CARBON MARKETS INVESTMENT CRITERIA FOR BIOCHAR PROJECTS

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ABSTRACT

The Climate Trust conducted an assessment of biochar to determine its appropriateness as a terrestrial carbon sequestration offset project. Biochar is an inert residue created by pyrolysis with the potential to rapidly sequester large amounts of carbon. This report describes what types of biochar projects can most readily qualify as high-quality greenhouse gas offsets for carbon market buyers and investors. The offset quality criteria outlined by the Offset Quality Initiative (2008) are applied to the biochar project type as a whole and to a pilot project at the Thompson Timber log yard in Philomath, Oregon. This report finds that attractive projects must meet the following three criteria. First, projects must use waste biomass that, in the absence of a project, would be left to decompose. Second, projects must produce at least 25,000 metric tons of biochar over 10 years. Third, projects must be able to account for, track, and monitor where all the produced biochar is incorporated into the soil. When applying these criteria to the pilot project in Philomath, this report finds that the pilot project could be an attractive offset project if it were to scale up to use all available waste biomass and apply it to a limited number of landscapes.

Keywords: Terrestrial carbon sequestration, biochar, pyrolysis, climate change, carbon markets, greenhouse gas offsets, biomass, West Coast Regional Carbon Sequestration Partnership, WESTCARB

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EXECUTIVE SUMMARY

Introduction

The West Coast Regional Carbon Sequestration Partnership (WESTCARB), led by the California Energy Commission, is one of seven U.S. Department of Energy regional partnerships working to evaluate, validate, and demonstrate ways to sequester carbon dioxide (CO_2) and reduce emissions of greenhouse gases (GHGs) linked to global warming. The nascent carbon offset market offers a venue for directing funds to innovative terrestrial sequestration project concepts. However, such innovative projects must be validated against a set of criteria that are commonly used to determine the appropriateness and viability of the project concept in the carbon offset market.

Heating organic material without oxygen in a process called pyrolysis thermo-chemically transforms biomass into a stable char residue that resists decomposition, while also producing oil and gas. This residue is called biochar when it is incorporated into soils as an agricultural amendment (Driver and Gaunt 2010; Lehmann 2007; Roberts et al. 2010).

Biochar could provide a major contribution to the global effort to reduce GHG emissions; some estimates suggest it could mitigate as much as one-eighth of global GHG emissions (Woolf et al. 2010). Given the substantial timber resources in the region, many of the WESTCARB states (Alaska, Arizona, California, Nevada, Oregon, and Washington) are suitable candidates to host biochar projects.

Biochar production reduces GHG emissions through the following pathways:

1. *Sequestering carbon in biochar*. Photosynthesis sequesters carbon in biomass as it grows. When this biomass decomposes, the carbon is released back to the atmosphere. If the biomass is instead converted through pyrolysis into biochar, the carbon originally sequestered in the biomass will be stored for a much longer time because much of the carbon in the biochar will not decompose for hundreds or thousands of years (Lehmann 2007). Biochar can slow the basic carbon cycle to sequester carbon for long periods of time, because it is significantly more inert than the original feedstock that created it.
2. *Displacing fossil fuel energy with renewable energy*. Pyrolysis also produces oils and gases that can be combusted to generate renewable energy. When biomass instead of fossil fuels create energy—and it is harvested in a manner that does not increase land-use emissions— it can avoid CO_2 emissions.
3. *Diverting waste from generating methane*. Many biomass feedstocks that could be pyrolyzed currently decompose in the absence of oxygen under water or in landfills. Rice residues, green waste, and manure, for example, are commonly left to decompose in rice paddies, landfills, or lagoons (Woolf et al. 2010). This anaerobic decomposition

releases methane (CH_4). Pyrolysis of these feedstocks prevents this anaerobic decomposition and avoids these CH_4 emissions.

Through these pathways, biochar has the potential to provide a material contribution to efforts to reduce the build-up of greenhouse gases in the atmosphere. Globally, it is estimated that, at its maximum sustainable potential, biochar could annually reduce 1.8 gigatons of carbon dioxide equivalent emissions (CO_2e), or 12% of the world's GHG emissions (Woolf et al. 2010). In the United States, pyrolyzing 40% of unused agricultural and forestry residues could reduce 230 million metric tons of CO_2e, or around 8% of the annual GHG reductions needed to reduce domestic GHG emissions by 50% by 2050 (Roberts et al. 2010).

Purpose

Biochar's potential will only be realized if biochar projects prove to be financially viable. One important step towards profitability is to enable biochar projects to monetize their climate benefits. Biochar projects could do this by selling GHG offsets to regulated emitters under a cap-and-trade system. The Offset Quality Initiative (2008) discussed nine criteria that must be met for projects to qualify as offsets under such a system. This report addresses how each of these nine citerion applies to biochar projects in general and to a specific case study in Philomath, Oregon.

Project Objective

The overall goal of WESTCARB Phase II is to validate and demonstrate the region's key carbon sequestration opportunities through pilot projects, methodology development, reporting, and market validation. WESTCARB research will facilitate informed decisions by policy makers, communities, and businesses on how to invest in carbon capture and storage technology development and deployment to achieve climate change reduction objectives. The sequestration opportunity presented here is producing biochar and applying it as a soil amendment.

Project Outcomes and Conclusions

This report finds that for a project to qualify as a high quality offset supplier, it should contain the qualities described in Table 1.

Table 1: Essential carbon market investment criteria for biochar projects

Project component	Desirable quality	Carbon market rationale
Feedstock	Projects are fed by waste biomass that would otherwise be burnt or left to decompose. Feedstocks grown specifically for the biochar project are produced on marginal or degraded land.	*Leakage*. Waste feedstocks (or feedstocks grown on marginal/degraded land) do not cause land-use change.
	Feedstocks do not potentially contain heavy metals. Feedstocks do not consist of municipal solid waste, sewage sludge, or tires.	*No net harm*. Heavy metals could potentially be concentrated through pyrolysis and contaminate soils, damaging the environment and human health.
Pyrolysis process	Pyrolysis will generate at least 25,000 metric tons of biochar over ten years. Bigger projects (100,000 metric tons of biochar or more) are the most desirable.	*Verification*. Because many verification costs are fixed regardless of the size of the project, verification costs are a smaller portion of the overall cost of large projects. Economies of scale favor large projects. Projects that produce less than 25,000 metric tons of biochar over their life will not be considered for carbon market investment unless a small-scale methodology and aggregation system is developed to reduce transaction costs.
Use of biochar	The biochar producer can account for, track and monitor where all the biochar is incorporated into soils. Vertical integration, where the producer of the char is also the user of the char, is the most desirable.	*Monitoring and Permanence*. De Gryze et al. (2010) suggest the most credible method to quantify biochar projects is to measure the quantity of biochar remaining in the soil 1, 5, 10, 20 and 50 years after it is incorporated with the soil. Vertical integration makes this monitoring economically feasible. If projects are not vertically integrated, they must at least be able to easily track and account for where all the biochar is integrated into soils.

Using these investment criteria as a guide, this report evaluates a pilot-scale biochar project in Philomath, Oregon. The project, conducted at a log yard that currently produces 6,000 metric tons of waste woody biomass per year, met all but the following two investment criteria:

1. The project is too small. The pilot project is projected to produce 8 metric tons of biochar per year, while it is estimated that biochar offset projects will need to produce at least 25,000 metric tons of biochar over their lifetime, or around 2,500 metric tons per year.
2. The project plans to sell biochar to many entities, making it difficult to account for where all the biochar will be incorporated into soils.

Given the quantity of waste biomass and land available to the log yard, however, it is feasible for the pilot project to scale into an attractive offset project. However, biochar's economic and agronomic benefits are not yet sufficiently proven to justify this scale of investment. Study of the pilot project is a first attempt to make this justification.

Recommendations

As the biochar industry matures and starts producing at scale, projects are likely to be eligible to sell their climate benefits as GHG offsets to regulated emitters under a cap-and-trade program. This makes biochar a promising project type for pilot-scale investment and carbon market protocol development. A protocol will help enable the biochar industry to scale up and focus on maximizing the potential climate benefits of biomass utilization.

