Roadmap for Climate Intervention with Biochar

A sequel to the 2020 White Paper "*Climate Intervention with Biochar*"

Parts One and Two of four parts

Release Date: 2023-02-05

Part One:
Goals for Carbon Dioxide Removal (CDR): Seven Candidate Technologies, with Focus on Biochar

Part Two:
A proposal to Achieve 1000+ t CO_2 Removal (CDR)/yr in 2023

[A pre-proposal for funding.]

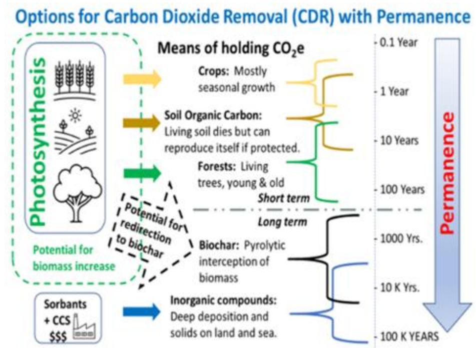
Paul S. Anderson, PhD
Woodgas International
www.woodgas.com

Executive Summary
of the Four-part Roadmap Document

The "Roadmap for Climate Intervention with Biochar" consists of four parts being released at different times. This Executive Summary is specific for Parts One and Two.

Part One: Setting Goals for Carbon Dioxide Removal (CDR): Seven Candidate Technologies, with Focus on Biochar.

[To update Part One of the white paper released in December 2020.]



The recognized seven CDR technologies are characterized more clearly to reveal how biochar is distinct among them.

Mission Innovation (MI) countries have committed to stimulate projects that can accomplish the goal of 1,000+ tonnes of CO_2 removal (CDR) per year by 2025. The CDR technology called Biochar is the only one (of seven) that is already accomplishing that goal. Twelve specific biochar methods and devices are named that can attain this First Goal of 1000 t CDR/yr capacity.

Higher goals of 10 kt, 1 Mt, and 1 Gt CDR/yr are proposed because biochar can attain them.

Scientific data about available biomass for possible pyrolysis is provided to justify the Fifth Goal of 10 Gt CDR/yr. The other four parts of the Roadmap explain how to achieve these goals.

Five Goals for CDR via Pyrolytic Biochar and Energy (BC&E)

All measurements refer to tonnes per year of carbon dioxide removal and storage.

Goal	Weight per year	Expressed as:	Target date
(Prove viable)	100 t	2 tonnes per week	(Currently operational)
First Goal	1000 t	1X = 1 thousand t = 1 k t	December 2023
Second Goal	10,000 t	10X = 10 thousand t = 10 k t	2025 - 2027
Third Goal	1,000,000 t	1000X = 1 Million tonnes	2030
Fourth Goal	1,000,000,000 t	1000 Million tonnes = 1 Gt	2040
Fifth Goal	10,000,000,000 t	10 Gigatonnes = 10 Gt	2050

Part Two: A proposal to achieve 1000+ t CO_2 removal /yr in 2023

A potential First Goal project is already operational in Kenya. Part Two is a pre-application to the sources of funding. The necessary funding would include commitments to purchase CDR credits and the produced biochar for three years while markets are being established.

Section VI: Project "Biochar Pamoja" in Kenya: The RoCC kiln technology and capacity

Section VII: Biomass and biochar: Specifics of sugarcane field trash ("residue" or "waste")

Section VIII. Financial analyses: How to accomplish the First Goal within 2023; Income and Expenses; Funds needed for CDR calculated based on operational expenses; Expenses for MRV, certification, and project profits

Part Three: How to scale to one million tonnes of CDR/yr by 2030 with biochar

Only the Kenya project details are pre-released in this document. Five other biochar approaches will follow in the full release of Part Three.

Part Four: Reaching gigatonnes (Gt) of CDR ahead of schedule

How to attain the Fourth Goal of 1 Gt CDR/yr by 2040 and the 10 Gt Goal by 2050, all with biochar that provides numerous co-benefits for rich and poor, North and South, and the planet.

Part One:
Goals for Carbon Dioxide Removal (CDR):
Seven Candidate Technologies, with Focus on Biochar

Section I: Introduction / Preliminaries (that apply to all four parts)

A. From white paper to roadmap and also to clear pathways for action:

1. In December 2020 I released my white paper "Climate Intervention with Biochar." (See https://woodgas.com/resources .) Its broad-view content is still highly valid and referenced often in this "Roadmap for… Biochar" continuation that contains numerous updates, especially in Part One for understanding the seven CO_2 removal (CDR) technologies, their limitations, and clear goals.

Parts Two and Three give pathway details for specific CDR action with biochar and woodgas, the products of pyrolysis of biomass.

Part Four is less specific and more like a "roadmap" for the accomplishing the full 10 gigatonne CDR per year potential of biochar for CDR.

White paper	a report or guide that informs readers concisely about a complex issue and presents the issuing body's philosophy on the matter.
Roadmap	a high-level strategic document that is created and maintained to communicate the strategic vision and objectives of a product or project.
Pathway	a trail, road or super-highway that connects a specific starting point to an end goal, complete with identifiable curves and corners for clear actions and practical results.

2. Outline

Part One:	Goals for Carbon Dioxide Removal (CDR): Seven Candidate Technologies
Part Two:	An action proposal to accomplish the First Goal of 1000+ t CO_2/yr in 2023
Part Three:	How to scale to one million tonnes (1 Mt) of CDR/yr by 2027 with biochar
Part Four:	Reaching gigatonnes (Gt) of CDR ahead of schedule; and Conclusion

3. All four parts of this Roadmap document are intended to be objective and scientific, but not specifically written as an academic paper. Scientific writing tends to stifle or hide expressions of passion and concern. But we also need to tie solid content to the current threats climate disaster . I am ultra-concerned that CDR via biochar might continue to be overlooked when we do need as much action as possible right away. Some paragraphs should be read as pleas for urgent action, saying "Do this now. Time is so short. Here is something for prompt full-force efforts. Please help. Tell others."

The intended audiences of the "Roadmap for…Biochar" range from CDR experts and funding sources to the interested public, with the objectives to inform and to motivate for action and impact. For verification of presented factual data, an internet search will easily yield confirmation. I frequently use Wikipedia, a reference source that I annually support with a donation and recommend for your support.

B. Preamble: The realities of climate, ER and CDR

The climate problem is real, frightfully real. The consequences of insufficient action will be devasting to society within this current century unless major changes occur. Societal and governmental responses thus far are horribly insufficient. The big picture boils down to this:

1. There MUST be Net Zero use of fossil fuels, either by greater efficiency, finding alternatives, or doing without, referred to as mitigation or emission reduction (ER). Business as usual (BAU) or Lifestyles as we know them (LAWKT) are not sustainable with dependence on fossil fuels, regardless of the other efforts.

2. Except for increasing global albedo to achieve Arctic Ocean refreezing, the use of solar radiation modification (SRM) (also called "Geoengineering" to alter how sunlight heats the planet) is too theoretical and uncertain to help solve the climate problem quickly enough. SRM could become a "desperation attempt" when it will be too late to prevent some of the worst effects of the climate disaster.

