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The Big California Biochar Model:

Forest biomass management, carbon drawdown, drought resiliency, and nitrogen conservation on a statewide scale.

By: Josiah Hunt, Charlie McIntosh

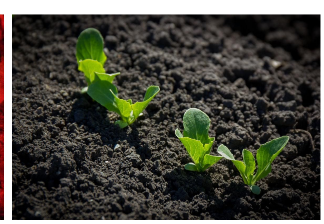
There is a forest management challenge in California. A mix of unsuccessful stewardship practices and changing weather patterns has left a large portion of the forests in poor health. Of key concern is the excess fuel loads in the forests that are leading to catastrophic wildfires and other ecosystem concerns. For reasons of local fire risk, regional ecosystem services, and global climate change mitigation, profound improvements in forest management are being sought by industry and government alike.

Excess fuel loads in the forest are being actively managed by state and private organizations, and in that context the excess fuel loads are generally referred to as “forest biomass”. Forest biomass can be transformed into biochar then used to improve the long-term health of farmland soils in the valleys below. This can provide a comprehensive forest management solution that elegantly works to improve water conservation and carbon drawdown at the same time. We have investigated what this could look like if brought up to scale with the scope of the problem at hand, and what we have discovered is profound.

- Forest biomass in CA can generate 1.5 million tons of biochar annually
- Improving 160,000 acres of land annually at an application rate of 1% SOM
- Adding 13,000 acre feet of water holding capacity to CA soils annually
- Achieving carbon drawdown of 9,165,021 tons annually at a cost of $35 per ton

This document and the associated worksheet offer a map, a guidance tool. We also have a plan of action, because the time for action is now. Pacific Biochar is actively producing and applying biochar in the ways shown below. We have developed a plan to renovate an additional series of existing biomass power plants in high fire hazard forest areas, allowing for fast and efficient scale up to meet the urgency of the situation. We seek to work collaboratively with interested parties to bring some portion of this model into reality.





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BIOMASS MANAGEMENT AND BIOCHAR PRODUCTION IN CALIFORNIA

Forest management is critical for avoiding megafires and for supporting forest health. But the details of how this is accomplished can be controversial. So as to be clear of what is being discussed here, we list, as it is listed in the California Biomass Collaborative document, the descriptions of the biomass groupings that are collectively referred to as Forest Biomass:

• *Logging slash* comprises branches, tops, and other materials removed from trees during timber harvest... Slash left on the ground after harvest can be a substantial source of surface fuels which can carry wildfire. Production of slash is estimated at nearly 8 million BDT/y.

• *Forest thinnings* are non‑merchantable components extracted during harvest activities and include understory brush, small diameter tree boles, and other material transported to the mill that cannot produce sawlogs. Thinning refers to silvicultural treatments designed to reduce crowding and enhance overall forest health and fire resistance. Thinning of forest and shrub lands by mechanical means (other than by prescribed fire) is often emphasized when the intent is to reduce the threat of catastrophic wildfire near houses or other vulnerable assets and where air quality is a concern. Thinning may or may not produce merchantable saw logs (close to half of which may end up as mill waste). The issue of mechanically thinning forests has been and remains controversial, but thinning is likely to increase, particularly in wildland‑urban interface areas, due to new federal legislation and increasing public concerns over the risk from wildfire. Estimates of the technical availability exclude forest reserves, stream management zones, coastal protection zones, coastal sage scrub habitats, national forest lands with slopes steeper than 35%, and private and other public forest lands with slopes steeper than 30%. There are an estimated 7.6 million BDT/y of thinnings.

• *Sawmill residues* are a byproduct of the milling of sawlogs that consist generally of softwood tree boles with a diameter at breast height (dbh) of about ten inches. Sawmill and other forest products manufacturing operations generate a variety of wood residues including bark, sawdust, planer shavings, and trim ends... A large fraction of this material is technically available for use, and about 1.3 million dry tons are already in use for power generation in the state with additional amounts used for landscape and other products… Around 6 million BDT/y are estimated to be generated at mills.