CHAPTER 1:
Introduction to Biochar

1.1 Definition of biochar

Biochar is frequently defined by how it is created and used rather than by its chemical composition or properties. Biochar is created through heating organic material in a low-or-no oxygen environment through a process called pyrolysis (Gaunt and Driver 2010; Roberts et al. 2010; Woolf et al. 2010; Lehmann and Joseph 2009). Pyrolysis causes biomass to thermo-chemically transform, leaving behind the concentrated carbon skeleton of the original biomass. During this transformation, pyrolysis releases gases and oils, which can be combusted to create energy. Feedstock, temperature, and time of exposure to pyrolysis determine the proportions of gas, oil and char produced and the characteristics of these outputs (Lehmann 2007; Lehmann and Joseph 2009; Roberts et al. 2010; Gaunt and Driver 2010; Woolf et al. 2010; McLaughlin et al. 2009; Lehmann, Gaunt and Rondon 2006).

The char portion created by pyrolysis is called biochar when it used as an agricultural amendment or strategy for environmental management (Driver and Gaunt 2010). When added to soils, biochar can help retain moisture and improve nutrient availability and therefore enhance soil productivity (Lehmann and Joseph 2009; Driver and Gaunt 2010). This increased fertility could be especially important as a tool to adapt to climate change, which will likely increase nutrient and moisture stress in many agricultural systems.

The biochar industry is still emerging, but has been the focus of significant interest by researchers, entrepreneurs, and government agencies over the past several years. Recent reviews by Terra Global Capital, Cornell University, and the University of California, Davis, provide summaries of biochar as a renewable energy resource and as a mechanism for carbon sequestration (Gryze et al. 2010). In addition, the biochar field is of interest to researchers (Lehmann 2010; Roberts et al. 2009; Zimmerman 2009), those interested in biochar as a carbon market mechanism (Driver and Gaunt 2010), and in national policy circles (Bracmort 2009).

1.2 Greenhouse gas emission reductions from biochar

In addition to improving soils, biochar may also provide a material contribution to the efforts to reduce concentrations of greenhouse gases in the atmosphere. Biochar, in its production and use, sequesters carbon while generating renewable energy and reducing greenhouse gas emissions from soils and the decomposition of waste.

Reductions from a biochar project vary based on how feedstocks would have been used in the absence of the project, the characteristics and quantity of biochar and energy created, and the type of soil into which the biochar is incorporated. The "% of Reductions" column in Table 1 generalizes what percentage of a biochar project's overall emission reductions come from each category. Carbon sequestration, renewable energy, and waste diversion represent the largest reductions. This report will therefore focus on these categories.

Table 2: Biochar emission reductions

GHG Reduction	Description	GHG	% of Reductions[1]
Carbon sequestration	Photosynthesis sequesters carbon in biomass as it grows. When this biomass decomposes, it releases the carbon back into the atmosphere. If the biomass is instead converted through pyrolysis into biochar, the carbon originally sequestered in the biomass will be stored for a much longer time—for hundreds or thousands of years depending on the characteristics of the biochar and the environment into which it is incorporated (Lehmann 2007). This is because biochar is significantly more resistant to decomposition than the biomass used to produce it. Pyrolyzing biomass therefore enhances carbon sequestration.	CO_2	50-65%
Renewable energy	The energy which can be produced from the gases and oils generated by pyrolysis can replace the combustion of fossil fuels. Pyrolysis could produce electricity (which would offset fossil-fueled power plants) or heat (which could replace thermal demand at or near the pyrolysis plant previously supplied with fossil fuels).	CO_2	20-40%
Waste diversion	Many feedstocks, including rice residues, green waste sent to landfills and manure, are left to decompose without oxygen in rice paddies, landfills, and lagoons (Woolf et al. 2010). This anaerobic decomposition emits methane (CH_4). Collecting and pyrolyzing feedstocks that would otherwise anaerobically decompose avoids CH_4 emissions.	CH_4	0-20%
Reduction in soil emissions	Applying biochar to soils may reduce soil emissions of nitrous oxide (N_2O) and increase the ability of soils to uptake CH_4. These reductions are highly variable and the precise mechanism through which they occur is not yet fully understood (Van Zwieten et al. 2010).	N_2O, CH_4	0-5%
Reduction in fertilizer manufacturing	Applying biochar to fields may reduce the need to apply other conventional fertilizers. Many conventional fertilizers are energy intensive to manufacture. Reducing the demand for fertilizers reduces its manufacture, thereby reducing CO_2 emissions. When nitrogen fertilizers are applied to field, a small percentage of the nitrogen is emitted as N_2O. Reducing nitrogen fertilizer applications also reduces N_2O emissions.	CO_2, N_2O	Not quantified

[1] Based on ranges reported in Woolf et al. (2010) and Roberts et al. (2010).

1.3 Climate mitigation potential

The potential for biochar to reduce emissions is determined by the quantity of biomass that is available for pyrolysis. Critics fears that, if feedstocks are not sustainably sourced, large-scale implementation of biochar (or other biofuels projects) could cause deforestation, habitat and biodiversity loss, soil erosion, loss of soil function, and soil contamination (Ernsting and Smolker 2009). One must define which feedstocks can be pyrolyzed without damaging the environment or human health to determine the sustainable mitigation potential of biochar. Woolf et al. (2010) states that, to be sustainable, feedstocks must meet the following criteria:

1. Not cause land-use change or deforestation.
2. Be produced on marginal or degraded land (if they are purposefully grown).
3. Be extracted at a rate that does not create soil erosion or loss of soil function (if they are taken from agricultural or forestry residues).
4. Not be sourced from industrial waste.

Assuming all feedstocks that meet these criteria are pyrolyzed, Woolf et al. (2010) estimated that the maximum GHG mitigation potential of biochar is an annual reduction of 1.8 gigatons of CO_2e. This is equivalent to 12% of current global GHG emissions. Large-scale implementation of biochar could produce a similar scale of reductions as wind, solar, efficiency, or nuclear—sectors that are the current focus of efforts to mitigate climate change.

The estimate from Woolf et al. (2010) is the theoretical upper limit of biochar's sustainable potential, not its likely potential. At a national scale, biochar can still provide a material contribution to efforts to reduce emissions. Assuming 40% of currently unused crop and forest residues were pyrolyzed in the United States, Roberts et al. (2010) estimate that biochar could annually reduce 230 million metric tons of CO_2e, or 8% of the annual reductions needed to reduce domestic emissions by 50% by 2050.

These promising mitigation potentials are based on drastic increases in biomass collection and use. Emission reductions of this scale are dependent not only upon the creation of many pyrolysis plants, but also on the collection and transportation infrastructure that is needed to get the biomass to these plants. The pyrolysis plants can also be brought to the biomass in the field; there are several companies fabricating field-scale mobile pyrolysis units.

Once biomass is in a usable place, it can produce many products with climate benefits, of which biochar is just one. Biochar, in many cases, may provide the greatest climate benefit. Woolf et al. (2010) found that creating biochar, rather than combusting the same sustainably procured biomass to extract the maximum amount of energy, on average reduced 22% to 27% more GHG emissions. The type of energy replaced is a critical factor. Full combustion of the biomass may yield a greater climate benefit than biochar when displacing energy generated with coal. The emissions benefit of creating biochar rather than full combustion for energy will likely increase as the carbon intensity of the global energy mix lowers through the implementation of cleaner technologies. This may make biochar an essential mitigation technology for achieving additional GHG reductions. Biochar has the potential to play a significant role in the effort to mitigate climate change and warrants additional study, research, financing, piloting and implementation.

1.4 Context for this report

To realize this mitigation potential, biochar projects must prove to be financially viable. A price on carbon emissions—which this report assumes will be achieved through a cap-and-trade system—is one policy that would increase the profitability of biochar projects. A cap-and-trade system would increase the cost of fossil fuel-generated energy, making the renewable energy from pyrolysis relatively cheaper. A cap-and-trade system could also generate a large pool of capital from regulated emitters that, through an offset system, could be invested into biochar projects to incentivize them to realize the carbon sequestration and waste diversion benefits discussed in section 1.3.

A cap-and-trade system would require regulated emitters to reduce GHG emissions. Offsets allow those regulated emitters to pay unregulated sectors to achieve these reductions. Offsets give regulated emitters the flexibility to find the lowest cost emission reductions available, regardless of what sector of the economy they come from. Biochar is a good illustration of the benefit of this flexibility. As the climate benefits of biochar are proven, no new policy needs to be designed to incentivize these benefits. Instead, if the reductions are low cost and can meet the quality criteria required for offset projects, regulated emitters can pay biochar project developers for offsets under the existing cap-and-trade system.

