents a risk for degradation despite the inactivity of their intended purpose (Ippolito, 2019). Many of these relics of the Anthropocene continue to produce ARD, an environmental issue regarded as the most pressing and difficult to manage impact of mining (Warhurst, & Noronha, 2000). ARD affects both ground and surface waters in many mining regions, and, once the reactive process begins, it may persist for centuries, or even millennia. This longstanding issue is demonstrated in the famous Rio Tinto Mine of modern-day Spain, that still, to this day, expels ARD after nearly 5,000 years of initial copper, silver, and gold extraction dating back to the rule of the ancient Phoenicians, Greeks, and Romans (Amaral Zettler et al., 2003).

ARD is a chemical waste issue caused be reactions occurring between frequently exposed pyritic minerals, sulfates, and extremophilic bacteria. Acid rock drainage occurs naturally within some environments as a part of the rock weathering process; however, it is commonly exacerbated by large-scale earth disturbances characteristic of mining hard rock minerals such as silver, lead, copper, and zinc (Campbell, et al., 2016). ARD occurs primarily when the mineral ore pyrite (FeS2) is exposed to water and oxygen from air, producing soluble iron and sulfuric acid. During oxidation, Extremophilic microorganisms will decompose the iron pyrite into small, water soluble particles to produce sulfuric acid, while also significantly lowering the pH of the water (Campbell, et al., 2016, Warhurst, & Noronha, 2000). As pH decreases, metals in other mineral ores become more readily dissolved. The resulting acid mine drainage may thus not only contain high levels of sulfate and iron, but other dissolved metals as well (Campbell, et al., 2016). With the inherent risks and hazards that ARD presents to both biotic and human environments, as well as the longevity of impacts, it is imperative that environmental managers and mining restoration professionals alike utilize all resources to address ARD at the source.

Contemporary studies show that biochar may be a viable option for remediating the impacts of mine drainage, as the char has the capacity to reduce soil acidity and increase binding sites for the adsorption of heavy metals (Ippolito, 2019). Additionally, biochar's capability to store carbon from biomass input, such as Engelmann spruce trees, allows that carbon to be sequestered back into the carbon cycle when the material is buried as a soil amendment. When the carbon is added to soils, it can help to promote plant growth in areas previously made infertile by the heavy metal runoff and acidic mine leaching (Ippolito, 2019). Cadmium, Lead, Copper, Zinc, and Titanium are all metals commonly leached from mines into water and soil systems; biochar has been found to ionically bind to all of these metals to catalyze their removal from the sensitive ecosystems (Ippolito, 2019; Fellet, 2011). With biochar's evolving applicability for mine restoration and sequestration, the need for restoring mine-impacted landscapes in Colorado and around the world may serve as the driver to make biochar production an economically viable solution for diverse environmental issues.

Mineral runoff of the 23,000 derelict mines in Colorado presents massive risks to both environmental and human health which presents the need for remediation under the Clean Water Act (CWA) and the standards of the Environmental Protection Agency (EPA) (Colorado Geological Survey, 2017). Many of the American Southwest's most critical beetle kill infestations have occurred in Colorado's Gunnison County, Saguache County, and Chaffee county which encompasses the Monarch Pass infestation. In these three neighboring counties, more than 384,000 acres of forest were affected and deemed critical during the period of 1996 to 2017 (Barry et al., 2018). The massive amounts of standing dead biomass could, in theory, be removed and processed by pyrolysis with its lower emissions factor to mitigate the imminent risk of rampant wildfires, while also producing biochar to remediate the 23,000 abandoned mines in Colorado. There are many inactive mines that if untreated would pose extreme risks to the environment and communities within Gunnison, Saguache, and Chaffee counties, thus emphasizing the pressing need for immediate remediations (Colorado Geological Survey, 2017). With the continually evolving research on the applicability for biochar to remediate damages caused by mine drainage, processing the abundant beetle kill in Colorado may serve to address multiple issues under the umbrella of the biochar processing strategy.