• *Shrub or chaparral* is comprised of mostly shrubby evergreen plants adapted to the semi‑arid desert regions of California, especially in the south state… Because shrub biomass has no current commercial value, it is only available as an energy resource through habitat improvement activities (such as thinning) or fuel treatment operations designed to reduce wildfire risks. For 2005, nearly 5 million BDT/y were estimated to be available.

The California Biomass Collaborative at UC Davis reported on the Gross (total) biomass resources and Technical (currently feasible and sustainable) biomass resources available annually in California. Forest biomass resources were found to be 26.8 million Bone Dry Tons (BDT) Gross, and 14.3 million BDT Technical (1). When including biomass resources from agriculture and municipal wastes, the total is 78 million BDT Gross per year and 35 million BDT Technical per year (1). These non-forest resources represent a diverse mix of materials with many possible uses (i.e. anaerobic digestion, composting, biomass energy, and biochar production). The non-forest materials are not being addressed in this report for two main reasons: a) Forest biomass management is a critical and pressing need in California b)

Composting and anaerobic digestion are commonly applicable management tools for ag and municipal wastes but far less applicable to forest residues.

For the remainder of this paper we will primarily use the numbers reported as Technical Forest Biomass to represent the resource base available for biochar production in California.

Also, for simplicity, we are showing the numbers for 100% utilization of Forest Biomass. To be clear, we are not proposing that 100% of Forest Biomass *should* be used for biochar production, we are modeling the question of whether 100% of that biomass *could* be used for biochar production - and what the outcomes would be. We have identified a reasonable pathway to achieving 17.5% utilization of Forest Biomass in the near-term, and with the use the associated spreadsheet, you can change the Biomass Utilization Factor input cell to see the outcomes of that scenario or other scenarios you would like to model.

ANNUAL FOREST BIOMASS RESOURCES - CALIFORNIA			
Gross Forest Biomass Resources	26,800,000	BDT biomass / year	[1]
Technical Forest Biomass Resources	14,300,000	BDT biomass / year	[1]

Table 1: Gross Forest Biomass resource base and Technical Forest Biomass resource base available in California on an annual basis (1)

ANNUAL BIOCHAR PRODUCTION - TECHNICAL FOREST BIOMASS					
Biomass Conversion Efficiency %	1.00%	5.00%	10.00%	20.00%	
Biochar Production	143,000	715,000	1,430,000	2,860,000	BDT biochar
Feedstock BDT : Biochar BDT	100	20	10	5	BDT feedstock / BDT biochar
Biochar Value	$32	$161	$322	$644	million dollars
Biochar Value / BDT Feedstock	$2.25	$11.25	$22.50	$45.00	dollars / BDT feedstock
Energy Potential / Ton Feedstock	4,663	4,092	3,377	1,948	kWh / BDT feedstock
Electrical Energy Generation	1,659	1,455	1,201	693	MW
Forest Biomass Utilization	14,300,000	14,300,000	14,300,000	14,300,000	BDT

Table 2: Biochar market potential utilizing Technical Forest Biomass resource base to estimate annual biochar production, biochar value, and energy generation potential.

We show biochar production scenarios under 4 different conversion efficiencies here (referring to the efficiency of conversion of feedstock biomass into biochar on a dry-weight basis). At higher conversion efficiency, biochar production per unit of biomass increases while energy generation per unit of biomass decreases. The biochar that is produced represents energy that was not consumed, and thus biochar production at the scope proposed will be largely determined by whether the carbon is valued greater in the soil than it is as a potential energy source. To represent a price point that we feel is safely in that range, we valued the biochar at $225 per ton, which we believe can be sufficient to incentivise industry development.

A conversion efficiency of 20% is entirely possible and is seen as favorable. But it is most likely that there will be a range of biochar production technologies used. Some that may have an advantage of mobility, may come at the cost of conversion efficiency. 10% conversion efficiency is therefore a more likely scenario in our opinion. If 100% of Technical Forest Biomass were used for biochar production at an average of 10% conversion efficiency, 1,430,000 tons of biochar would be produced annually.