3. It is unreasonable to rely on non-climate interventions (NCI) to reduce carbon emissions. NCI include divine miracles, nuclear war, or economic chaos with starvation. In reality, those could be in our future as consequences, not as solutions.

4. Carbon dioxide ***removal*** (CDR) is recognized as an essential compliment to Net Zero emissions. CDR should be understood to include sufficiently long-term CO_2 ***storage*** measured in multi-centuries, not necessarily multi-millennia. The word "removal" is understood to mean more than just

A major difference between ER and CDR

A. Emission reduction (ER) requires changing the lifestyles of people, including you and me. **ER relates to what you eat and wear and do.** Your carbon footprint is up close and personal. You will feel the impact of ER taking things away from you or requiring the use of alternatives that might not be attractive.

B. Carbon dioxide removal (CDR) occurs by impersonal actions of capturing molecules of CO_2 from the air and storing them for multiple centuries. Apart from humans paying to have CDR occur faster via DAC, CCE, EW, Plant growth, SOM, and OCS (Ocean-based), **CDR does not change your lifestyle. Only CDR via biochar production** can potentially have favorable direct daily impact in our future lifestyles with cooking and heating via the energy released as woodgas. Daily CDR by most families is a possibility via pyrolytic devices.

C. Therefore, **CDR is "nicer" and more "life-style friendly" than ER.** <u>CDR could be a moral hazard.</u>

D. The root of the climate problem is that human-caused ***emissions*** **from fossil burning are over 40 Gt CO_2 every year.** CDR cannot compensate for that amount of current and accumulated damage, not even with trillions of dollars.

E. The world needs to reduce its annual emissions to less than 10 Gt /yr AND **accomplish at least 20 Gt of CDR/yr** to cover unavoidable emissions and also accomplish drawdown of atmospheric CO_2, for at least 100 to 200 years.

F. Conclusion: Support realistic CDR and change your lifestyle (your emissions) to do without much of what you are accustomed to have. The more affluent you are, the more changes are needed.

“capture without long-term storage.” If in doubt, add the “S” to call it CDRS.

5. Of the above choices, the preferred pathways are ER to Net Zero and CDR to go lower than zero, thereby creating carbon NEGATIVE conditions and lowering the CO_2 level in our atmosphere. Are they enough? In theory, yes. Eventually, maybe. Likely, in doubt. Evidence shows that time is extremely short. In actual practice, much remains to be done in so many ways.

This Roadmap shows that biochar as CDR can contribute greatly to these goals, starting immediately. We search for understanding, solutions, and appropriate actions. We provide here a roadmap and some specific pathways for action.

Plant growth can capture atmospheric CO_2 for relatively short-term storage and then pyrolysis can transform the plant biomass into a) woodgas for chemicals and energy and b) into biochar to provide long-term storage that is crucial for true CDRS.

C. About the author, conflicts of interest, and reader involvement:

I am Paul S. Anderson, PhD, a 79-year-old retired university professor of geography (studies of our planet and societies), and certainly not a business manager nor entrepreneur nor engineer. Since 2001 I have become an international expert on small-scale pyrolysis, also called micro-gasification, as exemplified by Top-Lit Updraft (TLUD, pronounced “tee-lud”) cookstoves and barrels. I also invented and patented the Rotatable Covered Cavity (RoCC) kilns that are central to proposals in this Roadmap. Many documents and video recordings are found at https://woodgas.com/resources .

My qualifications for writing the white paper and Roadmap documents are precisely the reasons why I have evident conflicts of interest that I try to restrain in these writings. But our world is endangered, and there are messages to deliver. So, until someone else can present this content with appropriate vigor, I must try. My biosketch (to Dec 2020) is on page 50 of the white paper “Climate Intervention with Biochar” at my website. I will not live to 2050, so everything that I offer here is for those who hope to have reasonable lives on our increasingly hot, less-friendly planet.

This Roadmap (in its four parts or eventually unified as one document) is submitted openly for comments and review by each reader as a peer. All errors and omissions are mine; your assistance to identify them is appreciated. There can be many improvements, but seeking perfection would cause months of delay of release to the public and the possible project funders.

Most important, if you like the content or want to become involved, please start by telling your friends and leaders to read this Roadmap, thereby promoting open discussion. Please help move forward the CDR efforts with pyrolysis for biochar and energy (BC&E).

D. A Challenge: [Extracted and edited from the conclusion in Part Four.]

Stated bluntly, **it is time for YOU to help move CDR forward. And you can do it with biochar.** One important way is by telling your friends about this “Roadmap for … Biochar” again and again until it is eventually clearly evaluated (enacted or rejected) by the Mission Innovation (MI) countries and philanthropist billionaires. They have pledged to finance such efforts, but they need to be aware that the pathway of practical and cost-effective biochar exists.

Specifically, please use social media and your personal contacts to bring this opportunity for impact to the attention of MacKensie Scott, Jeff Bezos, Melinda French Gates, Bill Gates and others who have clear desires for impact and have financial resources to accept appropriate risks. I want to talk to them or other impact-funders about biochar and other ways for significantly changing the world starting right away.

Please put your own talents or funds forward to make CDR via biochar happen very, very soon. As shown in the Kenya efforts presented in Part Two, long-lasting true carbon removal is possible in meaningful quantities, but sufficient funding is crucial for start-up. Can you organize funding? And please get serious about reducing your personal and family carbon footprints, including rejecting products based on or dependent upon fossil fuels.

Biochar is the product of pyrolytic interception and conversion of short-storage biomass to accomplish long term CO_2 removal and storage (CDRS).

Section II: Defining the goals for CO_2 removal (CDR)

A. The First Goal is also called "MI Launchpad goal" or "1000 t" or "1 kt"

1. In order to stimulate carbon dioxide REMOVAL (CDR) efforts to prevent climatic disaster, a multi-nation-based effort called "Mission Innovation" (MI) announced in September 2022 and at COP 27 in November 2022 as an effort called "Launchpad" that is their mechanism for implementation of CDR support. See http://mission-innovation.net/wp-content/uploads/2022/11/CDR-Launchpad.pdf

> "First-wave members who have joined the Launchpad include Canada, the European Commission, Japan, Norway, the United Kingdom, and the United States. The Launchpad is a call to action and both Mission Innovation members and non-MI members are encouraged to join." (page 2.)

"In signing on to the CDR Launchpad, [each of the initial six CDR Mission Innovation plus numerous additional national] members commit to:

"1. Fund or support **at least one, 1,000+ metric ton CO2/year CDR project** by 2025. This can include commitments and projects already underway that have the potential to meet the target." (Emphases added.) To support this commitment, MI members have called for "providing at least $100 million collectively by 2025".

2. The same goal of 1 kt CDR/yr has also been declared by the XPrize (sponsored by Musk) that has already selected the initial 15 favorites that have each received one million dollars. However, anyone can still win the $50 million grand prize. https://www.xprize.org/prizes/elonmusk/articles/xprize-and-the-musk-foundation-award-15m-to-prize-milestone-winners-in-100m-carbon-removal-competition .