What does it mean for biochar projects to meet the quality criteria required of offset projects? Chapter 2 of this report will answer this question by applying the criteria outlined by the Offset Quality Initiative (2008) to biochar projects. De Gryze et al. (2010) discuss these issues in a paper commissioned by the Climate Action Reserve. This report will add the perspective of a carbon market investor to that analysis, outlining the specific criteria of biochar projects that will make them attractive for investment from carbon markets. Chapter 3 details a case study of the Thompson Timber/Starker Forests biochar project (TSY-Peak project) in Philomath, Oregon. Chapter 3 describes the project's hardware, inputs and outputs, economics, and GHG emissions impact. Chapter 4 compares the criteria outlined in Chapter 2 to the TSY-Peak project, discussing how the project would need to scale up in order to allow it to be eligible for offset crediting.

CHAPTER 2:
Offset Quality Criteria Applied to Biochar Projects

The Offset Quality Initiative, a consortium of national nonprofit organizations working to advance the environmental integrity of the carbon market, published a paper outlining the key criteria offset projects must meet (Offset Quality Initiative 2008). The paper concluded that, in order for projects to generate emission reductions credible enough to substitute for on-site reductions of an entity capped under climate policy, offsets meet the following criteria:

1. Be additional
2. Be based on a realistic baseline
3. Be quantified and monitored
4. Be independently verified
5. Be unambiguously owned
6. Address leakage
7. Address permanence
8. Do no net harm[2]

This chapter evaluates biochar projects in light of these criteria, recommends which types of biochar projects can most readily generate credible offsets and summarizes the types of projects that meet carbon market investor criteria.

2.1 Be additional

2.1.1 Definition of additionality

Offsets are intended to credit only new emission reductions that are "in addition" to reductions that would have occurred without the incentive provided by a carbon market. Determining the counterfactual case of whether or not a project would have been implemented in the absence of a carbon market is unavoidably subjective. Carbon markets have developed two methods of assessing additionality:

1. *Project specific analysis* – Project developers develop an additionality case that outlines a specific barrier, normally financial but also possibly technical or institutional, which impedes project development and is overcome by carbon finance.
2. *Performance standard* – Protocol developers (such as the Climate Action Reserve, Clean Development Mechanism, or a future government regulatory

[2] The Offset Quality Initiative (2008) criteria that offsets "be real" is not included in this chapter's analysis. Instead, all the requirements discussed in the chapter are an attempt to ensure that the offsets claimed by biochar projects are "real."

body like the US Environmental Protection Agency or Department of Agriculture) develop uniformly applicable criteria that determine which types of projects are or are not additional. For biochar projects these criteria could be based on feedstock type, location, or regulatory environment.

2.1.2 Developing a performance standard for biochar

A performance standard is the most appropriate method to evaluate the additionality of biochar projects. Requiring each project to articulate a project-specific additionality case is unnecessarily arduous considering that biochar projects are still at a pilot stage of development. Instead, all biochar projects in the United States should be considered additional so long as each project can prove that its development is not required by law. The Climate Action Reserve, a respected protocol developer, has a similar performance standard for anaerobic dairy digesters, which is a technology with significantly higher market penetration. Because anaerobic digestion is implemented on less than 2% of eligible U.S. dairy farms, the protocol considers any digester to be "above and beyond common practice" and therefore additional (Climate Action Reserve 2009).

Providing certainty that all appropriate biochar projects will be eligible to monetize offsets guarantees an additional revenue stream to all biochar projects and could help to catalyze commercial-scale deployment of the technology. A performance standard that guarantees the additionality of biochar projects is appropriate, and will continue to be appropriate, as long as biochar's deployment remains limited relative to its potential. As the technology matures, this performance standard can be reevaluated to ensure carbon finance is supporting additional projects.

2.2 Be based on a realistic baseline

To quantify the offsets a project is eligible to sell, the emissions of the offset project are compared with a baseline. The baseline represents the forecasted emissions that would have occurred if the offset project were not implemented. Although the baseline case always has higher emissions than the project case, project activities can increase emissions relative to what would have happened in the baseline and these increases must be counted.

This may happen in the following two cases for biochar projects, depending on how the biomass feedstock would have been managed in the baseline case:

1. The biomass used as feedstock for the pyrolysis unit in the project case would have been fully combusted to generate energy in the absence of a project. Full combustion would generate more renewable energy than pyrolysis alone. Comprehensive accounting must calculate any additional emissions that result, because of the biochar project, from the fossil fuels that replace what would have been energy generated by biomass.

2. The biomass used as feedstock to the pyrolysis unit in the project case is left to decompose in the forest, field, or compost pile in the baseline scenario. Decomposition would incorporate a portion of the feedstock's carbon into soil organic matter. Baseline calculations should therefore be based on a model of the decomposition of the feedstock that accounts for the carbon that would have been sequestered into soil organic matter.

It is essential to incorporate baseline management of feedstocks in a biochar offset protocol. High quality biochar projects must be able to track how, in the absence of a project, their feedstocks would have been managed. This is likely to favor projects with simplified supply chains and waste streams; projects that receive many different feedstocks from many different places may struggle to establish a credible baseline.

2.3 Be quantified and monitored

All offset projects are quantified and monitored according to a protocol written specifically for the project type. There is currently no protocol that captures all the climate benefits associated with biochar projects. However, there are protocols in various stages of development for many of the different categories of reductions. Table 3 outlines the current state of protocol development. Carbon sequestration, the largest and most innovative reduction generated by biochar projects, does not have a mature protocol. This must be created before biochar projects participate in the carbon market.

Table 3: Overview of pertinent carbon market protocols for biochar projects

GHG Reduction	Mature protocol?	Pertinent Protocols	Discussion
Carbon sequestration	No	Carbon Gold's *proposed* protocol to the Voluntary Carbon Standard	This proposed protocol has been criticized by the International Biochar Initiative[3] and De Gryze et al. 2010 as insufficient to accurately quantify biochar's carbon sequestration benefit. A new protocol to quantify the carbon sequestration of biochar is needed.
Renewable energy	Yes	Clean Development Mechanism	The Clean Development Mechanism uses a variety of respected protocols to quantify the carbon benefit of renewable energy. These could be adapted to biochar projects.
Waste diversion	Yes	Clean Development Mechanism	The Clean Development Mechanism's AMS- III.L. "Avoidance of methane production from biomass decay through controlled pyrolysis" is a protocol specifically for pyrolysis projects. It is limited to projects that reduce less than 60,000 metric tons of CO_2e per year.
Reduction in soil emissions	No	None	The precise mechanisms through which biochar reduces N_2O emissions and increases CH_4 uptake are not fully understood. These reductions vary according to rainfall, temperature, land-use change, and plant growth behavior (Van Zwieten et al. 2010). There is currently insufficient understanding of this reduction to quantify its greenhouse gas benefit and monetize it as an offset.
Reduction in fertilizer manufacturing	No	None	Developing a protocol to quantify this benefit could be relatively straightforward so long as the quantity of fertilizer saved is clear and easy to document.

[3] The International Biochar Initiative's comments are available on-line at http://v-c-s.org/docs/CG-DR.pdf.

2.4 Be independently verified

Biochar projects, like all other high quality offsets, must undergo verification. After a project developer monitors a project according to its protocol, an independent third party verifies its accuracy.

Verification is often the largest transaction cost of offset projects. Verification of anaerobic digester projects, for example, usually costs $10,000 annually, or $100,000 over the life of a project. Verification costs for forestry projects, which require forest sampling and growth and yield modeling, are approximately $15,000 to $30,000 per site visit, with up to 30 site visits for one project. Many of these costs are fixed regardless of the size of the project or the number of credits it produces. Verification costs can exceed the value of the resulting offsets for very small projects, thereby excluding them from the carbon market.

The economies of scale associated with verification imply that there will be a threshold of offsets that a biochar project must produce in order to justify these transaction costs. As a minimum, projects must reduce at least 50,000 metric tons of CO_2e over their lifetime. The market as a whole, however, favors projects that produce at least 200,000 metric tons of CO_2e reductions over their lifetime.

To understand what these size thresholds mean for biochar projects, one must estimate the number of offsets that the average metric ton of biochar will generate. As discussed, the number of offsets each project generates will vary according to how the feedstock would have been managed if the project was not implemented, the characteristics of the biochars that are produced by the project, and the ultimate destination of the biochar. The literature has some approximate values for the emission reductions associated with the average ton of biochar. Granatstein et al. (2009) estimate that biochar offsets 2.93 metric tons of CO_2e per metric ton of biochar when applied to the soils. Roberts et al. (2010) estimate 2.88 metric tons of CO_2e are offset for each ton of biochar applied to the soils. These values, however, do not incorporate baseline sequestration of the feedstock or decomposition of portions of the carbon in the biochar over 100 years. Based on these values and the principle of conservativeness, carbon market investors could estimate that each metric ton of biochar produced by a project could potentially generate 2 metric tons of CO_2e reductions.