BIOCHAR APPLICATION IN AGRICULTURAL LANDS

The potential for biochar production in California is immense, as demonstrated above. How does it match up with the 25 million acres of agricultural lands where much of the biochar will be applied?

"California's agricultural abundance includes more than 400 commodities. Over a third of the country's vegetables and two-thirds of the country's fruits and nuts are grown in California. California is the leading US state for cash farm receipts, accounting for over 13 percent of the nation's total agricultural value" (CDFA Statistics).

ANNUAL BIOCHAR PRODUCTION - TECHNICAL FOREST BIOMASS		
Biomass Utilization Factor	100.00%	Percent
Biomass Conversion to Biochar Efficiency %	10.00%	Percent
Forest Biomass Utilization	14,300,000	BDT biomass
Biochar Production	1,430,000	BDT biochar
ANNUAL BIOCHAR APPLICATION ON AGRICULTURAL LAND		
At 1% Soil Organic Matter in top 6" of soil (used in following formulas)		
Biochar Application Rate	9.04	BDT biochar / acre
Biochar Application, Land Covered	158,209	acres per year
Time Till 100% Coverage Ag Land	160	years

Table 3: Annual biochar application potential on agricultural lands (in acres) at varying application rates

Agricultural lands account for over 25 million acres in California as reported by the California Agricultural Statistics Review 2017-2018 (2). Applying biochar on agricultural lands can improve soil health, water conservation, and nitrogen management.

Soils commonly contain some amount of biochar, naturally occurring from wildfire or human management (23). The naturally occuring biochar content of soils regularly goes unacknowledged as a distinct material. In soil analysis it will show up in the category of Organic Matter by default when the common test method of Loss On Ignition is used, in which case the biochar is combusted along with the rest of the organic matter. In the experience of the authors, considering biochar as a portion of SOM, and using general understandings of SOM, provides a very useful guide in application rates and expectations. There is a growing international awareness of the critical role SOM plays in food security and climate change mitigation.

A single application of biochar at 9 tons/acre, cultivated into the top 6”, is roughly equivalent to a 1% increase in SOM in that soil profile. At that application rate 158,209 acres of land could be improved each year. It would take about 160 years to cover every acre of agricultural land currently in use – allowing for focus on marginal soils first, and illustrating that there is more than enough soil to receive the biochar produced, even at 100% utilization of forest biomass.




CARBON SEQUESTRATION AND GHG EMISSION REDUCTION

California plans to be net carbon-neutral by 2045. This will come in the form of energy efficiency, renewable energy, and also in carbon drawdown. Biochar represents an optimal form of drawdown that is natural, stable, and with many other benefits to humanity such as food security and water conservation. Biochar can provide a climate change mitigation strategy with climate change adaptation benefits.

PART 1, DIRECT CARBON SEQUESTRATION

Using biochar to sequester carbon in soil is a viable strategy because of biochar’s long-term stability. Unlike other forms of organic matter, biochar (pyrogenic organic matter) is not easily decomposed by microorganisms. Studies consistently demonstrate that woody biomass pyrolyzed at high temperature (> 500ºC) for a sufficient amount of time (a few minutes) produces a biochar with $H:C_{org} < 0.4$ and a mean residence time > 1000 years (3, 4, 24).

ANNUAL BIOCHAR PRODUCTION - TECHNICAL FOREST BIOMASS		
Biomass Utilization Factor	100.00%	Percent
Biomass Conversion to Biochar Efficiency %	10.00%	Percent
Forest Biomass Utilization	14,300,000	BDT biomass
Biochar Production	1,430,000	BDT biochar
DIRECT CARBON SEQUESTRATION		
Carbon Sequestration Potential, C	1,215,500	tons - C
Carbon Sequestration Potential, CO2	4,207,251	tons - CO2e

Table 4: Annual direct carbon sequestration potential from biochar production and soil application.