3. Likewise, large corporate sponsors Microsoft and the six-company cooperative called Frontier (www.frontierclimate.com) are already picking and supporting potential providers trying to reach that first goal of 1000+ Mt CDR/yr. They are offering corporate voluntary-market pre-purchases of CDR credits at high prices to stimulate efforts for CDR.

4. We will refer frequently to this clearly defined **First Goal of 1 kt CDR/yr** in this Roadmap document. This First Goal is open to ALL of the CDR approaches.

First Goal: at least one 1,000+ metric ton CO_2/year CDR project by 2025.

Caution: These goals are for PER YEAR tonnes, expressed as /yr or /year or per year. Some reports or goals specify "xxx t CDR" to designate *cumulative* amounts over periods of time.

B. Further CDR goals for all CDR technologies (but presented specifically for Pyrolytic Biochar and Energy (BC&E))

This Roadmap document stretches beyond the initial 1 k t CDR/yr First Goal, not with multipliers such as 2X or 5X, but with eight (8) orders of magnitude as listed below: k = thousand; M = million or mega; and G = giga or billion. Lower-case "t" refers to metric tonnes. [Short tons (2000 pounds) are not used in CDR documents.]

Goal Weight	Goal Name	Situation as of January 2023
100 t CDR/yr	(pilot projects)	(Fully working & ready to scale up.)
1,000 t = 1 kt	**First Goal:** of MI Launchpad, etc.	MI to sponsor & facilitate this. See Part Two
10 k t	**Second Goal**: 10,000 t CDR/yr	We show how to do this in Section X.B.
100 k t	(intermediate)	See Section X.C
1000 k t = 1 Mt	**Third Goal**: 1 Million t CDR/yr	We explain how to do this in Section X.D
10 M t	(intermediate)	
100 M t	(intermediate)	
1000 M t = 1 Gt	**Fourth Goal:** 1 Gigatonne CDR/yr	We discuss this in Part Four
10 G (& beyond)	**Fifth Goal:** 10 Gt CDR/yr	For the future in Part Four

Five Goals for CDR via Pyrolytic Biochar and Energy (BC&E)

All measurements refer to tonnes per year of carbon dioxide removal and storage.

Goal	Weight per year	Expressed as:	Target date
(Prove viable)	**100 t**	**2 tonnes per week**	**(Currently operational)**
First Goal	**1000 t**	**1X = 1 thousand t = 1 kt**	**December 2023**
Second Goal	**10,000 t**	**10X = 10 thousand t = 10 kt**	**2025 - 2027**
Third Goal	**1,000,000 t**	**1000X = 1 Million tonnes = 1 Mt**	**2030**
Fourth Goal	**1,000,000,000 t**	**1000 Million tonnes = 1 Gt**	**2040**
Fifth Goal	**10,000,000,000 t**	**10 Gigatonnes = 10 Gt**	**2050**

C. Personal goals

1. For me: My numerous goals include attracting, recruiting, and involving others, many others, and obtaining essential funding to help accomplish the CDR and climate-saving goals that are needed literally to help secure worthy living conditions for all people in the coming times of crisis.

2. For you: I encourage you to set your own goals. I hope that you will decide to become very involved with the climate issues and lifestyle changes. Maybe this Roadmap can be of assistance.

Section III: Seven candidate CDR technologies

1. Various authors discuss this array of technologies and candidates, as presented in "Part I: Biochar among the NETS" in my white paper. To avoid re-printing here what is already available, I respectfully request that you review Section II and Section III (pages 7 – 11) of the white paper that starts this way. Visit https://woodgas.com/wp-content/uploads/2022/01/Climate-Intervention-With-Biochar.pdf .

Section II (of the white paper). Introduction to CDR technologies:

A. Seven NETs

Negative emission technologies (NETs) are based on the ways to have carbon dioxide removal (CDR) from the atmosphere. Seven NETs are commonly named (See Box 1 and Figure 1). All of them could be useful (or essential) in this 21st Century fight to avoid horrendous environmental and societal devastation. But only **one is ready for implementation at scale starting now and able to reach significant amounts of CO_2 removal within the next few years.** However, it is among the least recognized or funded.

…

[There is much more in Section II and also in]

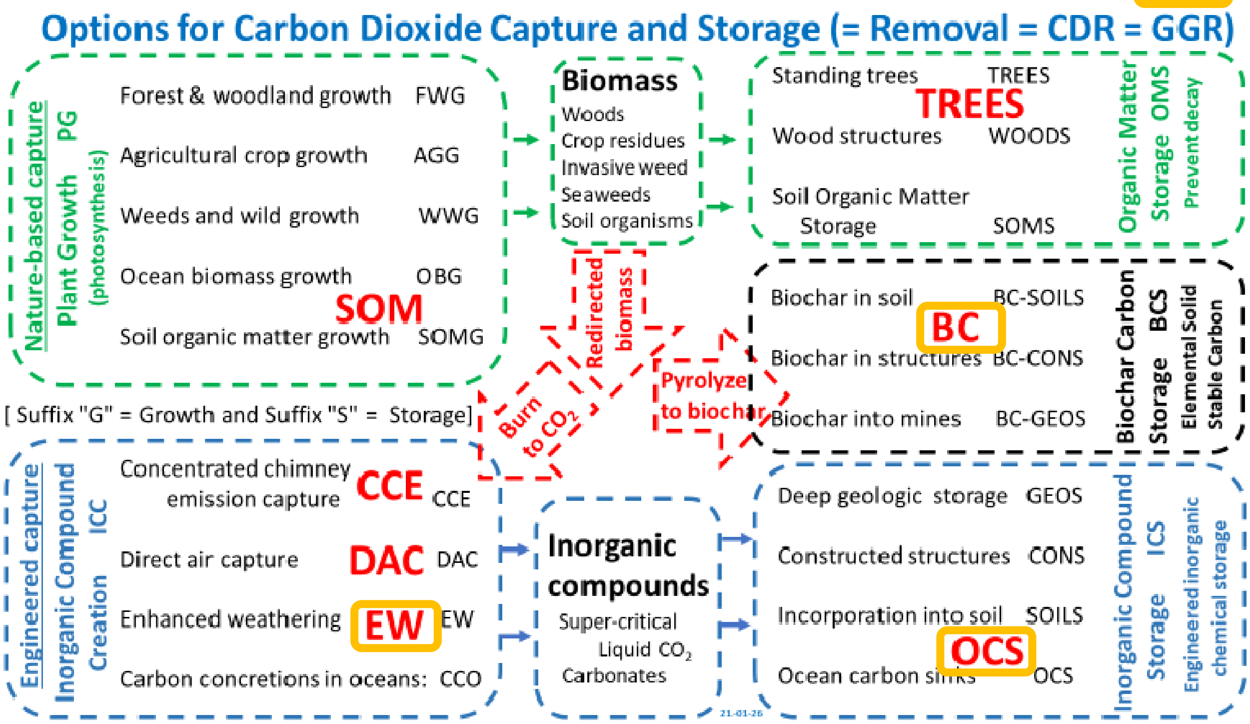
Section III: Evaluation of CDR technologies

The current and near future capabilities of the seven NETs are presented in this summary and in *Table 1: Comparisons of NETs for Seven CDR Technologies* (on next full page).