Given these general assumptions, projects that will produce 100,000 metric tons of biochar over 10 years are the most likely to attract investment. Projects that generate less than 25,000 metric tons of biochar over 10 years are unlikely to attract offset investors.

Many efforts are underway to attempt to reduce verification costs for smaller projects. Some examples include creating separate protocols for small projects that allow small projects to aggregate credits and reduce participation costs. That said, large projects that generate at least 25,000 metric tons of biochar over their lifetime are likely to attract the first investment from carbon markets because they can be accurately quantified and verified in a cost-effective manner.

2.5 Be unambiguously owned

Table 4: Ownership of GHG emission benefit table for projects in the United States

GHG Reduction	Description	Location of Reduction	Qualify for Crediting?
Waste diversion	The feedstock would have produced CH_4 if left to decompose anaerobically instead of being used by the biochar project.	Upstream. Experienced by owner of the feedstock, whose decomposing feedstock would otherwise generate CH_4.	Yes.
Carbon sequestration	Conversion of biomass to biochar keeps carbon sequestered by preventing the biomass from decomposing and releasing CO_2.	Upstream. Experienced by owner of the feedstock, whose decomposing feedstock would otherwise generate CO_2.	Yes.
Reduction in soil emissions	Applying biochar to soils may reduce soil emissions of N_2O and CH_4.	Downstream. Experienced by the farmer utilizing the biochar.	Yes.
Reduction in fertilizer manufacturing	Applying biochar to fields may reduce the need to apply other conventional fertilizers, which are energy intensive to manufacture. Reducing the demand for fertilizer reduces fertilizer manufacturing, thereby reducing CO_2 emissions.	Not Part of Supply Chain. Experienced by many different manufacturers of conventional fertilizers.	No, unless it is determined that fertilizer manufacturers are not covered under a cap-and-trade system.
Electricity displacement	Electricity produced by biochar projects could offset electricity produced by other fossil-fueled power plants that no longer have to supply the same quantity of electricity to the grid.	Not Part of Supply Chain. Experienced by many different power plants supplying electricity to the grid.	No.
Fossil fuel displacement	The heat produced by biochar projects may fulfill thermal demand at the pyrolysis plant that was previously supplied with fossil fuels.	The pyrolysis plant.	No, unless it is determined that the displaced fuel is uncapped by a state or federal cap-and-trade program.

In order to sell an offset credit, a project developer must develop clear and uncontested title to the emission reductions that result from the biochar project. Projects reduce emissions at multiple points along the supply chain, and there is potential for multiple entities to claim the same reductions if the supply chain isn't vertically integrated. To avoid this outcome, any project developer selling an offset credit must have attained unambiguous and documented proof of ownership from any other entity with a potential claim to the emission reductions. This project developer could be the owner of the feedstock, the pyrolysis plant or the user of the biochar.

Table 4 outlines six different emission reductions that result from biochar projects, discusses where the actual reduction occurs (upstream or downstream from the biochar manufacturer), and determines whether the reduction can be credited as an offset.

2.5.1 Emissions benefits that meet ownership requirements: waste diversion, carbon sequestration, and soil emission reductions

Of the three entities that have potential claims to the emission reductions—the owner of the biomass feedstock, the owner of the pyrolysis plant, and the farmer who applies the biochar—it makes the most sense for the pyrolysis plant owner to claim the reduction. If this is the case, the plant owner must obtain contracts with the other parties to demonstrate clear and uncontested right to the reduction. These contracts would need to be produced at the time the offset is sold. Similarly, if either the feedstock owner or the landowner applying the biochar wants to sell the reduction, they would need to obtain clear and uncontested rights to the reductions from the other parties and produce those contracts when they sell the offsets.

In many biochar projects, the feedstock owner, pyrolysis plant, and user of the biochar are the same entity. These vertically integrated projects do not face any ownership ambiguity and are therefore the easiest to implement. They are likely to be the easiest projects to monitor and verify as well for the reasons in Section 2.7.1.

2.5.2 Emissions benefits that do not meet ownership requirements: reduction in electricity displacement, fertilizer manufacturing, and fossil fuel displacement

Three of the reductions achieved by a biochar project could have ownership claims placed on them by entities that are likely to face GHG reduction requirements from a cap-and-trade program or similar policy. These entities would be in the electricity, fertilizer production, and fossil fuel distribution sectors. If these sectors are capped, portions of the reductions achieved through the biochar project's existence will make it easier for these sectors to comply with their cap. As such, these portions of reductions will be ineligible to generate offsets because they will be claimed under the cap.

Until it is determined whether a U.S. cap-and-trade scheme covers fertilizer production and fossil fuel distribution, offsets that represent these benefits should not be sold. However, the electric sector has already developed a complementary mechanism to monetize the benefit of renewable energy generation called Renewable Energy Certificates (RECs). Biochar projects should take advantage of that mechanism by selling RECs for the electricity they produce.

2.5.3 Conclusions

- A project developer can claim clear, uncontested, and unambiguous ownership over the emission reductions that result from waste diversion, carbon sequestration, and soil emission reductions.
- These reductions occur upstream and downstream of the pyrolysis plant. If the plant is the entity claiming and selling these reductions, it must obtain contractual title to the reductions to ensure the feedstock owner and the user of the biochar do not double count reductions.
- A project developer cannot claim unambiguous title to the reductions that result from electricity displacement, reduction in fertilizer manufacturing, and fossil fuel displacement. The means through which electricity producers, fertilizer manufacturers, and fossil fuel distributors will claim ownership over these or any reductions depends upon the type of GHG regulation that emerges at the state and federal level. Until this regulation is clear, biochar project developers should not claim these reductions.

2.6 Address leakage

Leakage occurs when the implementation of an offset project causes emissions to rise outside of that specific project's accounting boundary. Projects must avoid or account for leakage to accurately represent an emission reduction. This section recommends avoiding leakage by prohibiting the crediting of biochar projects that use feedstocks that cause land-use change.

2.6.1 Leakage from land-use change

If the feedstock used by a biochar project has alternate beneficial uses, the project could cause land-use change. Some examples of feedstocks with other beneficial uses include:

- Merchantable wood – The feedstock provider or another market participant may increase harvest outside of the project's boundary to make up for the merchantable wood that is now used by the biochar project. Those reduced carbon stocks must be accounted for.
- Corn, soybeans or other food products – New land could be deforested in order to grow food that is no longer sold to the market because it is used for a biochar project.

The economic modeling needed to accurately account for the direct and indirect land-use impacts of projects that utilize biomass feedstocks with other beneficial uses is still in its infancy. When different models analyze the same project, they produce disparate results. Roberts et al. (2010) compared the land-use impacts of a biochar project feed by switchgrass (a bioenergy crop) using two different models. One model estimated land-use change leakage to be more than twice as large as the other (0.89 metric tons of CO_2e versus 0.41 metric tons of CO_2e for each ton of swtichgrass used by the project). Accurate accounting for land-use change requires more study before it can be integrated into a protocol for biochar projects.

Feedstocks that, in the absence of a project, will simply be burnt without generating energy or left to decompose do not cause land-use change. Due to high collection and transportation costs, lots of biomass is simply considered waste that is either burnt or left to decompose. These feedstocks do not need to account for leakage and have a correspondingly greater emission benefit. Until accounting protocols for land-use change mature, biochar project that use feedstocks without any alternate beneficial use will be the most attractive for carbon market investment.

In agreement with these recommendations, De Gryze et al. (2010) recommend focusing protocol development on the following feedstocks:

1. Corn stover (waste leaves and stalks of the corn plant) that is left to decompose in the field in the absence of a biochar project.
2. Switchgrass that is grown on marginal/degraded land.[4]
3. Yard waste that is landfilled or composted in the absence of a biochar project.
4. Wood waste that is left to decompose in the absence of a biochar project.