6: Biochar and Carbon Sequestration

Carbon sequestration is the process of plants and soils storing carbon within the plant biomass or soil organic matter. This ecosystem service prevents the carbon from being released into the atmosphere or it captures the greenhouse gases and stores them within the organic material (Paustian et al., 2019). In plants, this carbon uptake occurs during photosynthesis, thus creating the large carbon stocks in forests such as the coniferous expanse at Monarch Pass. Sequestering amendments such as biochar and compost can be used to reduce the rates of turnover of organic carbon stocks already in the soil (Paustian et al., 2019). When tree biomass is burned in traditional management, a great majority of the carbon is released back into the atmosphere. Biochar, however, retains a much more significant amount of the carbon from the biomass by storing it in the solid char product instead of the gas product. With this quality, biochar production has vastly lower emissions than traditional burning because the soil amendment retains the carbon in its solid form. Biochar has thus far been used as a novel strategy to increase the carbon stocks of amended soils to increase nutrient flow and offset emissions by a potential of up to 9.5 gigatons annually (Yousaf et al., 2016). While it is predicted that biochar has an incredible potential to sequester carbon, it has never been implemented at the scale needed to attain the 9.5 gigatons figure (Yousaf et al., 2016). A study of biochar's sequestration potential concluded that by burning and burying ten percent of the world's biomass waste, the char could sequester nearly five gigatons of carbon annually, while human activity adds an approximate net 4.1 gigatons of CO_2 emissions to the atmosphere per year (Matovic, 2011). If this estimated ten percent of the world's biomass waste was processed into biochar for the use of carbon sequestering, an annual negative net sequestration profile could be achieved to mitigate contributions to climate change.

The global human population releases roughly 28 gigatons of CO_2 into the atmosphere each year, but much of that is naturally sequestered by vegetation and the world's oceans (Matovic, 2011). Coniferous forests being killed by bark beetle infestations are vegetative expanses that have historically sequestered the CO_2 from the atmosphere. Processing this biomass waste into biochar could serve to negate annual anthropogenic emissions, while also lessening the loss of sequestration capacity to the infestations.

Solid wood and forest materials are considered one of the five main sources of biomass waste (Need.org, n.d.). An estimated 44% of the world's biomass waste is wood primarily accumulated during deforestation for agricultural expansions (Need.org, n.d.). Beetle infestations are also becoming a growing source of wood waste biomass. The exact percentage of how much total biomass waste is being created by the beetle infestation pandemic is unclear, considering how widespread the infestations are in relatively remote areas of the world. The issue is enormous, but so is the potential for innovation. If biochar processing could be used to manage the sheer amount of beetle infestation standing dead forest accumulated around the world, this could help contribute to the vision of using biochar and carbon sequestration to meet the net negative emissions output while potentially remediating impacted soils at mine sites.

The production of biochar from forest wastes can serve as innovative means for removing massive amounts of loaded fuel from a degraded forest, reducing the risks of massive forest fires, and producing a viable byproduct with many uses. The carbonaceous biochar can persist in the soil ten to 100 times longer than the original biomass, thus initiating a massive climate impact mitigating storage of carbon (Lehmann & Joseph, 2009). The global potential of biochar to sequester carbon both above and belowground ranges from 0.5 to 1.1 Petagram of carbon per year, which is roughly equal to the amount of carbon released annually to the atmosphere from land use change, or about 25% of the carbon released from fossil fuel burning (Lal et al. 2018).

7: Biochar and Revegetation

One of the most prominent cases of biochar being utilized for the successful revegetation of a mine impacted landscape occurred during the reclamation of the Hope Mine, sponsored by the Aspen Center for Environmental Studies. The Hope Mine is an abandoned mine located in the White River National Forest approximately six miles south of the City of Aspen, Colorado. The Hope Mine was an active silver mine operating throughout the early 19^{th} century that changed ownership numerous times before finally being acquired by the USFS in 2003 (Aspen Center for Environmental Studies, 2011).