…

2. After releasing the white paper, further clarity about CDR types was presented in my 2021 presentation "Understanding Carbon Dioxide Removal and Storage (CDRS)," available as a 16-page PDF document and as a webinar video recording found at https://woodgas.com/resources [2021-02-18]. Of greatest importance and illustrated as a summary is Figure 4 on page 12, here being renumbered as Figure 1 and named "Summary of CDR Options" for this Roadmap document.

Figure 1: Summary of CDR Options. [The 3 hybrid technologies are marked with orange boxes]



3. To improve further on the above graphic, we can regroup the seven CDR technologies into three (not two) main groups:

a. **Nature-based CDR** (CO_2 found in living or once-living organisms)

1) PG Plant growth (using solar-powered photosynthesis to make many types of biomass (carbohydrates) that tend to have short-term duration of weeks to less than 100 years). This is much more than afforestation/reforestation (AF/RF) or trees.

2) SOM Soil organic matter (living and dying organisms including plant roots, bacteria and fungi that can hold and increase organic carbon in soils)

b. **"Hybrid" or other CDR** (physiochemical-nature-based capturing and/or long-term carbon storage without photosynthesis)

3) BC Biochar (using pyrolytic processes for thermochemical transformation of previously produced short-duration (weeks up to < 100 yrs) biomass into long-stable elemental carbon. Can be nearly 50% of plant-growth carbon. The other 50% is available as woodgas.)

4) EW Enhanced weathering (using human-facilitated crushed rocks to have greater surface area for ambient chemical reactions capturing carbon into quite stable inorganic compounds on land or in water / oceans)

5) OCS Carbon concretions in oceans (living animals or chemical reactions take carbon from ocean waters to create solids (coral reefs and precipitates) with long-term sequestration)

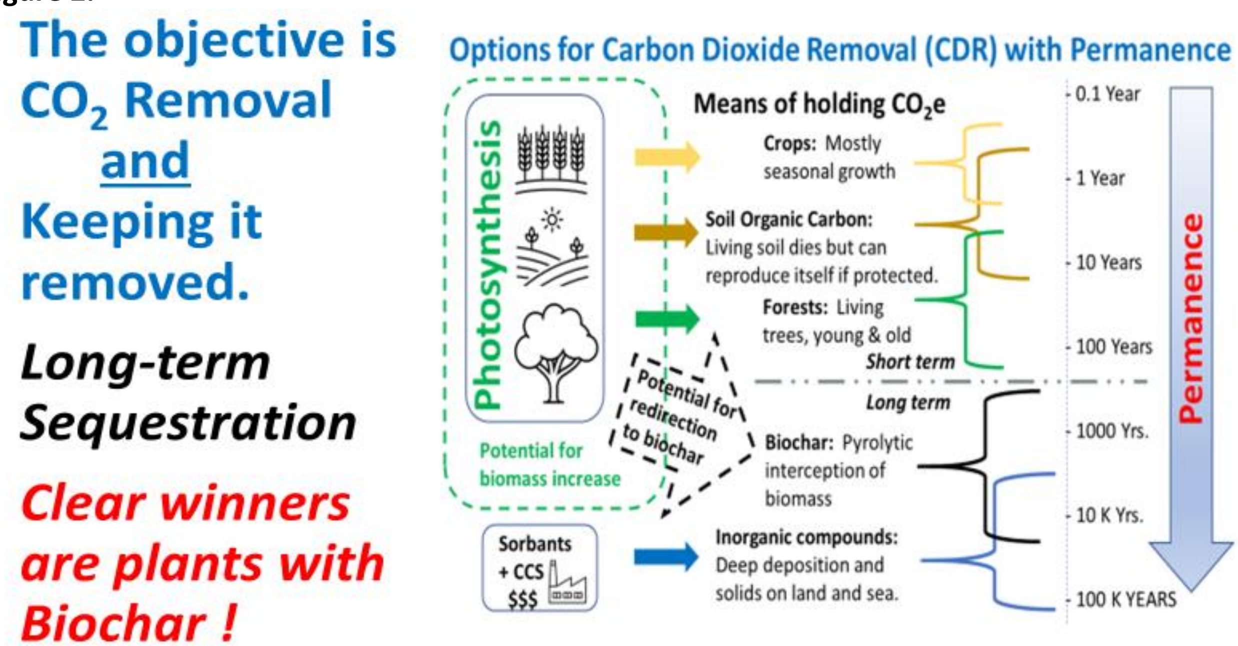
c. Engineered CDR (human-fabricated devices and methods for physio-chemical extraction and collection of CO2 gas)

6) CCE (or BECCS) (Collection of concentrated chimney emissions of CO2 from biomass combustion using constructed devices for CO2 collection and long-term geologic storage)

7) DAC Direct air capture (using constructed devices for CO2 collection from ambient air and then long-term geologic storage)

4. The seven CDR technologies are displayed in Figure 2 according to their permanence of storage. In general, for our climate crisis, one hundred years is insufficient, and over 1000 years is of little value considering the urgency. In this sequence biochar is well-positioned in the 500-to-1000-year range. And this recent publication on biochar permanence (https://www.biochar-journal.org/en/ct/109-Permanence-of-soil-applied-biochar) declares that 550 degree C biochar "…will persist after soil application for more than 1000 years, independent of the soil type and climate."

Figure 2:



The Negative Emission Technology (NET) called Biochar is pyrolytic interception and conversion of biomass to accomplish CO_2 removal and storage (CDRS). Biomass that would otherwise decay back to CO_2 becomes about 50% volatile woodgas and about 50% solid biochar with variations because of ash and non-stable solid carbon. The woodgas offers useful chemicals and energy and the biochar offers permanence and co-benefits in soils and construction materials.

5. The two primary aspects of CDR are the capture and the storage. Capture occurs either by photosynthesis or chemical reaction. Storage occurs in the forms of carbohydrates, graphitic carbon, biooil, carbonates, and solid or liquid carbon dioxide, sometimes with intermediate physical states. Interestingly, millions of tonnes of each type and various forms are already being produced in our natural or engineered realms. Plant growth, charcoal production, and chemical processing for carbonates and carbon dioxide are many thousands of times greater than the 1000+ tonne CDR First Goal. But most plant matter decays, charcoal is burned, carbonates are hard to collect or quantify, and CO_2 for soft drinks or dry ice or even for injection into oil fields (enhanced oil recovery) are simply gone or, if retained, are not worth (until recently) the effort to try to claim CDR credits. For example, large thermoelectric power plants powered by biomass (as are BECCS and BiCRS multi-million-dollar facilities) can already produce the 1000+ t First Goal. And CO_2 production from fossil fuels makes things worse, not better. Instead of encouraging or stimulating "more of the same", the 1000+ tonne First Goal seeks ways to reach gigatonnes while being financially feasible, or at least potentially feasible.