2.6.2 Feedstock opportunities in the Pacific Northwest

Given these limitations, the Pacific Northwest still contains enough waste feedstocks to open opportunities for biochar projects. The Oregon Department of Energy estimates that 0.7 million short tons of woody biomass waste are unused and available in Oregon annually (Oregon Department of Energy 2007). Beyond current waste streams, a 2006 study commissioned by the Oregon Forest Resources Institute demonstrated there are approximately 4.25 million acres (15% of Oregon's forest lands) in need of thinning to reduce wildfire risk and to restore forest health (Lord et al. 2006). An estimated 1.0 million bone dry short tons per year could be produced from thinning treatments on these Oregon forest lands, not including merchantable sawtimber (Lord et al. 2006). Biochar project development in the Pacific Northwest could likely be well supplied by wood waste that does not induce land-use change.

Straw has also been studied as a potential feedstock for biomass energy utilization in the Pacific Northwest (Banowetz et al. 2008). An estimated 5.7 million short tons are available annually across the region (Oregon, Washington, and Idaho) and an estimated 0.69 million short tons in Oregon.

[4] This switchgrass is not a waste product, but De Gryze limits it to switchgrass grown on marginal/degraded land because using this land does not displace food or timber production and therefore does not cause land-use change.

2.6.3 Conclusions

- The largest potential source of leakage for biochar projects is land-use change.
- Feedstocks that affect the market for timber, wood products, or food are the most likely to create direct and indirect land-use change.
- Methodologies to account for this land-use change are immature and therefore cannot be trusted for offset accounting.
- Carbon markets should, at this time, only credit biochar projects that utilize feedstocks that are unlikely to cause land-use change.
- These feedstocks include agricultural residues, yard waste, and wood waste that, in the absence of a biochar project, are burned or left to decompose.

2.7 Address permanence

All carbon sequestration, including the carbon that is sequestered in biochar, can be reversed. In biochar projects, reversals could happen unintentionally− if the biochar decomposes, erodes or is burnt. Reversals could also occur intentionally− if the land where the biochar is incorporated is developed or tilled.[5] Sequestration cannot be monitored if the soil containing the biochar is removed and conservativeness dictates that it should be accounted for as a reversal.

Project developers must demonstrate that the carbon in the biochar which is sold as offsets is present 100 years after the biochar is produced. This is the industry standard for permanence in forestry projects under the Climate Action Reserve. Unlike forestry and other types biological of sequestration, which accumulate carbon through photosynthesis over time, biochar projects begin with the maximum quantity of carbon sequestration. This carbon is then lost to varying degrees over time through decomposition, erosion, burning, development, soil removal, or intensive tilling.

2.7.1 Accounting for the decomposition of biochar

Decomposition of the carbon sequestered in biochar is likely to be the largest and most consistent loss of carbon over a project's crediting period. The rate at which biochar decomposes varies significantly and depends primarily on the feedstock, the method of pyrolysis (temperature and length of time) used to make the biochar, and the environment where the biochar char is incorporated. This makes it difficult to create standard decomposition rates for each type of biochar because there are so many permutations of production and use.

Since the characterization and therefore rates of decomposition vary, De Gryze et al. (2010) recommend field measurements of the quantity of biochar that remains after original application. On-site measurements can be used to calibrate a "two-component kinetic model" of decomposition. As more data is gathered, the model can predict with increasing certainty the quantity of biochar that will remain in the soil after 100 years. The paper suggests sampling 1, 5,

[5] Compared with other strategies to sequester carbon, like forestry or soil carbon projects, biochar's risk of reversal is low because it sequesters carbon in a more stable form that is resistant to reversal.

10, 20, and 50 years after biochar is applied to soils. Offsets are delivered to the project developer as greater certainty develops, through monitoring and modeling. A full description of this methodology, which is beyond the scope of this paper, can be found in the "Monitoring of Biochar Carbon in Soils" section of De Gryze et al. (2010).

The requirement for long periods of on-site measurement of biochar represents a significant limitation to owners of pyrolysis plants that want to sell biochar on the retail market to nurseries, gardeners, farmers, and other small-scale buyers. To sell offsets, pyrolysis plants must be able to account for and track where all of the biochar produced is incorporated into soils. This biochar must then be monitored and verified over a 50-year period. This requirement will make vertically integrated projects (that use all biochar they produce) the most attractive projects for carbon investment. Other projects that produce biochar and sell it to a limited number of buyers will also likely be eligible, so long as they can account for where the biochar they have sold is now incorporated into soils.

Retail biochar producers, whose biochar is incorporated into many different soils, will not be eligible to generate offsets because tracking and monitoring all soils where it would be applied would be prohibitively costly and complicated. The monitoring methodology suggested by De Gryze et al. (2010) is one suggested approach, and the implications of it are carried throughout this report. Because this methodology prohibits so many types of biochar projects from participating in the carbon market, alternative approaches may need to be investigated.

2.7.2 Other unintentional reversals: fire and erosion

Although less likely, unintentional reversal could result from a fire, which releases sequestered carbon to the atmosphere, or a major erosion event, which removes the biochar from the site and therefore makes it impossible to monitor and verify.

To mitigate these unintentional reversal risks, forestry projects are required to set aside offsets in a buffer pool, which is drawn upon in the event of an unintentional reversal. The risk of reversal for biochar projects is likely smaller than in forestry. Instead of requiring a buffer pool, the risk of fire and erosion should simply be mitigated to prevent high-risk projects from qualifying for carbon finance. Therefore this report recommends a biochar protocol require wildfire control measures and restrict projects on steep slopes. If the risk of fire or erosion were found to be greater than anticipated, a buffer pool to compensate for unintentional reversals would need to be developed.

2.7.3 Intentional reversals: development, soil removal, intensive tillage

If soils incorporated with biochar are removed, intensively tilled, or developed, the biochar in these soils can no longer be monitored or verified. Any issued offsets would therefore be reversed. In forestry offset projects, project developers compensate for intentional reversals by purchasing offsets for at least each of the offsets that were issued and sold by a project. The Climate Action Reserve contractually obligates forestry project developers to do so through its

Project Implementation Agreement. A similar contract with the landowner who incorporates biochar into their soils will need to be developed.

Attaining commitment from the entity that will incorporate biochar into their soils to not develop the land, remove soil, or intensively till their land over the next 100 years will likely significantly limit the number of entities interested in selling offsets from biochar projects. This commitment, however, is essential to ensuring the permanence of biochar projects.

2.8 Do no net harm

Biochar projects could potentially cause the following adverse effects on human health or the environment:

1. If feedstocks contain heavy metals, pyrolysis could concentrate these heavy metals into the biochar. Heavy metal-laced char applied to agricultural fields could then contaminate food, habitat, and watersheds.
2. Chars can develop polycyclic aromatic hydrocarbons (PAHs), some of which have been identified to be carcinogenic, mutagenic, and teratogenic.
3. If biochar is ground finely and applied to the top of the soil, it can become airborne by winds. Airborne char is air pollution and could create a fire hazard.

Only projects that take actions to mitigate these possible adverse effects should qualify for offset crediting. A protocol should require the following mitigation measures:

1. Biochar projects that pyrolyze municipal solid waste, sewage sludge, or tires do not qualify in order to mitigate the potential for concentrating heavy metals. Projects should also be required to periodically test the chars they produce to ensure they do not contain heavy metals.
2. All projects must frequently test their chars for PAHs.
3. Projects that surface apply finely ground biochar must wet the char before application (or implement other measures to minimize air pollution) to mitigate airborne particles.

The three potential adverse affects listed above are not comprehensive. Other unforeseen environmental and human health consequences could arise. It is essential to the credibility of both the biochar industry and the carbon market that comprehensive and regularly updated sustainability protocols are implemented to ensure biochar projects cause no net harm.

2.9 Summary of carbon market investment criteria for biochar project

To summarize, the characteristics of a biochar project that will enable it to most easily meet the criteria outlined by the Offset Quality Initiative are discussed in Table 5. Carbon market investors will evaluate potential investment opportunities in the biochar sector against the qualities outlined in this table.