The Hope Mine Biochar Project was the first and largest whole-mine reclamation project completed with biochar in the United States (Aspen Center for Environmental Studies, 2011).

The legacy mine was selected by the USFS Aspen-Sopris Ranger District as the site of a demonstration trial for determining the effectiveness of biochar in field settings. The site was selected due to the abundant mine waste that had been piled into large, concentrated masses eroding directly in Castle Creek, a source of Aspen's water supply. While the city's water department found no apparent evidence of heavy metals contamination, there was concern for catastrophic erosion in the event of heavy rain events. A traditional mine cleanup of the site would have required a budget ranging in the millions (Aspen Center for Environmental Studies, 2011).

Biochar and compost amendments were dispersed on approximately 0.6 acres of unvegetated waste rock in October 2010 (USFS Sopris Ranger District, 2011). Three monitoring events occurred in June, July, and August of 2011 at approximate 30-day intervals. Monitoring methods included measurements of vegetation cover percent and soil moisture percentage (USFS Sopris Ranger District, 2011). Biochar and varied amounts of soil amendments including biosolid compost, mycorrhizal fungi, and hydromulch were dispersed throughout the northwestern hillside of the Hope Mine in test plots. Control plots and plots without biochar were also utilized for quality control (USFS Sopris Ranger District, 2011). One year after the amendments were dispersed at the mine site, detailed monitoring assessments found that soils amended with biochar resulted in approximately 313% more plant growth than soils amended with compost alone. Additionally, the soils treated with biochar retained significantly more moisture than those without. An excellent root zone and soil organic matter level was developed in both areas that received both compost and biochar treatments. The optimal application rate was a 10-20% ratio of compost and biochar mixed together, which led to slope stability and erosion control both being achieved in just one year after the biochar treatment (Aspen Center for Environmental Studies, 2011).

The Hope Mine Biochar Project was primarily made feasible due to collaborations between the public and private sectors. With the inactive mine being on Forest Service land, the decision to enact the biochar strategy, ultimately, was made by the federal land managers under the framework of the NEPA process (USFS Gunnison Ranger District, 2021). Before being proposed to the USFS, the project was planned by the Aspen Center for Environmental Studies, a well respected non-profit organization. The public private partnership framework could, in theory, be replicated to address mine sites anywhere. The costs of a traditional site clean-up were also a crucial factor that made this biochar project both appealing and feasible. Both the Aspen Center for Environmental Studies and the USFS saw the pressing need for the restoration of the site; however, the lofty expenses associated with cleanup led the Aspen Center for Environmental Studies to pursue alternative means of reclamation with biochar. Stressed local and federal budgets were not planned in advanced for a traditional remediation project at the scale of the Hope Mine, so the cost efficient option of biochar and amendments was very appealing. With contemporary studies on the benefits of biochar, the Aspen Center for Environmental Studies and the USFS took a chance to experiment with the amendment. The investment surely paid off, as revegetation was highly successful and is now regarded as one of the greatest examples of alternative management in mining reclamation. (USFS Gunnison Ranger District, 2021).

Photograph 1: Extent of groundcover during the 2011 growing season, Hope Mine, CO.

Photograph 2: Development of root zone within vegetative cover with mine rock acting as a barrier, Hope Mine, October 2011, 12 months after application of cover. Bottom of tape represents boundary.

Figure 3: Photographic documentation of the successes at the Hope Mine Restoration. (Imagery from Aspen Center for Environmental Studies, 2011)

8: Efforts, Conversations, and Progress Thus Far

8.1: Monarch Ski area and Biochar Now LLC

On Thursday, March 4th, 2021, I conducted a conference call to establish communications between Monarch Ski Area and Biochar Now LLC. In the months prior to this call, I had begun communications with Monarch Ski Area's Vice President of Mountain Operations Scott Pressly. Conversations with Pressly centered around repurposing Monarch's beetle kill into biochar as opposed to burning the material on site, which had been done since November of 2019. Concurrently, a relationship was developed with Biochar Now LLC Representative Tony Myers. Throughout the timeline of this MEM project Mr. Myers had acted as a consultant. With a plethora of experience in the biochar industry, Mr. Myers generously provided many resources to help me create a literature review of biochar's applications. At the end of February 2021, Pressly had informed me of Monarch Ski Area's beetle kill management plans for the Summer or Fall of 2021.