6. The status of each of the seven CDR methods to accomplish the First Goal of 1000+ t CDR/yr should be presented by leaders / advocates of each type. I acknowledge my bias as I present my comments about each, with the note that every gigatonne of CO_2 removal will be appreciated:

a. Projects with **Plant Growth (PG,** not just trees for AF/RF forestation) and **Soil Organic Matter (SOM)** are good. We need the biomass, and we need healthy soils. But they are probably not eligible for CDR funding because they lack permanence because most biomass dies and decays too quickly. The strength of SOM is not in stable accumulation, but in the ability of living organisms to keep reproducing and recycling the same carbon over and over, and even increasing via life processes.

b. **Enhanced (rock) weathering (EW)** and **Ocean Carbon Sinks (OCS)** have long-term potential but need their own breakthroughs and roadmaps for significant impact within the next few decades. They are great candidates for the First Goal support, and then the Second, Third and Fourth Goals.

c. **Direct Air Capture (DAC)** is the CDR "darling technology" of the investment world that is banking on some technology breakthrough. Air with CO_2 is everywhere in unlimited supply, available to living plants and machines. Just build large enough machines and enough pipelines for transport of CO_2 to appropriate bedrock sites. Much can be done with a few trillion dollars and decades of time. A roadmap by DAC advocates will be interesting to see. When can we hope for some hundreds of millions of tonnes of DAC-based CDR per year and at what price?

d. **CCE or BECCS = burn biomass to make energy plus creating tonnes of CO_2 for capture in chimneys and eventual deep-earth burial.**

My evaluation of BECCS is already provide in Section VIII the white paper, but it merits reemphasizing in the box below, especially because BECCS is still being promoted. BECCS depends on biomass supply, as does CDR via biochar. Biomass for both is plentiful up to at least 100 times the Third Goal of one million t CDR/yr. But they will be competitors for biomass at the 1 Gt CDR/yr Fourth Goal and above. Based on price per t CDR and co-benefits, biochar is far better (IMO).

Section VIII. (of the white paper) "Anything BECCS can do, BC&E can do better; char can do anything better than BECCS" (Proposed lyrics for a CDR song)

A. BC&E can significantly exceed the expectations of BECCS.

1. Different technologies: BECCS *appears* to have the advantage because it starts with technology for releasing 100% of the energy by burning biomass all the way to ash, … In contrast, BC&E *appears* to offer less because it releases only 70% of the total biomass energy for possible productive use. 30% of the energy remains in the captured 50% of the carbon atoms …[in biochar that has so many co-benefits].
2. Different levels of readiness: … [BECCS is not ready for big time.]
3. Sizes of units: … [BECCS is not for appropriate for widely distributed usage.]
4. BC&E devices are significantly less expensive, … [and able to make profits.]

B. The integrated assessment models (IAMs) used to project future climate situations should be recalculated with the impact of biomass utilization based on BC&E and not on BECCS. This could change for the better the IAM projections that are used in so many models of global temperature increases. [BECCS was selected because it could be modeled. Model biochar instead.]

C. The focus on electricity production via BECCS is misleading, …

In case the point is not clear, this conclusion is provided:

Stop the push for BECCS and get busy with BC&E.

e. **Biochar (BC)** is a hybrid CDR technology that focuses on accomplishing long-term storage with co-benefits. It relies on biomass supply from **Plant Growth (PG)** that is CDR focused on carbon capture. And it enables stronger CDR results by **Soil Organic Matter (SOM).** And when rock powder of CDR **Enhanced Weathering (EW)** is mixed into soils with biochar, additional benefits of soil health, SOM, and plant growth can help feed the world. Also, insufficiently examined thus far is the prospect of pyrolysis of ocean-grown biomass in support of CDR via **Ocean Carbon Sinks (OCS).** All of this is compatible with concepts of regenerative agriculture and syntropic farming (box on next page).

6. Supply of biomass. For our introductory overview, an important concern is how much CDR can be accomplished via biochar. Documents by various authorities commonly place the top annual amount as perhaps 2 Gt because of yearly biomass supply. In the 2020 white paper I projected up to 9.2 Gt per year. There were no comments for the past two years disputing that number, possibly because it was not seen by others or ignored as being too unrealistic. I have reexamined that calculation and have raised the amount to be 10 Gt CDR/yr via biochar. Rebuttal is welcome, encouraged, and beneficial. But to underestimate the CDR potential of biochar would be a grave error and cause delays.

There is sufficient biomass for at least 10 Gt of CO_2 removal (CDR) per year ! It is our challenge and responsibility to accomplish that amount as soon as possible !

Because there is certainly no shortage of biomass for pyrolysis to accomplish the First and Second Goals, the basis for the 10 Gt projection is placed in Part Four where we discuss gigatonne quantities. For those who would like the rationale now, I refer you to Section V of my white paper.

The Roadmap gives details for multi-gigatonne CDR via Biochar, including possible syntropic advantages. (See Box.)

8. The world could benefit from success of all of the technologies. But eventually only a few of the specific variations of each technology will dominate, and even fewer of the individual businesses will succeed in the big time. Some CDR technologies will require much time (decades for DAC?) and multiple millions/billions of dollars to reach the stated 1000+ tonne First Goal. Some other CDR ways are already accomplishing 1000+ t CDR/yr, although permanence (durability) of storage may be a challenge. We suggest here (and examine later) the "sweet spot" at which rapid abundant capture of CO_2 into renewably grown biomass can be transformed via pyrolysis into biochar that has sufficiently long-term (multi-century) storage to help resolve or buy more time for societies to survive the emerging climate challenges.

C. Fifteen early XPrize winners and corporate-selected efforts are eligible for MI Launchpad support, so we can see some early favorites in those initially selected (discussed below).

Box. Syntropy with Biochar

"Entropy" deals with disorder and availability losses in systems, most often in reference to energy.

"Syntopy" is the opposite, dealing with improved order and resultant gains in systems.

A good example is "syntropic agriculture" that is akin to "regenerative agriculture" that builds up soil.

Syntropic and entropic are adjective forms, and do not refer to the "tropic" regions.

When biomass is pyrolyzed, the thermal transformation into woodgas and biochar adds value. The term "Syntropic Biochar" is proposed for circumstances in which biochar is an active contributor to making situations better with multiplier benefits, as with soil enhancements.

D. The efforts to achieve 1000+ t CDR/yr must consider costs, benefits, permanence, and the ability to scale to 10X and 100X. Even scaling to 1000X would only yield 1 million t CDR/yr, which is merely one-thousandth of one gigatonne, a tiny fraction of the additional 40 gigatonnes of CO_2 per year we spew into the atmosphere. It is interesting that the 1000+ t goal now seems quite insignificant while not yet attained by long-term CDR even with expenditures of millions of dollars, with the exception of CDR via biochar, our next topic.