Biochar is primarily carbon, C. But the primary unit of measurement for carbon accounting is CO_2, which is two O's heavier than C. We use the simple molar ratio of C to CO_2 to estimate the equivalent removal of carbon dioxide from the atmosphere. It is important to acknowledge that a comprehensive life-cycle analysis is needed for precise predictions of carbon sequestration and drawdown potential. Alternative fate of the biomass in question, characteristics of the biochar produced, footprint of process, and additional benefits gained from applications are important factors in accurately predicting and accounting for carbon drawdown.

Direct carbon sequestration of biochar into soil is attractively simple and definite, it is like coal in reverse. Carbon that was captured from the air by plants is now made stable and put in the ground. Achieving a direct carbon drawdown of 4 million tons CO_2e annually while helping the State manage catastrophic fire risk is pretty cool.

PART 2, GREENHOUSE GAS EMISSION REDUCTION BY ANCILLARY BENEFITS
The use of biochar can result in greater efficiency of soil processes, composting, manure management, ruminant digestion, and other agricultural activities that contribute to greenhouse gas emissions. These greenhouse gas emission reductions are in addition to the carbon body of biochar that is sequestered in soils. Collectively, they are referred to here as ancillary benefits. As displayed in the worksheet, the combined effect of the ancillary benefits can have a greater CO_2 drawdown impact than the embodied carbon in the biochar. Three things that are important to note here:

1.) Although the numbers in the worksheet are mostly shown as annual, in some cases, such as biochar applied to soil, the benefits can be compounding year upon year.

2.) Annual biochar production, at 100% utilization of forest biomass residues, is beyond sufficient for modest amendment of the entire scope of enteric fermentation, manure management, and composting.

3.) Unlike the assuredness of stable carbon locked away in soil, the ancillary benefits achieved are entirely dependent on management, providing opportunity for achieving drawdown beyond expectation (wise and/or lucky), or achieving drawdown below expectations (unwise and/or unlucky).

ANNUAL BIOCHAR PRODUCTION - TECHNICAL FOREST BIOMASS		
Biomass Utilization Factor	100.00%	Percent
Biomass Conversion to Biochar Efficiency %	10.00%	Percent
Forest Biomass Utilization	14,300,000	BDT biomass
Biochar Production	1,430,000	BDT biochar
GREENHOUSE GAS EMISSION REDUCTION - ANCILLARY		
GHG ER, Enteric Fermentation (cow burps)	2,493,955	tons - CO2e
GHG ER, Manure Management	2,335,936	tons - CO2e
GHG ER, Composting	108,800	tons - CO2e
GHG ER, Soil (annual)	19,079	tons - CO2e
GHG ER, combined impact of ancillary	4,957,770	tons - CO2e
TOTAL: GHG ER + direct sequestration	9,165,021	tons - CO2e

Table 5: Annual GHG emission reduction from ancillary benefits including enteric fermentation, manure management, composting, and soil.

California's annual greenhouse gas emissions from agriculture account for 8% of total statewide greenhouse gas emissions (12). Soil management accounts for 17% of total agricultural emissions. A meta-analysis found that biochar can reduce N_2O emissions from soil by an average of 54% (13, 25). Emissions from soil are primarily due to N2O from irrigated and fertilized cropland, accounting for 9,600,000 million acres in California. Using these figures we calculated potential greenhouse gas emissions reductions from irrigated cropland using biochar at 1% SOM application rate. The number reported is the improvement annually, thus an application in year one would reduce soil GHG emissions by 19,000 tons in that year and every year to follow. After ten years of application, at the above mentioned rate, a greater area of soil would be amended with biochar, achieving a projected 190,000 tons of GHG emission reduction annually.

Animal manure management also releases greenhouse gases (i.e. CO_2, N_2O, and CH_4), accounting for 34% of emissions from agriculture. The dairy industry is the largest producer of manure and manure related emissions followed by poultry and swine manure. Manure is commonly managed in composting operations, manure lagoons, and via anaerobic digestion. Using biochar as an additive to composting operations can dramatically reduce emissions and nutrient losses while improving compost stability (28, 26, 14, 19). Biochar has been shown to reduce emissions from dairy manure composting by 27-32% (14) and chicken manure composting by up to 50% (19). As an additive in anaerobic digestion biochar can improve biogas production, in animal bedding it can reduce odors and volatile compounds, and as a biocover biochar can reduce emissions from manure lagoons. However, exact numbers for emissions and tonnage are difficult to find for each manure management technique. For the calculations in the table above (Table 7) we have applied an assumption of 20% emissions reductions based on literature, studies on manure composting, and our own experience. We think it is possible to achieve higher rates of emission reduction with some innovation in these areas, a goal Pacific Biochar is keen to take part in.