Table 5: A summary of carbon market investment criteria for biochar projects

Project component	Desirable quality	Carbon market rationale
Feedstock	Projects are fed by waste biomass that would otherwise be burnt or left to decompose. Feedstocks grown specifically for the biochar project are produced on marginal or degraded land.	*Leakage*. Waste feedstocks (or feedstocks grown on marginal/degraded land) do not cause land-use change, for which carbon accounting is immature.
	Feedstocks do not potentially contain heavy metals. Feedstocks do not consist of municipal solid waste, sewage sludge, or tires.	*No net harm*. Heavy metals could potentially be concentrated through pyrolysis and contaminate soils, damaging the environment and human health.
	Projects can track how their feedstock was managed before the implementation of the biochar project and forecast how it likely would have been managed in the absence of project implementation.	*Baseline*. Baseline accounting must account for any energy generated by a feedstock before the project was implemented and any portion of the feedstock that was incorporated into the soil organic matter.
	The seller of the offsets can obtain clear contractual title to the emission reductions that result from waste diversion and carbon sequestration from the original owner of the feedstock.	*Ownership*. This ensures the project developer will not double count the reductions of the project.
Regulatory environment	Projects are not required to be implemented by law.	*Additionality*.
Pyrolysis process	Pyrolysis will generate at least 25,000 metric tons of biochar over ten years. Bigger projects (100,000 metric tons of biochar or more) are the most desirable.	*Verification*. Because many verification costs are fixed regardless of the size of the project, verification costs are a smaller portion of the overall cost of large projects. Economies of scale favor large projects. Projects that produce less than 25,000 metric tons of biochar over their life will not be considered for carbon market investment unless a small-scale methodology and

		aggregation system is developed to reduce transaction costs.
Use of biochar	Projects incorporate biochar into soils. Stable soils that are unlikely to erode during extreme weather events are most desirable.	*Permanence*. Biochar faces less of a risk fire or erosion, and therefore unintentional reversal, when it is incorporated into soils.
	Entity using the biochar is willing to contractually obligate him/herself to not develop, intensively till, or remove the soil in which biochar will be incorporated for the next 100 years.	*Permanence*. Carbon must remain sequestered for 100 years. This cannot be guaranteed if development, intensive tillage, or soil removal occurs.
	The biochar producer can account for, track, and monitor where all the biochar is incorporated into soils. Vertical integration, where the producer of the char is its user of the char, is the most desirable.	*Monitoring and Permanence*. De Gryze et al. (2010) suggest the most credible method to quantify biochar projects is to measure the quantity of biochar remaining in the soil 1, 5, 10, 20, and 50 years after it is incorporated with the soil. Vertical integration makes this monitoring economically feasible. If projects are not vertically integrated, they must at least be able to easily track and account for where all the char produced is integrated into the soils.

CHAPTER 3:
Case Study of the TSY-Peak Biochar Pilot Project

In order to address issues of waste utilization from industrial processes, reduce energy costs, create viable co-products, and reduce CO_2 emissions, the Thompson Timber log yard in Philomath, Oregon has incorporated a pilot-scale slow pyrolysis biochar system into its existing forestry mill operation. Although the company is still testing and refining its system, it agreed to share input and output data and available but limited financial data for this case study in order to advance the developing biochar industry and to explore means of generating company revenue from biochar and offset sales.

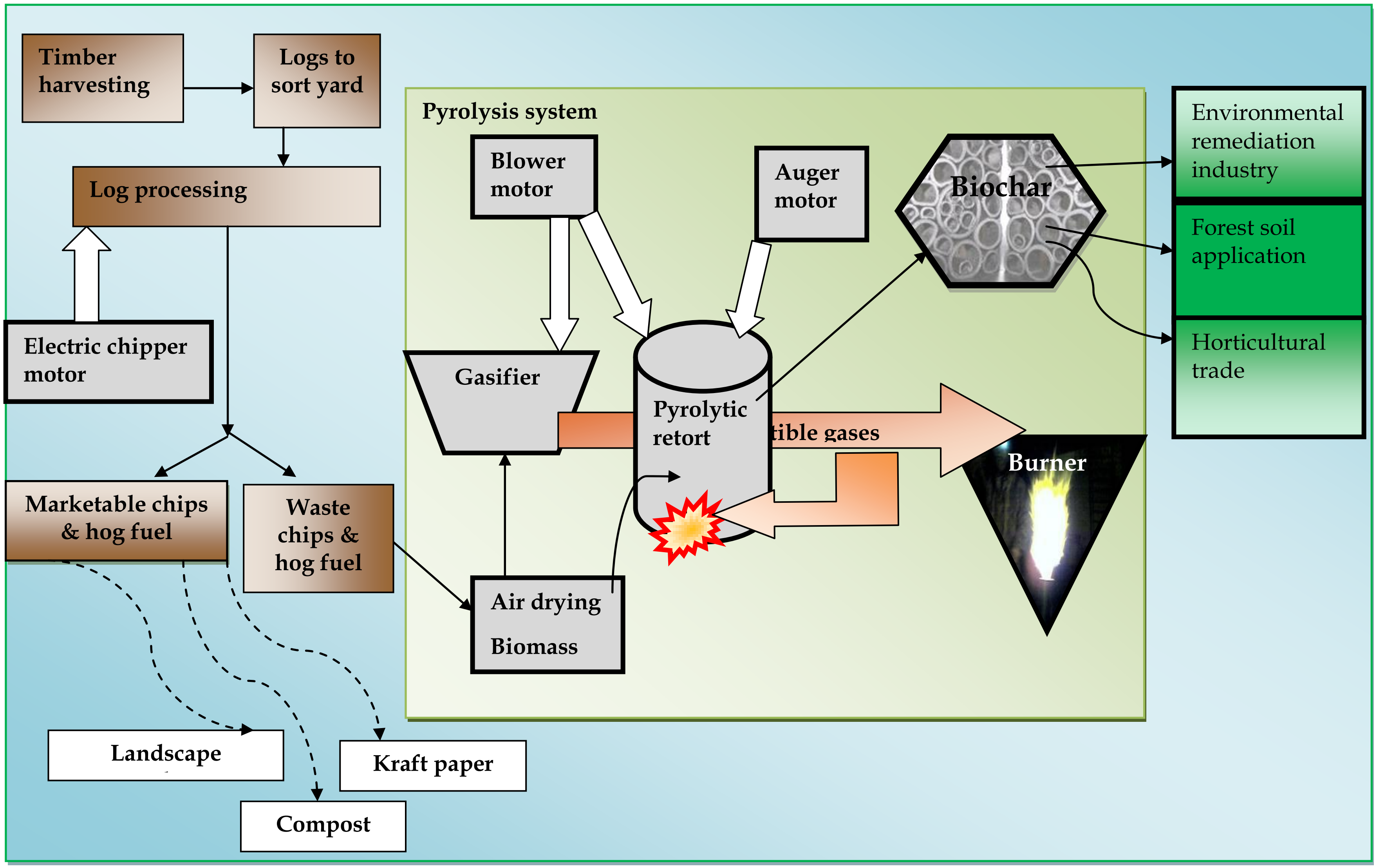
This chapter will use the pilot-scale system at Thompson Timber log yard as a case study. It provides an overview of the project's hardware, feedstock, inputs and outputs, economics, and greenhouse gas emissions. With this description as a foundation, the next chapter concludes by applying the Offset Quality Initiative criteria described in Chapter 2 to the pilot project.

3.1 Description of project hardware

Construction of the biochar system, referred to as TSY-Peak, began in January 2010. The project reached its initial test phase in June 2010 and is still undergoing refinement and development. Currently, the TSY-Peak biochar system is a slow pyrolysis biochar unit with the capability to create biochar under various temperatures, ranging from 350°C to 600°C. The system produces biochar and combustible gases; it is designed to minimize the production of bio-oil.

The system has three main components: a gasifier, a pyrolytic retort, and external motors (including start-up, cooling, blower, auger, and shaker motors). Figure 1 is a diagram of the TSY-Peak system and the project boundary.

Figure 1. Project diagram. Solid line arrows indicate flows of material (logs, chips, biochar). Black arrows indicate flows of energy (diesel fuel, electricity for the system motors, or combustible gases). Dashed lines indicate current product uses for the wood waste. (Adapted from Roberts et al. 2010)



A Fluidyne Pacific Class down-draft gasifier provides thermal drive for the entire system. The gasifier utilizes a small portion of the oversized wood chips that are screened out during the chipper plants' sorting process. These chips are air dried to 15% moisture. Wood chips are thermally reduced in a high temperature, low oxygen environment, to yield a relatively low heat value combustible gas known as producer gas. At approximately 164 BTU per standard cubic foot, producer gas by volume has around one-seventh the heat energy of natural gas. However using this pathway the thermal requirements of the pyrolytic retort can be achieved with low value biomass. The gas is ignited and then used to heat the pyrolytic retort.