Section IV. About pyrolysis, biochar, woodgas, and PyCCS

A. Our focus shifts to the only candidate technology that has multi-century permanence, is ready for deployment, has much lower costs, has major co-benefits for the Sustainable Development

Goals (SDGs), has worldwide applications to receive global support, and can actually already attain First Goal quantities with some biochar production technologies. Specifically and uniquely, those attributes relate to pyrolysis of biomass, a thermal-induced, low-oxygen chemical transformation of plant growth that produces:

1. Biochar (char or charcoal that is intended for irretrievable dispersion into soil or construction materials, not for burning)

2. Woodgas (pyrogas of many types, some of which can be condensed into biooil, tar and wood vinegar, and some that remain as gases. The woodgas can be combusted for thermal energy, but with care for clean, complete combustion to eliminate undesirable emissions, commonly called "smoke."

The name Pyrogenic Carbon Capture and Storage (PyCCS, pronounced "Pikes") can be applicable because biochar accomplishes CCS, however some also want it to include (or require?) capture of biooils and/or emission gases, including CO_2 capture for geologic storage. PyC can mean pyrogenic carbon, which includes biochar but is not exclusive for biochar. Each document should define its terminology.

We use the term "biochar" for the solid carbonaceous product intended for long-term storage (a.k.a. sequestration) by dispersion into soil or construction materials. Biochar is composed of stable graphene-sheet carbon, mobile (removable) carbon compounds, and inert mineral ash. Biochar contains approximately 50% of the carbon atoms gathered by plant growth of the biomass via photosynthesis that creates carbohydrates. Its irretrievable dispersion into soil accomplishes long-term (multi-century) capture and storage. The other 50% of carbon atoms from the biomass is transformed into a gas called "woodgas," the pyrolytic volatile chemicals available for capture or for combustion (or as pollution if improperly handled). [NOTE: Woodgas is certainly a biological gas, but the term "biogas" has already been designated for gases from anerobic digestion of wet biomass. So "woodgas" and pyrogas refer to pyrolytic gases from any dry biomass, including grasses, agro-refuse, aquatic biomass, and all types of woody biomass.]

B. Pyrolytic production of biochar and woodgas can have various pros and cons (costs / benefits) that can result in emission reduction (ER) as well as the CDR benefits.   These include:

1. non-thermal useful chemicals, biooil for geologic sequestration, and electricity generation via combustion, and

2. simple clean thermal energy (heat) that may or may not be used to reduce the need for fossil fuels for simple heating.

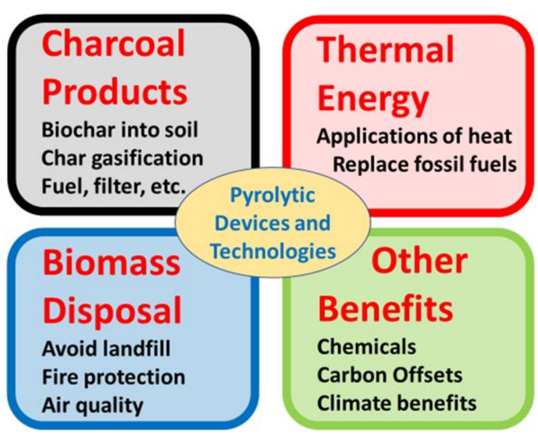


Figure 3: Four sources of profit via pyrolytic conversion (PC) of biomass into biochar and woodgas.

C. A seven (7) level classification of pyrolysis devices according to the average amount of dry biomass per 10 hour period is summarized in Figures 4 and 5. Photos and corresponding notes about costs and capabilities are found in "TLUD, Small Scale Gasification, and Flame Cap Kilns: Small to Medium Devices for Low-Cost Biochar Production" at:
https://woodgas.energy/wp-content/uploads/2020/12/Small-and-medium-pyroysis-BC-Week-10-minutes-2020-12-08.pdf
Figure 5 Source is: https://woodgas.com/wp-content/uploads/2022/08/Small-and-medium-pyrolysis-20-minutes-2022-08-30.pdf

Figure 4:

Sizes for Pyrolytic Biochar Production

Classified by Orders of Magnitude of *input of biomass* per 10 hrs of operation

Details are in the Green Carbon Webinar of 25.06.2020.
https://www.youtube.com/watch?v=tdpqx_bzT20

Size	*Objectives*		Technologies
Laboratory (< 1 kg)	R&D /testing		TLUD cookstoves: Champion & Fabstove
Micro (1 to 10 kg.)	Cooking		
Small (10 to100 kg)	1) Making biochar, 2) disposal of excess biomass, 3) some use of heat	Major gap in avail-able techno-logy	TLUD barrels; Retorts: barrels and "Adam Retort"; Flame cap kilns: open-top: pit, cone, ring, trough; covered top: Rotatable covered cavity (RoCC) w/ dif. diameters 2-ft – 12-ft+
Midi (100 kg to 1 ton)			
Medium (1 t to 10 t)			Air curtain burners
Large (10 ton to 100 t)	Char/chem/ power gen.		Rotary kilns
Industrial (> 100 t)	CHP (char is secondary)		Collection of exhaust char

Figure 5:

Sizes for Pyrolytic Biochar Production

Classified by Orders of Magnitude of input of biomass per 10 hrs of operation

Size	Biomass input per 1 hour:	Biochar yield (est.): Biochar as % of weight of dry woody biomass.
Laboratory (< 1 kg)	< 100 grams	
Micro (1 to 10 kg.)	0.1 - 1 kg. (cooking 1 hr.)	18 – 22 %
Small (10 to 100 kg)	1 - 10 kg.	15 – 25%
Midi (100 kg to 1 ton)	10 – 100 kg.	
Medium (1 t to 10 t)	100 kg – 1 t	15 – 25%
Large (10 ton to 100 t)	1 – 10 t (high volume)	5 – 15%
Industrial (> 100 t)	> 10 t	3 – 10%

Est. equipment costs:
Highly variable by location and features:
Cookstove: US$30 - 200
TLUD barrel: $20 - 100
Flame-cap: $200 - 1200
RoCC kiln: small $100 - 1000
RoCC kiln: medium $2K – 10K
RoCC kiln: large $20K – 80K
Rotary kilns: $120K – 5 M
Industrial sites: $millions

D. Pyrolytic conversion (PC) to accomplish the 1000+ t CDR /yr goal:

1. Using the above listed seven orders of magnitude in sizes, there are at least three major categories of biochar production equipment, mostly distinguished by capital costs for startup and quantity of biomass processed per single installed unit. The three categories are:

a. Large and industrial scale facilities for biochar or energy or both. Some are already producing many thousands of tonnes of biochar per year (IBI and USBI sources). Most of it is not being claimed as CDR credits for various reasons, including a) lack of full MRV data, b) the excessive cost of MRV and sales, and/or c) the relative low income from CDR in relation to operations costs and/or the costs of modifications for biochar collection, such as at power plants. We leave those for discussions by others.

Please note that there are large and industrial systems that already produce thousands of tonnes of char appropriate to be biochar, easily meeting the MI Launchpad goal every year. Much if not most of that production that is by multi-million dollar industrial-scale biomass energy plants is neither counted nor presented as being eligible for financial assistance as CDR accomplished. Why?