Another significant contributor to California's agricultural greenhouse gas emissions comes from enteric fermentation related to animal feeding and ruminant digestion. Biochar can reduce emissions from enteric fermentation via feed supplementation (0.6% dry weight) by 22% (15). Emissions from enteric fermentation account for 33% of emissions from agriculture. Cows account for the vast majority of enteric fermentation emissions, consuming 17.5 million tons of feed annually. If biochar was supplemented at 0.6% dry weight, 105,462 tons of biochar would be needed to supplement 100% of cattle feed and reduce emissions from enteric fermentation by 2.49 million tons CO2e.

It is important to note here a few factors of complexity. Biochar applied to soil can provide emission reduction every year, for years to come, and when annual biochar applications continue, it can have a curved rate of increase similar to compounding interest. Biochar applied in animal feed is a one time gain for that pathway, but then lives on in the compost, and again in the soil - the cumulative benefit of that is not yet mapped out in any research we are aware of. And there is risk for double counting, for instance; would the emissions reductions of biochar application to soil be as dramatic if the fertilizer applied were a biochar amended manure? Gas dynamics are very difficult to measure in these systems where cows are moving around, compost piles are turned in the wind, soil dynamics change as soon as you put a hood over them… The biggest takeaway that there are a lot of emissions in this sector, and biochar, essentially a charcoal filter, can play a large role in efficiency gains, and with wonderful results.

Also, it is important to remember that we are showing numbers associated with 100% Biomass Utilization of Forest Biomass. While this is useful in painting a simple picture of the possible, it is important to remember that there are other uses for the Forest Biomass that will be employed, and while we can not predict exactly what portion of Forest Biomass will be used in biochar production, it is safe to say that it will not be 100%.

PART 3, CO2 DRAWDOWN COST

Show me the money! Here we calculated the projected cost per ton CO_2 drawdown. One assumption of critical importance here is the value per ton biochar. For this exercise we suggest that a stable value per ton of biochar at $225 could be sufficient to support the industries required for its production. This is an educated guess, and can be easily modeled under different scenarios by changing the input cell of the Biochar Monetary Value in the spreadsheet that is associated with this narrative.

ANNUAL BIOCHAR PRODUCTION - TECHNICAL FOREST BIOMASS		
Biomass Utilization Factor	100.00%	Percent
Biomass Conversion to Biochar Efficiency %	10.00%	Percent
Forest Biomass Utilization	14,300,000	BDT biomass
Biochar Production	1,430,000	BDT biochar
COST PER TON CO2 DRAWDOWN		
$ per ton CO2, direct sequestration	$76	dollars per ton CO2e
$ per ton CO2, GHG ER, ancillary combined	$65	dollars per ton CO2e
$ per ton, CO2, total of direct and ancillary	$35	dollars per ton CO2e

Table 6: Cost per ton of CO_2 drawdown from direct carbon sequestration, ancillary benefits, and combined.

Direct carbon sequestration can, in this scenario, be accomplished at $76 per ton CO_2e. If a market were to offer $25 per ton CO_2e, the cost of biochar to the farmer would be discounted by about a third.

Greenhouse gas emission reduction of ancillary benefits can, in this scenario, be accomplished at $65 per ton CO_2e. Combined, the direct carbon sequestration (the carbon embodied in the biochar) and the ancillary benefits offer a carbon drawdown at $35 per ton!

WATER CONSERVATION

Water is a critical issue in the state of California with water conservation practices being implemented statewide. During dry years, agricultural water use can account for up to 61% of water used in the state (5). Conserving water by increasing the water holding capacity of California soils could have a major impact on water resources in the state. Biochar's ability to hold water has been identified as a useful tool for altering soil hydrology (27).