At the beginning of the call on March 4th, I reminded the participants of the purpose of the MEM project and the objective to repurpose beetle kill stocks into biochar to create a supply which could later be allocated to restoration projects. Mr. Myers followed and provided some background on the diverse applications of biochar and the benefits that it can bring to numerous industries and sectors. Mr. Pressly then explained the history of Monarch Ski Area's beetle kill management and how it has evolved since the publication of the USFS 2018 Forest Vegetation Management Plan. He then explained that Monarch would be felling approximately 60-70 acres of beetle kill in the summer of 2021. Helicopter flights will fly the beetle kill to Monarch's 1.75 acre Paradise Parking lot. It is planned for a majority of the beetle kill to be sold as fire wood and the remaining biomass will be burned on site unless alternative management is decided upon. There is currently no estimated tonnage of beetle kill that Monarch will have available for processing by September 2021, so it is difficult to budget exactly for trucking between Monarch Ski Area and the Biochar Now LLC facility in Berthoud, Colorado. If an estimate could be provided, Biochar Now would be willing to pay around $60/ton of dried beetle kill. A break even cost at this rate would be $.033 per mile. A more detailed explanation of trucking costs can be found in Section 9.1: Biochar Costs Comparison.

Of course, there are other benefits beyond mitigated burning that Monarch would receive from such a biochar operation. One would be the ability to advertise and promote its contribution to solving the pressing climate issue. If Monarch is contributing to carbon sequestration, eliminating a massive wildfire hazard, and solving local water quality problems, this is a "triple win" for them as a company. These actions might be akin to the Aspen Ski Area helping to capture methane from inactive coal mines and using it to generate electricity for ski area operations, an action that Aspen is justly proud of, and which has been widely advertised and discussed in the media (Aspen Snowmass, 2021).

The greatest challenges of this proposed biochar based forest management plan stem from the costs of trucking the dead trees to Biochar Now LLC in Berthoud, and then trucking the resulting biochar back over Monarch Pass to sites such as the Pitch Mine. The carbon emissions of this trucking plan may also be significant. Fortunately, a mobile pyrolysis kiln unit may be available for use in the future, which could help reduce the severity of these limitations.

In theory, a small scale project to demonstrate feasibility could be done within existing constraints. Dead wood could be transported to a distant facility where it would be converted to biochar and returned to the Western Slope for use in inactive mining reclamation, despite the expense and carbon footprint of such a solution. This would require short term funding to make the pilot project viable.

In the longer term, Biochar Now is in the process of developing mobile biochar kilns on trailers that could allow the biochar operations to occur practically anywhere. It is anticipated that the mobile kilns would be available by July of 2021 (Biochar Now, 2021). These kilns would have the capacity to process about one ton of beetle kill per day. Myers expressed that a hindering limitation with the mobile operation option is that once the feedstock is processed into biochar, it needs to be shredded to appropriate sizes for various applications. Additionally, the use of the mobile kiln units will be costly. An exact quote has not been given, but Biochar Now expressed that the use of the mobile kilns will likely not be feasible with a limited amount of available feedstock piled by Monarch Ski Area during the summer of 2021. The contracts for use of the Biochar Now mobile kilns are currently being delegated for uses such as the incineration of inactive glass and carbon fiber wind turbines, and the removal of large quantities of biomass produced from natural disaster events such as hurricanes (Biochar Now, 2021).