1. The char / biochar is a by-product of incomplete combustion that is collected (usually in a cyclonic particle collector) so that it does not pollute the environment. It is typically taken back to the combustion chamber to produce a few more kilowatts of power.

2. For most existing facilities, there is too little gross value and even less net value for the businesses producing that biochar. For a few, the sale of physical biochar is an important income stream, but without any monetary compensation for accomplishing carbon sequestration via biochar into soils or construction materials.

3. There is too much expense (and/or inconvenience) to add on the equipment and staff at existing biomass energy plants to handle the biocarbon / char or to claim CDR credits.

4. There is currently no demand (or profit) for building new multi-million-dollar biomass power plants either with or without the biocarbon collection for CDR.

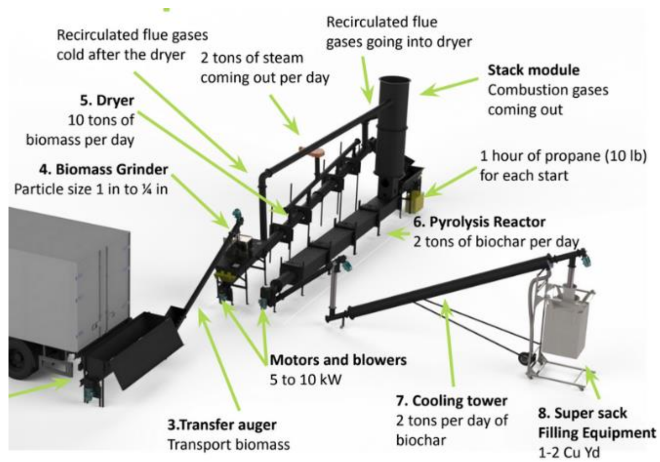
As a result, biomass-fueled power plants, such as 2.6 GW output of the giant DRAX facility in the UK, burn millions of tonnes of biomass, including industrially produced pellets, all the way to ash.

b. Rather expensive mid-size pyrolytic conversion (PC) systems with substantial engineering costs (roughly $500 K to $1.5 million) usually attain some benefits of electricity and/or chemical production. We are neither listing nor reviewing the full list of candidates. Numerous variations are similar to the two XPrize winners, an XPrize Top 60 awardee, and one with corporate pre-purchase of CDR, respectively numbers 1 through 4:

1) Bioeconomy Institute https://www.biorenew.iastate.edu/ (photo shows only one of their several pyrolytic conversion systems)

2) Net Zero https://netzero.green/ (photo of system in Cameroon and Brazil)

3) ARTi https://arti.com
Modular units of 2 t of biochar production per day can produce ~700 t/yr, which is more than the Initial Goal of 1,000+ t CDR/yr. Up to 5 units can be housed in one shipping container.



Photos of Charm equipment mainly show shipping containers that hold the equipment.

4) Charm https://charmindustrial.com/ Biooil production is primary, with some biochar production.

5) ECHO2 https://www.rainbowbeeeater.com.au/
"An ECHO2 module operating 24x7 has the capacity to remove approximately 5,000 tonnes of CO_2 equivalent (CO_2e) per year, one of the reasons it is one of the projects chosen by Shopify and Microsoft."
https://www.reutersevents.com/sustainability/biochar-black-gold-soils-getting-big-bets-offset-markets

6) Biochar Now https://biocharnow.com/
"The Biochar Now site is organized with kilns clustered around a utility pole and then replicated to support the desired number of kilns."

These six and others certainly have a role in biochar production, and many could produce the targeted 1000+ t CDR/yr Goal. The issues are more likely to be financial viability for scaling up to the higher goal of one million tonnes of CDR per year.

c. Less expensive and "smaller" pyrolysis systems are the third category, the focus of the remainder of this Roadmap document. In general, the technologies focus on biochar production and disposal of excessive biomass. Except for cookstoves, they do not use the heat to create value. However, the thermal energy must be released exceptionally cleanly to the atmosphere, meaning minimal (acceptable by local standards) smoke or other bad emissions.

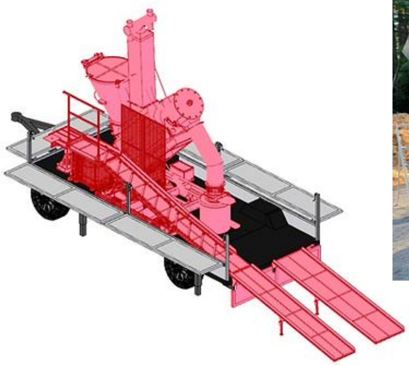
7) The smallest are micro-gasifiers, that is, pyrolytic cookstoves that make biochar. They are the only cooking devices of any type that are carbon negative. Major sub-types include Top-Lit UpDraft (TLUD = "tee-lud") stoves that are of natural draft (ND) or forced air (FA) varieties. Micro-gasifiers are discussed in Part Three.

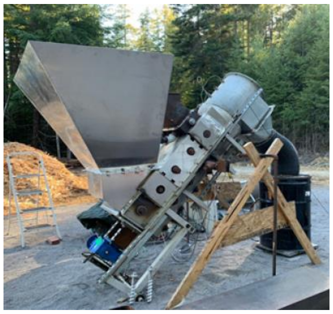
a) Champion (Natural Draft TLUD) https://woodgas.energy/wp-content/uploads/2020/12/TLUD-Case-Study-Deganga-2016-09-30.pdf and

b) Fabstove (Forced Air) https://fabstove.com

Examples 8 through 12 utilize different pyrolysis technologies. Numbers 8 and 9 are used by two XPrize winners of one million dollars each.

8) PlantVillage https://plantvillage.psu.edu/
Kon Tiki flame cap kiln technology.





9) Takachar & Safi Organics
https://www.takachar.com/

10) New England Biochar
https://newenglandbiochar.com/
Photo shows a version of an Adam Retort. These have also been made of bricks in Africa.

11.a) Wilson Biochar
https://wilsonbiochar.com/ Ring of Fire (far left) and
11.b) Terra Preta Developments
https://www.terrapretadevelopments.com.au
Kon-Tiki-Tas (near left). Both are Flame Cap (Cavity) kilns with open tops.

12) Woodgas International
https://woodgas.com The two-barrel RoCC kiln in Kenya and the 4-ft diameter RoCC kiln in California are Rotatable Covered Cavity kilns (Flame Cap). They are introduced in the next section and discussed in detail in Part Two.

E. Comparison of five (or more) of the less expensive pyrolysis approaches

The last five enterprises named above offer less expensive (probably between $500 and $20,000) pyrolytic devices and methods that could scale by replication to accomplish the First Goal of 1,000+ metric ton CO_2/year CDR by 2025. The approach of all five teams is exceptionally similar in that they create biochar that can be put into soil or other long-term, irretrievable storage. The main difference is in pyrolysis technologies to produce the biochar.

Not by plan, three of the five (PlantVillage, Takachar-Safi, and Woodgas International) have project activities in the Bungoma County area of western Kenya, with promises of biochar production using their own proprietary pyrolytic technology. Each has its own strengths and weaknesses. For example:

The PlantVillage team is exceptionally strong on agricultural issues and research;

The Takachar-Safi team leads in mixing and marketing of biochar-enhanced fertilizer;

The Woodgas Pyrolytics team has the (admittedly biased) perspective of being ahead regarding biochar production with its revolutionary (pun intended) Rotatable Covered Cavity (RoCC) kiln technology.