ANNUAL BIOCHAR PRODUCTION - TECHNICAL FOREST BIOMASS		
Biomass Utilization Factor	100.00%	Percent
Biomass Conversion to Biochar Efficiency %	10.00%	Percent
Forest Biomass Utilization	14,300,000	BDT biomass
Biochar Production	1,430,000	BDT biochar
WATER CONSERVATION		
Increased WHC (gallons)	4,271,631,982	gallons
Increased WHC (acre-feet)	13,109	acre-feet
Days of Water Use (SF - residential)	115	days

Table 7: Annual increases in California soils' water holding capacity (WHC) using biochar at an application rate equivalent to a 1% increase in SOM in the top 6 inches of soil.

In order to quantify the impact of biochar applications on water conservation we use a commonly quoted figure for increasing the water holding capacity of soil by increasing soil organic matter (SOM):

"One percent of organic matter in the top six inches of soil would hold approximately 27,000 gallons of water per acre!" (6)

Biochar, applied at 9 tons / acre and tilled into the top 6", is equivalent to a 1% increase (w/w) in SOM in that soil profile. Using these values, we calculated the potential annual increase in water holding capacity of California soils resulting from biochar applications. Each year of biochar application, California's soils would gain the water holding capacity of 4.27 billion gallons of water (13,109 acre-feet). For a visual reference, imagine an acre of land with a column of water edge to edge and about 2.5 miles tall added to California's water holding capacity every year.

According to the San Francisco Public Utilities Commission the residents of San Francisco use a total of 37 million gallons of water per day (7). Using the results from Table 5, the annual increase in water holding capacity in California soils is the equivalent of 115 days of residential water use in the city of San Francisco. Assuming an average cost per acre-foot of $1,700 for water reservoir expansion, as stated in a publication by Water in the West - Stanford University (8), the economic value of increased water holding capacity (essentially a reservoir in the soil) could be in excess of $22 million dollars per year. After 10 years of annual applications of biochar, the cumulative effect would be to increase the water holding capacity of California soils by more than 42 billion gallons, about 3 years of San Francisco's residential water use.

NITROGEN MANAGEMENT

"Nitrogen, in various reactive forms, is indispensable to the productivity of California agriculture. And yet, only about half the nitrogen applied ends up where we intend; the balance leaks, polluting our air and water, with detrimental effects on our environment and human health."

- California Nitrogen Assessment: *Challenges and Solutions for People, Agriculture, and Environment*

Nitrogen management has become a primary concern for land managers and communities with respect to human health, crop production, waste management, and environmental degradation. Biochar appears to be an ideal tool to help in more efficiently managing nitrogen.

ANNUAL BIOCHAR PRODUCTION - TECHNICAL FOREST BIOMASS		
Biomass Utilization Factor	100.00%	Percent
Biomass Conversion to Biochar Efficiency %	10.00%	Percent
Forest Biomass Utilization	14,300,000	BDT biomass
Biochar Production	1,430,000	BDT biochar
NITROGEN MANAGEMENT		
Maximum Nitrogen Retention Capacity	257,400	tons - N
N Leaching Reduction, Ag Land	574	tons - N (annually)

Table 8: Nitrogen retention potential using biochar to improve nitrogen management in California soils.

Biochar can retain nitrogen in pores and on surfaces, reducing leaching into groundwater and reducing atmospheric emissions. Importantly for agricultural purposes, the nitrogen that becomes bound to biochar remains largely plant available. To identify the theoretical maximum impact of using biochar to increase nitrogen retention we looked at a recent study by Hestrin et. al. that explored the mechanisms involved in ammonia retention on biochar. In this article the total nitrogen retention capacity of biochar was measured at 0.18 g-nitrogen / g-biochar carbon (11). This N retention potential is profoundly higher than most other natural materials found in soil. Using the retention capacity measured by Hestrin and the biochar application rate found to increase SOM by 1% (9 tons / acre) we calculated the increased nitrogen retention capacity of biochar-amended soil to be 1.62 tons / acre or an additional 257,400 tons of nitrogen retained in soil annually across the state. It would take incredible effort to achieve this theoretical maximum, it is assumed that this will not be fully realized, but yet it does illustrate a very interesting goal.