Given the potential value of biochar in a pilot project at the Pitch Mine, and the need for Monarch Ski Area to dispose of a considerable quantity of beetle kill in a way that promotes carbon sequestration, the cost issue of producing the biochar in Berthoud may be resolvable on a pilot project basis. If these pilot projects produce positive results and there is an initiative to 'scale up' the operation to deal with dead standing trees in a larger area and serve more mines, producing the biochar locally in a permanent large scale biochar plant seems to be the preferred solution.

8.2: Homestake Mining Company

The Homestake Mining Company is the management entity currently responsible for all reclamation activities at the Pitch Mine Reclamation Site in Saguache County, Colorado. David Wykoff, the Reclamation Manager at the site has been very open and willing to allow students to utilize the inactive mine site for hands-on learning experiences at the Pitch Mine. In the fall of 2020, Dr. Jennie DeMarco and I wrote a proposal for the development of WCU student projects at the Pitch Mine. Included in this proposal is the implementation of an on-site soil amendment experiment. A full summary of this proposed action is included below in Appendix B. Mr. Wykoff and the Homestake Mining Company have agreed to facilitate this research project at the mine site for a future graduate student. The company has also allocated funding to hire an intern at the site for the summer of 2021. The application of the on-site soil amendment experiment and the internship will undoubtably strengthen the relationship between the Homestake Mining Company, WCU, and WARM, which will be needed to bring in the Homestake Mining Company as a potential end market user for a massive stock of biochar.

During a conversation with Dave Wykoff in April of 2021, he expressed that WCU and WARM may continue to be involved with activities at the Pitch Mine Reclamation Area for years to come. Mr. Wykoff explained that in the late summer or fall of 2021, revegetation efforts would take place on a large hillside of the Pitch Mine that experienced significant earthmoving and tree removal for erosion control in the summer of 2020 (see Figures 4 and 5). The revegetation efforts will involve the mass dispersal of hydromulch and native seeds on the expanse of land. Mr. Wykoff stated that if WCU and WARM can identify and supply a stock of biochar, the Homestake Mining Company will disperse the material on the hillside with the hydromulch treatment. Fortunately, large amounts of biochar are available for this project. In the fall of 2020, another MEM graduate student, Heather Reineking and Dr. Jennie DeMarco helped to organize a biochar enhanced restoration project at the Ben Butler Mine near Silverton, Colorado. The Colorado DRMS delivered four cubic yards of biochar that were never utilized at the site. Kirsten Brown, project manager at the CDRMS has expressed that WCU and WARM are welcome to pick up the biochar to transport it to the Pitch Mine. Acquiring this stock of biochar at the Butler Mine should be prioritized. The opportunity to disperse the biochar at the Pitch Mine presents the capability for WARM to recreate a modified version of the Hope Mine reclamation. If the biochar should truly enhance the revegetation of this hillside at the Pitch Mine, the project could be the Pilot Project needed to display biochar's applicability for restoration enhancement on the Western Slope.

Figure 4: Slope of the Pitch Mine Reclamation Area available for biochar enhanced revegetation. (Photo taken by Nathan Gore)

Figure 5: UAV photo of the hillside of interest at the Pitch Mine Reclamation Area. (Photo provided by Dave Wykoff at the Homestake Mining Company)

9: Conclusions and Recommendations

This review and preliminary assessment of local management options will, hopefully, serve as the first steps for future students in the WCU MEM or consultants at the SDSG to continue this work and to make biochar based natural resource management more normalized. To make this proposed action come to fruition, future environmental managers will need to continually study successes of existing projects, which will evidently help inform local, original projects. Ultimately, I believe that the large scale biochar based management of an area, such as Monarch Pass or the Pitch Mine Reclamation Area, will require that initial, smaller scale pilot programs be integrated into existing management practices. Should the experimental projects show that biochar based solutions are more cost efficient or enable a more effective mine remediation water or revegetation treatment, the successes could lead to incrementally larger management strategies. Additionally, building local relationships, such as those with the Pitch Mine Reclamation Area, Monarch Ski Area, or the USFS, could lead to future MEM, WARM, or SDSG projects to explore biochar strategies.