Figure 2. Fluidyne Gasifier (left background, metallic surface) and pyrolytic retort (right front, black paint) in the log-sorting yard of Thompson Timber/Starker Forest, Philomath OR.
Photo Credit: John Miedema

The second hardware component in the system is called a pyrolytic retort (PR). The PR consists of two steel tubes, one nested inside the other, approximately 8 feet in length and 13 feet in height. The inside of the outer tube is lined with fire bricks to a height of 3 feet. Inside is a second smaller tube where hog fuel is loaded. The inner tube also has an auger that mixes the hog fuel to ensure that it pyrolyzes at an even temperature during biochar production (Figure 2).

The PR was constructed with scrap metal and parts from the forest mill site with other materials being added as needed (tubing, valve boxes, and temperature gauges). The PR can be loaded with up to 400 pounds of biomass feedstock, but approximately 200 pounds are used per run.

The third components are small electric production motors used to run the system. The gasifier uses a start up motor, two cooling motors and a shaker motor. The PR uses a blower motor and a hydraulic unit to power a mixing auger. Each eight hour work day the motor systems use approximately 2.468 kilowatt hours (kWh) of electricity.

3.2 Description of the feedstock

Thompson Timber Company produces approximately 2 million metric tons of clean woodchips and 5,000 metric tons of hog fuel (wood waste bark from log sorting and grading as well as other non-merchantable material) per year during normal operations. The chipped material is a mixture of Pacific Northwest forest species: approximately 75% Douglas fir (*Pseudotsuga menziesii*), 15% red alder (*Alnus rubra*) and 10% big leaf maple (*Acer macrophyllum*). Logs are transported by truck from approximately 50 miles. Once the logs are brought into the Thompson Timber yard, they are sorted and scaled. Merchantable sawlogs are separated and sold to local timber mills and for export, whereas un-merchantable sawlogs are fed into the log-chipper.

Bark and wood cambium that falls to the ground during the sorting and scaling process creates a waste stream of no value. The remaining bark that is removed as the unmerchantable logs are loaded onto the chipper is set aside as hog fuel. The de-barked log is then run through a chipper that produces a chip product approximately 2 inches by 2 inches in size. As the logs are processed two products are created: hog fuel and wood chips. The hog fuel is set aside and the chips are run over a series of screens for size and quality selection. Wood chips that meet size and quality criteria are collected and sold to the domestic kraft paper market (for construction of products like paper plates). The chips that fail to meet the quality standard are collected to run the gasifier for the TSY-Peak system.

The hogfuel (bark and low quality chips) is not otherwise used for energy production currently, either on site by the company or after it is sold to buyers. It is sold for local landscaping applications and used by a local compost company. Thompson Timber Company runs its chipper using an electric motor using energy from the local power company.

In addition to the 5,000 metric tons/year of hog fuel that is sold by Thompson Timber Company, there is approximately 6,000 metric tons of waste available for biochar production. Only a very small portion of this waste stream is being used for the pilot system (Figure 3).

Figure 3. Wood waste used in the TSY-Peak biochar system. Left is the hog fuel used to power the gasifier. Right is the waste biomass currently left to rot in the log yard, which feeds the pyrolytic retort.
Photo Credit: Matt Delaney (left) and Peter Weisberg (right)

3.3 Biochar system operations

3.3.1 Inputs

The TSY-Peak biochar system is a batch processor that averages about two runs per day. It takes about an hour to prepare the system before each run, approximately two hours to make biochar, and another hour for the system to be switched off and cooled down enough to remove the char from the bottom of the PR. On average, 120 pounds of chips are used in the gasifier and 200 pounds of hog fuel are used in the PR for a total of 320 pounds of biomass feedstock. Improved insulation of the PR could dramatically reduce the amount of chips required for the gasifier.

Under current estimates, the log yard will run the pyrolysis plant three days a week for 45 weeks out of the year. Annually, the plant will use 16.2 metric tons of hog fuel to power the gasifier and 27 metric tons of waste biomass to feed the PR.

To start the biochar system, oversized chips are taken off the top sizing screen at the chipper plant. A small portion of these oversized chips fall through a four-inch gate into a 1.4 yard tipping bin and are transported via forklift from the chipper plant to the pilot system (which is about 200 yards away). The chips are spread onto the ground and air-dried (Figure 4).

Figure 4. Air-dried hog fuel used in the TSY-Peak biochar system
Photo Credit: Matt Delaney

Oversized wood chips that are dried to 15% moisture content are loaded into the top of the gasifier. A small bed of charcoal is placed at the bottom of the gasifier manifold. The gasifier is started by turning on the blowing motor which forces air over the charcoal bed. The draft mechanism draws a sub-stoichiometric amount of ambient air across the hearth of charcoal which is then lighted by a propane torch. This results in a high temperature oxidation zone with a lower temperature (about 850^{o} C) anoxic reduction zone just below. Combustible producer gas, the outcome of this gasification process, is fed through a high temperature flexible hose (approximately 2 inches in diameter) to a burner inserted in the base of the PR. The resulting ~ 1200^{o} C flame and combustion gases circulate around the outside of the inner PR tube.

Over a short period of time, the PR reaches a sufficient temperature to start producing biochar. The auger motor turns the PR material to maintain even temperatures. Pyrolysis oils and gases produced within the PR are re-circulated from the top of the tube back into the combustion chamber at the base of the retort, where they are burned to maintain the desired operating temperature. If temperatures begin to exceed desired parameters these gases are flared in by auxiliary burner, which is illustrated by the flame in Figure 2.

3.3.2 Outputs

Approximately 120 pounds of gasifier wood chips and 200 pounds of wood waste are used per run, with an output of approximately 52 pounds of biochar. On a bone-dry basis, this is a 19% yield. Considering just the pyrolytic retort (again on a bone-dry basis) an average of 31% yield of biochar from the wood waste is achieved. Other systems average 30% yields with ranges of 28-33% depending on the feedstock (Roberts et al. 2010). The resulting biochar is approximately 0.5 to 1.5 inches in size (Figure 5). The TSY-Peak project currently anticipates loading 27 metric tons of feedstock into the PR each year it operates at its current scale; at this rate, the plant should produce 8.25 metric tons of biochar per year.

The operators of the TSY-Peak project plan to sell the biochar to research universities, to apply the char to portions of their own forests 15 to 50 miles away, and to sell the biochar for other horticultural applications.

Figure 5. Biochar product produced by the TSY-Peak system.
Photo Credit: Matt Delaney

Waste heat generated by the PR is currently not utilized on-site, but the company is investigating small-scale electrical production. The hot exhaust gases are also not currently utilized (other than to heat the PR) but Thompson Timber has begun the construction of an enclosed chamber to dry and preheat the fuel inputs using these gases.

3.4 Economics

Capital costs for the TSY-Peak project are very low. Other than the gasifier, which was purchased as a unit, the motors and PR were modified from equipment that was available on the Thompson Timber log yard. This kept capital costs extremely low, at an estimated $59,000. Below are the line-item costs:

- Fluidyne Pacific Class down-draft gasifier: $15,000.
- Pyrolytic retort: $13,000.
- Motors: $0 (modified from unused motors at the log yard).
- Labor: $31,000.

Annual operations and maintenance costs are estimated to be $33,324. Major costs are saved through utilizing waste feedstock.

- Maintenance: $3,000. Estimated at 3-5% of the capital costs (De Gryze et al. 2010).
- Labor: $30,000.
- Opportunity cost of feedstock: $324. An estimated 16.2 metric tons of wood chips are used per year to feed the gasifier. The log yard could alternatively sell these chips for an estimated $20/ton. The feedstock fed into the PR has no opportunity cost, because without the project it would be left to rot in the log yard.

Annual revenue is currently limited to the biochar produced by the pilot system. The system is currently projected to produce 8 metric tons of biochar a year. While the value for biochar is uncertain, biochar for researchers and nurseries has sold for $200/ton (Miles 2009) to $500/ton.

- Annual biochar sales: $1,600 - $4,000

3.5 Greenhouse gas emissions

3.5.1 Sources of greenhouse gas emissions

Source	**Data/assumptions**	**Emissions**
Electricity used at the pyrolysis plant	The plant consumes 2.468 kWh to produce 13 pounds of biochar. The average kilowatt hour consumed by the project emits 0.902 pounds of CO_2e (EPA 2007).	0.17 mt CO_2e/metric ton of biochar

Emissions from harvesting and transporting the feedstock to the pyrolysis plant are not included in this accounting because waste biomass and hog fuel are created with or without the pyrolysis process. The biochar project therefore does not increase harvesting or transportation emissions. If they did, these GHG emissions are relatively small—around 0.34 mt CO_2e/metric ton of biochar produced by the plant, based on the assumptions of Manomet (2010).