Another approach to assessing biochar's impact on nitrogen management focuses on reducing nitrogen leaching from soil, a major issue for agricultural producers looking to prevent losses of nitrogen and for communities where groundwater resources have been contaminated by excess nitrate pollution from over-fertilization. The California Nitrogen Assessment found that nitrogen leaching accounts for 367,000 tons of nitrogen entering California's groundwater annually (9). A review of biochar's impact on soil nitrogen dynamics found that biochar can reduce nitrogen leaching by 25% (10, 26).

Using these numbers, at 10% Conversion Efficiency, and 100% Biomass Utilization, between 574 - 1512 tons of nitrogen could be prevented from entering California's groundwater with each year's application. An impact that compounds annually with annual biochar applications on unamended soils. It is important to highlight that even at 20% conversion efficiency annual biochar production will not be sufficient to cover 100% of California's agricultural lands in a single year and that initially soil applications will target areas with the highest emissions (i.e. irrigated and fertilized cropland). Therefore, both calculations are included for reduced nitrogen leaching; the first referencing a portion of total agricultural land and the second referencing a portion of irrigated cropland only.

CONCLUSION

These results indicate that biochar can be used effectively to store large quantities of carbon in agricultural soils while improving drought resiliency and fertilizer efficiency across the state. On it's pathway towards soil, there are a cascade of uses where biochar can help reduce greenhouse gas emissions from agriculture, such as with animal feed, manure management, and co-composting. While it is not proposed here that 100% of the Forest Biomass *should* be used for biochar production, it does show that 100% of the Forest Biomass *could* be used for biochar production, and with very appealing outcomes. Incorporating some portion of this biochar option into the State's forest management plans, soil health management plans, and in GHG emission reduction plans, offers an effective way to transform megafire problems into comprehensive solutions with long lasting benefits.

DISCUSSION

POLICY IMPLICATIONS

Definitely. And we are working on some already. Interested to help? Sharing this with your local officials can be helpful. Contact us to collaborate.

RESEARCH OPPORTUNITIES

Yes please. Contact us for collaboration.
Applications of biochar to reduce greenhouse gas emissions from composting is one of our areas of primary focus right now. Accurately measuring the gas emissions from commercial

scale compost, and at multiple sites with varying feedstocks (particularly manure)… that is something we aim to do a lot more of, and are actively seeking collaboration in this regards.

There is also a unique situation where millions of tons of pyrogenic carbon (biochar) have been deposited across a few hundred thousand acres in California, spanning several decades, and with some amount of records. This offers a window into long term effects across a wide scope. Areas of particular interest include: long term influence of pyrogenic organic matter on non-pyrogenic organic matter, long term influence on soil water dynamics, long term influence on soil N dynamics, yield differences over time, soil types with greatest relative positive response, persistence rates of aged biochar.

INVESTMENT AND/OR COLLABORATION OPPORTUNITIES

Let's talk. Whether investment, collaboration, philanthropy, or other, we want to get some big things done, we have a plan to get there, and the time for action is now. We have identified a way to reach 1.4 million tons CO2e drawdown annually (17% biomass utilization with 10% conversion efficiency) with a $25M infrastructure cost and 24 month timeline. This would be using only renovations to existing facilities surrounded by high fire hazard forest materials, using methods already industry tested. This allows for a low carbon footprint of start up, utilization of already trained staff in rural areas, and using existing permits and power contracts to allow for expediency. The supply of forest biomass is in excess, the cost of scaling up biochar production is surprisingly low, the key limiting factor is demand. Biochar has great ecological value, like an infrastructure investment in your soil, and can improve agricultural productivity for generations, but it can be difficult to get positive gain on your biochar purchase in the first year - creating a significant barrier to demand. Three key functions can help alleviate this: carbon credits, regional demonstration projects, and a loan program to allow farmers to pay for the biochar in a timeframe that better matches the biochar's payback.