The market research supports the fact that although the Colorado Western Slope contains it's fair amount of beetle kill and inactive mines, the most substantial biochar production centers and subsequently biochar reserves are located in the Eastern Slope. While trucking the beetle kill and biochar long distances is not ideal, the operations may still be feasible and even carbon neutral or negative, due to carbon sequestration and the possible prevention of large scale wildfires.

Budget cuts and social distancing measures imposed upon the world by the COVID-19 pandemic have made applied progress toward biochar management difficult; however, significant progress has been made in building local relationships across industries and inform various sectors about the possibilities. An interview with a representative of the local USFS indicated that expansive biochar strategies for beetle kill management may currently be a future vision more than a current reality, however, the Biden Administration has already made efforts to combat climate change and has promised to prioritize projects for carbon sequestration (White House, 2021). Progress and successes will ultimately cumulate and lead to the alternative management of beetle ridden forests across the nation. Eventually, local, and national climate change policies incentivizing projects including biochar, may arise. When these policies and incentive programs are enacted, pilot projects, such as the Hope Mine Biochar Project or applications planned in this report, may provide baseline methodologies for future management plans.

Students or consultants continuing this work should prioritize efforts towards the pilot project at the Pitch Mine Reclamation Area. This invitation for collaboration from the Homestake Mining Company is a great opportunity to demonstrate biochar's applicability for mine revegetation in an experiment resemblant of the Hope Mine Biochar Project. Additionally, conversations should be continued with Monarch Ski Area. Repurposing forest waste for biochar may be the most straightforward through work with Monarch Ski Area, as the private entity already has the framework for removing the beetle kill from the mountain itself, as well as the need for removing it from the site. The continuation of these relationships appears to be the most promising steps toward establishing relatively local pilot programs for mine reclamation and beetle kill management respectively. The execution of these relatively small scale projects will prove the viability of this management strategy, which will hopefully pave the road for larger, more programmatic plans with tiering benefits.

At its core, this project was designed and written so that it could be utilized by future environmental managers to continue to build progress toward biochar based solutions. Those with access to this document are welcome to re-use the presented information for the timely composition of shorter, primer style, documents tailored towards specific projects or sites. Future workers may also supplement this report with more recent findings to continue building a compendium of best practices and a portfolio of applicable sites. Through extended research, both in the science of biochar and its place within the market economy, students and consultants will enable the first steps towards the future of adaptive land management and the addressing of numerous wicked problems.

Resources Cited

Amaral Zettler, L. A., Messerli, M. A., Laatsch, A. D., Smith, P. J. S., & Sogin, M. L. (2003). From Genes to Genomes: Beyond Biodiversity in Spain's Rio Tinto. *The Biological Bulletin*, *204*(2), 205–209. https://doi.org/10.2307/1543560

Anawar, H. M., Akter, F., Solaiman, Z. M., & Strezov, V. (2015). Biochar: An Emerging Panacea for Remediation of Soil Contaminants from Mining, Industry and Sewage Wastes. *Pedosphere*, *25*(5), 654–665. https://doi.org/10.1016/S1002-0160(15)30046-1

Anderson, N., Jones, J., Page-Dumroese, D., McCollum, D., Baker, S., Loeffler, D., & Chung, W. (2013). A Comparison of Producer Gas, Biochar, and Activated Carbon from Two Distributed Scale Thermochemical Conversion Systems Used to Process Forest Biomass. *Energies*, *6*(1), 164–183. https://doi.org/10.3390/en6010164

Aspen Center for Environmental Studies. (2011). *Hope Mne Biochar Project*.

Barry. (2018, February 7). Forest Health Report Focuses on Dealing with Colorado's Dead Trees. *Colorado State Forest Service*. https://csfs.colostate.edu/2018/02/07/forest-health-report-focuses-dealing-colorados-dead-trees/

Biochar for Carbon Capture. (n.d.). *Biochar Production: Fast and Slow Pyrolisis*. Retrieved February 26, 2021, from https://biocharforcarboncapture.com/research/fast-and-slow-pyrolisis

Biochar Now. (2018a). *Biochar Now Issue Patent*.