Emissions associated with transporting the biochar from the Thompson Timber log yard to the forest where it is applied are also not included in this accounting. Trucks from the log yard must go back to the forests to collect additional logs. While these trucks currently return empty, under the project scenario they will return with biochar. It is therefore assumed that the biochar projects do not add any transportation emissions to return biochar to the soils.

Emissions from combustion of the pyrolysis oils, pyrolysis gases and the producer gas are not included in the accounting above. All of the combustible gases, the producer gas from the gasifier, and the pyrolysis oils and gases evolving from the top of the pyrolytic retort are captured and fed to the combustion chamber surrounding the base of the unit. An auxiliary burner flares excess combustible gas. All combustible gases developed in the TSY-Peak system see a flame front prior to exiting the system to the atmosphere, so no methane in the pyrolysis gases and producer gases is released to the atmosphere.

3.5.2 Sources of emission reductions

Source		**Emission Reductions**
Carbon sequestered in the biochar	Assume 1 metric ton of biochar is 0.80 metric tons of carbon and that only 80% of this carbon will remain 100 years after it is created (Roberts et al. 2010). These assumptions are justified below.	2.35 mt CO_2e sequestered /metric ton of biochar. **Subtracting emissions from the electricity used to create the biochar, each metric ton of biochar reduces roughly 2.18 mt CO_2e.**

Testing the amount of carbon in the biochar produced by the TSY-Peak biochar system is underway currently and the results are not available at the time of publication, but studies of biochar indicate increasing carbon content by pyrolysis temperature, ranging from 55% to 93% (McLaughlin et al 2009; Okimori 2003). Researchers at Oregon State University conducted an analysis of ponderosa pine wood chips and found a similar pattern, with biochar carbon content ranging from 50% to 92% with pyrolysis temperatures ranging from 100 ^oC to 700 ^oC (Keiluweit et al. 2010). The operating temperatures of the TSY-Peak biochar system is approximately 500^oC, so a carbon content of 80% or, approximately of 2.93 mt CO_2 is kept out of the atmosphere, per ton of biochar.

Based on Roberts et al. (2010), it is assumed that 80% of the carbon in the biochar remains sequestered over 100 years. Project-specific monitoring of the biochar over time will be needed in order to accurately measure and then model this decomposition as discussed in Section 2.7.1.

The TSY-Peak project has no renewable energy or waste diversion benefits. The project is not yet generating any energy from the syngas or waste heat. The waste biomass and hog fuel are left to decompose aerobically in the absence of the biochar project, so there are no methane reductions associated with managing this feedstock with pyrolysis.

CHAPTER 4:
Conclusion

Building from the description of the project in the previous chapter, the conclusion of this report will analyze the TSY-Peak project under the carbon market investment criteria of Chapter 2 and then summarize the lessons learned from this case study.

4.1 Analysis of TSY-Peak's potential for carbon market investment

Table 6 compares the desirable qualities for offset investment outlined in Chapter 2 to the qualities of the TSY-Peak project described in Chapter 3. The criteria not met by the TSY-Peak project are discussed after the table.

Table 6: Comparison of the TSY-Peak project with carbon market investment criteria

Project component	Desirable quality	Criterion met by TSY-Peak?
Feedstock	Projects are fed by waste biomass that would otherwise be burnt or left to decompose. Feedstocks grown specifically for the biochar project are produced on marginal or degraded land.	Yes. The Thompson Timber log yard annually generates 6,000 metric tons of waste biomass and hog fuel that is currently left to decompose in the log yard or as a yard amendment. Before the project, the hog fuel was not used as an energy source. Utilizing this feedstock for biochar will not cause direct or indirect land-use change.
	Feedstocks do not potentially contain heavy-metals. Feedstocks do not consist of municipal solid waste, sewage sludge or tires.	Yes. The hog fuel and wood waste used by the project does not contain heavy metals.
	Projects can track how their feedstock was managed before the implementation of the biochar project and project how it likely would have been managed in the absence of project implementation.	Yes. All feedstock comes from the Thompson Timber log yard, which can easily document how it has been managing its wood waste and hog fuel.
	The seller of the offsets can obtain clear contractual title to the emission reductions that result from waste diversion and carbon sequestration from the original	Yes. The pyrolysis plant and feedstock owners are the same entity, so there is no potential for double counting.

	owner of the feedstock.	
Regulatory environment	Projects are not required to be implemented by law.	Yes. The project has been implemented voluntarily.
Pyrolysis process	Pyrolysis will generate at least 25,000 metric tons of biochar over ten years. Bigger projects (100,000 metric tons of biochar or more) are the most desirable.	No. The pilot program is currently projected to generate 8 metric tons of biochar per year, or 80 metric tons over 10 years. (See discussion below on the potential to scale the project.)
Use of biochar	Projects incorporate biochar into soils. Stable soils that are unlikely to erode during extreme weather events are most desirable.	Yes. Thompson Timber's nearby upland forests have slopes between 3% and 60%. Sufficient forest space should be available to only incorporate biochar in areas that do not face the possibility of major landslides.
	Entity using the biochar is willing to contractually obligate him/herself to not develop, intensively till, or remove soil from the soil in which biochar will be incorporated for the next 100 years.	Likely yes. Starker Forests, which supplies the material for the Thompson Timber log yard, are highly productive forests that have been used as timberland for nearly 100 years.
	The biochar producer can account for, track, and monitor where all the biochar is incorporated into soils. Vertical integration, where the the producer of the char is also the user of the char, is the most desirable.	No. The pilot program plans to sell biochar to a variety of researchers, nurseries, and farms. (See discussion below.)

The TSY-Peak project passes all the investment criteria outlined except two:

1. The pilot project is too small. It is projected to produce 8 metric tons of biochar per year, while it is estimated that biochar offset projects will need to produce at least 25,000 metric tons of biochar over their lifetime, or around 2,500 metric tons per year.
2. The project plans to sell biochar to many entities, making it difficult to account for where all the biochar is incorporated into soils.

The quantity of waste biomass available at the Thompson Timber log yard opens the potential for a larger project which could qualify for offset funding. The log yard current produces 6,000 metric tons of waste biomass per year. A much larger pyrolysis plant that converts 30% of the biomass input into biochar could produce 1,800 metric tons of biochar per year with this waste alone. By bringing in additional waste, a larger TSY-Peak project could operate at a scale that is attractive for carbon investment.

This larger project would also need to simplify the number of entities to whom it sells biochar in order to qualify for carbon finance. This, too, is a possibility. There are approximately 60,000 acres of forests owned by Starker Forests, on which biochar could potentially be applied. The amount of biochar applied per acre varies but one common suggestion is 10 metric tons of biochar per acre (De Gryze et al. 2010; Blackwell et al. 2010). In this scenario, the forest lands associated with the log yard alone could demand 600,000 metric tons of biochar.

4.2 Conclusion

Given the availability of significantly more feedstock and land, it is feasible for the TSY-Peak project to scale into an attractive offset project. This would require commitment to pyrolyzing all available material at the log yard and applying at least 25,000 metric tons of biochar to available forest land. Biochar's economic and agronomic benefits are not yet sufficiently proven to justify this scale of investment. The TSY-Peak project is an attempt to begin proving these benefits.

Revenue from offset sales alone is not enough to drive this investment. If each metric ton of biochar results in approximately 2 metric tons of CO_2e reductions, at an assumed offset price of $6/metric tons of CO_2e, offset sales are only $12/metric ton of biochar produced. A cap-and-trade system could raise prices to $15 to $40/metric tons of CO_2e, or $30 to $80/metric ton of biochar produced. The TSY-Peak project sold biochar for research or agricultural applications at $200 to $500 per metric ton. A long-term buyer willing to purchase a large quantity of biochar at these prices is the fundamental driver for the economics of these early stage biochar projects that face an uncertain market for their product. That said, carbon offset sales can add another significant revenue to biochar projects.

Given the potential of biochar to sequester carbon, generate renewable energy, increase soil productivity, and provide jobs in natural resource-based rural economies, policy makers, investors, engineers, agronomists and carbon market participants should focus on developing the sector. Pilot projects that prove these benefits are the essential next step for the industry. During this early stage of project implementation, a carbon market protocol to qualify the right subset of biochar projects and quantify their carbon sequestration and waste diversion benefits must be developed. This protocol could add an additional revenue stream to biochar projects, accelerating their implementation by increasing economic profitability, and aligning the economic incentives needed for these projects to maximize their climate benefits.

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