As you can see, there are several areas where investments and collaborations can help move this natural solution forward. If you are interested in working with Pacific Biochar Benefit Corporation, please contact us for more information.

REFERENCE SECTION

REFERENCE VALUES, TABLES

REFERENCE VALUES - BIOCHAR			
Biomass Utilization Factor	**100.00%**	percent	User input
Biomass Conversion Efficiency	**10.00%**	percent	User input
Electrical Energy Generation Efficiency	20.00%		assumption
Biochar Price	$225.00	dollars / BDT biochar	assumption
Biochar Carbon Content	85.00%		Pacific Biochar
BC +100 (H:Corg < 0.3)	94.40%	at H:Corg of 0.3	[4] [24]
Biochar Heating Value	9,484	kWh / BDT biochar	UPDATE (J. Turner)(mixed conifer)
Biomass Heating Value	4,806	kWh / BDT biomass	UPDATE (J. Turner)(biochar)
Molar ratio (CO2 : C)	3.67	(44/12)	conversion factor
Direct Carbon Sequestration	2.94	tons CO2 / BDT biochar	calculated
Biochar Application, Feed (0.6% w/w)	105,462	BDT biochar / year	calculated
Biochar Application, Manure (5% w/w)	582,500	BDT biochar / year	caculated
Biochar Application, Compost (5% w/w)	95,000	BDT biochar / year	calculated
Biochar Application Rate, (1% SOM, top 6")	9.04	BDT biochar / acre	calculated
REFERENCE VALUES - CALIFORNIA			
Gross Forest Biomass Resources	26,800,000	BDT biomass / year	[1]
Technical Forest Biomass Resources	14,300,000	BDT biomass / year	[1]
Total Agricultural Land	25,300,000	acres	[2]
Total Irrigated Agricultural Land	9,600,000	acres	[20]
Total Annual GHG Emissions	429,400,000	tons CO2e / year	[12]
Annual GHG Emissions, Agriculture	34,352,000	tons CO2e / year	[12]
Annual GHG Emissions, Enteric Fermentation	11,336,160	tons CO2e / year	[12]

Annual GHG Emissions, Manure	11,679,680	tons CO2e / year	[12]
Annual GHG Emissions, Composting	340,000	tons CO2e / year	[12]
Annual GHG Emissions, Soil	5,839,840	tons CO2e / year	[12]
Dairy Cow Population	1,735,350	cows	[18]
Dairy Feed, per Cow per Day	55.5	lbs feed per cow / day	[21]
Annual Dairy Feed Consumption	17,576,926	tons feed / year	calculated
Annual Manure Production	11,650,000	tons manure / year	[1]
Annual Statewide Compost Production	1,900,000	tons compost / year	[17]
Annual N-Leaching, Agriculture	367,000	tons N / year	[9]
San Francisco Residential Water Use	37,000,000	gallons / year	[7]
REFERENCE VALUES - GHG ER, WATER, & NITROGEN			
Soil WHC (+1% SOM, top 6")	27,000	gallons / acre	[6]
Nitrogen Retention Capacity	0.18	g N / g BC	[11]
Nitrogen Leaching Reduction	25%		[10] [26]
N2O Emissions Reductions, Soil	54%		[13] [25]
N2O % of Total GHG Emissions, Soil	97%		[12]
GHG ER, Soil	52%		calculated [25]
GHG Emission Reductions, Enteric Fermentation	22%		[15]
GHG Emission Reductions, Manure Management	20%		assumption
GHG Emission Reductions, Composting	32%		[14] [19] [28]
REFERENCE VALUES - GENERAL			
Acre to Sq. Ft.	43,560	sq. ft. / acre	conversion factor
Soil Volume (6" Depth)	21,780	cu. ft. / acre	calculated
Soil Bulk Density	83	lb / cu. ft.	[16]
Gallons to Acre-Feet	325,851	gallons / acre-foot	conversion factor

Table 9: Reference Values used in the tables above.

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