Biochar Now. (2018b, January 23). Products. *Biochar Now*. http://biocharnow.com/products/

Biochar Now. (2021). *Interview with Biochar Now*.

California Department of Fish and Wildlife. (2020). *Science: Wildfire Impacts*. https://wildlife.ca.gov/Science-Institute/Wildfire-Impacts

Campbell, K., Todd, McCleskey, McKnight, Nordstrom, Runkel, & Ryan. (2016, May 24). *Acid Mine/Rock Drainage*. Center for Water, Earth Science and Technology. https://www.colorado.edu/cwest/research/research-themes/water-and-environmental-quality/acid-minerock-drainage

Carswell, C. (2012, November 28). The bark beetle feedback loop. *High Country News*. https://www.hcn.org/blogs/goat/the-bark-beetle-feedback-loop

Colorado Geological Survey. (2017). *AML*. Colorado Geological Survey. https://coloradogeologicalsurvey.org/hazards/aml/

Colorado State Forest Service. (2017). *2017 REPORT ON THE HEALTH OF COLORADO'S FORESTS*.

Colorado State Forest Service. (2018). *2018 REPORT ON THE HEALTH OF COLORADO'S FORESTS - SPECIAL SECTION: PROTECTING OUR COMMUNITIES*. https://csfs.colostate.edu/media/sites/22/2019/03/FINAL-307714_ForestRpt-2018-www.pdf

Cudmore, T. J., Björklund, N., Carroll, A. L., & Staffan Lindgren, B. (2012). Climate change and range expansion of an aggressive bark beetle: Evidence of higher beetle reproduction in naïve host tree populations. *Journal of Applied Ecology*, 1036–1043. https://doi.org/10.1111/j.1365-2664.2010.01848.x@10.1111/(ISSN)1365-2664.CLIMATE_JPE

Danielson, L., & Hartson, E. (2018). *Uranium Production in the Gunnison Basin*. http://sustainablelibrary.org/document-index/uranium/

EPA. (n.d.). *Impacts of Mining on Headwater Streams of the Southern Rocky Mountains*.

Finley, B. (2015, October 8). EPA crew at Standard Mine above Crested Butte triggers waste spill. *The Denver Post*. https://www.denverpost.com/2015/10/08/epa-crew-at-standard-mine-above-crested-butte-triggers-waste-spill/

Hawken, P. (2017a). Biochar. In *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. Penguin Random House LLC. https://drawdown.org/solutions/biochar-production/technical-summary

Hawken, P. (2017b). Biomass Power. In *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. Penguin Random House LLC. https://drawdown.org/solutions/biomass-power

Hawken, P. (2017c). Compost. In *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. Penguin Random House LLC.

Henry, C., & Bergeron, K. (2005). *COMPOST USE IN FOREST LAND RESTORATION*. 37.

Ippolito, J. A., Berry, C. M., Strawn, D. G., Novak, J. M., Levine, J., & Harley, A. (2017). Biochars Reduce Mine Land Soil Bioavailable Metals. *Journal of Environmental Quality*, *46*(2), 411–419. https://doi.org/10.2134/jeq2016.10.0388

Ippolito, James A., Cui, L., Novak, J. M., & Johnson, M. G. (2019). Biochar for Mine-land Reclamation. In *Biochar from Biomass and Waste* (pp. 75–90). Elsevier. https://doi.org/10.1016/B978-0-12-811729-3.00005-4

Kenton, W. (2011). *Carbon Credit Definition*. Investopedia. https://www.investopedia.com/terms/c/carbon_credit.asp

Korneliussen, I. (2012, July 30). *How long before a tree rots away?* https://sciencenorway.no/a/1374769

Kung, C.-C., McCarl, B. A., & Chen, C.-C. (2014). An Environmental and Economic Evaluation of Pyrolysis for Energy Generation in Taiwan with Endogenous Land Greenhouse Gases Emissions. *International Journal of Environmental Research and Public Health*, *11*(3), 2973–2991. https://doi.org/10.3390/ijerph110302973

Lal, R., Smith, P., Jungkunst, H. F., Mitsch, W. J., Lehmann, J., Nair, P. K. R., McBratney, A. B., de Moraes Sá, J. C., Schneider, J., Zinn, Y. L., Skorupa, A. L. A., Zhang, H.-L., Minasny, B., Srinivasrao, C., & Ravindranath, N. H. (2018). The carbon sequestration potential of terrestrial ecosystems. *Journal of Soil and Water Conservation*, *73*(6), 145A-152A. https://doi.org/10.2489/jswc.73.6.145A

Lehmann, J., & Joseph, S. (Eds.). (2009). *Biochar for environmental management: Science and technology*. Earthscan.

Mann, C. C. (2006). *1491: New Revelations of the Americas Before Columbus*.

Matovic, D. (2011). Biochar as a viable carbon sequestration option: Global and Canadian perspective. *Energy*, *36*(4), 2011–2016. https://doi.org/10.1016/j.energy.2010.09.031

Novak, J. M., Ippolito, J. A., Lentz, R. D., Spokas, K. A., Bolster, C. H., Sistani, K., Trippe, K. M., Phillips, C. L., & Johnson, M. G. (2016). Soil Health, Crop Productivity, Microbial Transport, and Mine Spoil Response to Biochars. *BioEnergy Research*, *9*(2), 454–464. https://doi.org/10.1007/s12155-016-9720-8

Paustian, K., Larson, E., Kent, J., Marx, E., & Swan, A. (2019). Soil C Sequestration as a Biological Negative Emission Strategy. *Frontiers in Climate*, *1*. https://doi.org/10.3389/fclim.2019.00008

Ronsse, F., Hecke, S. van, Dickinson, D., & Prins, W. (2013). Production and characterization of slow pyrolysis biochar: Influence of feedstock type and pyrolysis conditions. *GCB Bioenergy*, *5*(2), 104–115. https://doi.org/10.1111/gcbb.12018

Shrestha, R. K., & Lal, R. (2006). Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. *Environment International*, *32*(6), 781–796. https://doi.org/10.1016/j.envint.2006.05.001
Urbanska, K. M., Webb, N. R., & Edwards, P. J. (1997). *Restoration Ecology and Sustainable Development*. Cambridge University Press.
USFS. (2020). *AREAS WITH TREE MORTALITY FROM BARK BEETLES SUMMARY FOR 2000 – 2019 WESTERN US*.
USFS Gunnison Ranger District. (2021). *Interview with USFS*.
USFS Sopris Ranger District. (2011). *Biochar Field Trial, Hope Mine Aspen Mining District, CO*. 48.
Warhurst, A., & Noronha, M. L. (2000). *Environmental Policy in Mining Corporate Strategy and Planning*.
White House. (2021, January 27). *FACT SHEET: President Biden Takes Executive Actions to Tackle the Climate Crisis at Home and Abroad, Create Jobs, and Restore Scientific Integrity Across Federal Government*. The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/27/fact-sheet-president-biden-takes-executive-actions-to-tackle-the-climate-crisis-at-home-and-abroad-create-jobs-and-restore-scientific-integrity-across-federal-government/
Wibowo, Y. G. (2019). *A Review of Biochar as a Low-cost Adsorbent for Acid Mine Drainage Treatment*. 10.
Yousaf, B., Guijian, L., Ruwei, W., Qumber, A., Muhammad, I., & Ruija, L. (2017). *Investigating the biochar effects on C-mineralization and sequestration of carbon in soil compared with conventional amendments using the stable isotope (δ13C) approach—Yousaf—2017—GCB Bioenergy—Wiley Online Library*. https://onlinelibrary.wiley.com/doi/full/10.1111/gcbb.12401