The limited interaction between the three projects is friendly and all wish success to all projects. Nothing prevents them from collaboration, but constraints on uses of funding impose rules and limitations.

The precise details of the Woodgas Pyrolytics proposal to accomplish the 1000+ t CDR/yr goal are provided in the Part Two of this document.

[End of Part One]

Part Two:
A proposal to Achieve
1000+ t CO_2 Removal (CDR)/yr in 2023

Presented as a stand-alone pre-proposal directed to all MI members. This is also Part Two of
"Roadmap to Climate Intervention with Biochar"

Section V. The MI CDR Goal and our request for funding

The Action Plan 2022-26 of the Carbon Dioxide Removal Mission (referred to as Mission Innovation (MI)), is found at: https://explore.mission-innovation.net/wp-content/uploads/2022/09/Carbon-Dioxide-Removal-Mission-Action-Plan-Sept-2022.pdf .

Section 2.4 Initial Projects includes,
Sprint 1: CDR Launchpad
Activity Area: Joint pilot-scale/demonstration projects
Scope and Objectives
In which the first objective on page 15 states:

"In signing on to the CDR Launchpad, [each of the six CDR Mission] members commit to:
1. Fund or support at least one, 1,000+ metric ton CO_2/year CDR project by 2025. This can include commitments and projects already underway that have the potential to meet the target."

PROPOSAL: With specific details in the sections below, we propose a project in Kenya to accomplish this First Goal of removal of 1,000+ metric ton CO_2/yr CDR during 2023.

And we invite MI members and other contacts to assist with the funding and to consider other countries for replication or to be first.

Our calculations are conservative and are based on ongoing operations and field work. We explain possible options to overshoot the goal to satisfy whatever confidence levels may be imposed as evidence for meeting the goal.

We point out (but do no claim in this proposal) multiple co-benefits of our CDR actions, including:

1) reduction / mitigation of emissions (ER),
2) soil health,

3) soil-water retention,
4) food production,
5 sustainable employment for impoverished people, and
6) contributions toward meeting numerous sustainable development goals (SDGs).

Section VI: Project "Biochar Pamoja" in Kenya

(Pamoja means "Together" in Kiswahili)

A. Background: Since 2001, Paul Anderson has specialized in small-scale pyrolysis technologies, first with TLUD ("*tee- lud"*) micro-gasifier cookstoves (discussed in Part Three), and since 2014 with what have become Rotatable Covered Cavity (RoCC) kilns, the basis for this project. In November 2019 he and Gilbert Mwangi had one RoCC kiln constructed and successfully trialed in Kenya. The initial report is found here: https://woodgas.com/wp-content/uploads/2022/02/RoCC-barrel-Kenya-example-2020-03-28.pdf The work was interrupted by COVID-19.

Figure 6: Gilbert Mwangi (left) and Paul Anderson with RoCC kiln in Kenya 2019

In April 2021 the efforts were restarted with Gilbert moving to Bungoma County in western Kenya. After initial trials and refinements, biochar production on a regular basis began in July 2021 with maize stover, field clearings, and eventually sugarcane field trash. The RoCC kiln size was doubled to 2 barrels in length (Figure 7), and a team approach with four kilns was developed.

B. Pyrolysis equipment (biochar production equipment): We utilize the Rotatable Covered Cavity (RoCC) kilns invented (and patented in 2020) by Anderson and Gilmore. Introductory materials and technical explanations are found in various documents at www.woodgas.com/resources . Photos and reports specific to Kenya activities are found at https://woodgas.com/ken . We do not repeat that information here. But one slide (Figure 8) explains how the RoCC technology functions.

Figure 7a (above) and 7b (below): Two views of 2-barrel RoCC kilns in Kenya 2022

Our calculations are based on using the 2-barrel RoCC kiln design shown in the photos. These RoCC kilns plus associated equipment of pitchforks, shovels, scales, weighing barrels, etc. can be locally made in Kenya for an estimated $250 per set of equipment.

Figure 8:

C. Current biochar production and our offer of 10X expansion to reach the 1000+ t CDR/yr goal:

We currently have actual production capabilities for over 100 tonnes CO_2 removal (CDR)/year using five 2-barrel RoCC kilns. **We propose a 10X replication (utilizing 40 RoCC kilns) in order to reach the 1000+ t CDR/yr goal, to be accomplished during 2023.**

Section VII: Biomass and biochar

A. Biomass types:

We focus mainly on sugarcane field trash (also called cane trash or CT) because it is available year-round on over 100,000 hectares in Kenya. But the project can also use corn stover (corn stalks) left in the fields after the one or sometimes two seasonal harvests. There are also some biomass

Box 1: Sugarcane in western Kenya is grown by about 170,000 smallholder farming households averaging 0.8 ha (2 acres) per family farm. The abundance of biomass conveniently close to our operations far exceeds our capacity to convert it into biochar. Scaling to 10X or even 100X project size is feasible if the CDR market price is sufficient and stable.

supplies from hedge trimmings along the pathways and from clearing of extensive weeds such as Mexican sunflower. Our project processes the different feedstocks and their biochars separately for proper testing and measurement, reporting and validation (MRV).

All of the feedstocks are truly agro-residues ("waste") that are 1) required to be cleared so that the next crop planting or cane regrowth can proceed, and 2) would either be left to rot in piles or more likely be burned in the fields, contributing to smoky air pollution and health problems. Some of the emission reduction (ER) type of carbon credits could be claimed but are not included in this proposed project because the needed MRV for ER is completely different, less precise, and ER carbon credits are less valuable (monetarily) than the carbon removal units for CDR via biochar.

Our field data includes use of 4 RoCC kilns during two days of operation in a 1520 m^2 (0.38 acre) field with a heavy layer of cane trash (CT) (photo below) to produce 445.8 kg of biochar recorded in our system as Pile 23. This revealed that 1 RoCC kiln in one day could make 56 kg of CT biochar from 190 m^2 or 0.019 ha. That would be a rectangle 10 m wide x 20 m long, or even 25 to 30 m long if the biomass was less abundant. This is equivalent to a yield of about 2.3 kg per m^2 (2.3 tonne of CT biochar per hectare).

Figure 9: A 13.5 x 1124 m (0.15 ha) field of sun-dried sugarcane field trash prior to processing by four RoCC kilns that created 445.8 kg of biochar in two days, near Bungoma city, Kenya in late 2022.

A second measured production run (for pile 29) produced 412.8 kg from 0.24 ha, yielding 52 kg biochar per kiln-day with a production density of 1.72 tonne per hectare. Further measurements will help understand the reasons for the variation in results. For further calculations, we will assume an average of 1.7 to 2.0 t of cane trash biochar per hectare.

Figure 10: Corn stalks (maize stover) dried in field after harvest are suitable for biochar production in RoCC kilns. Background shows traditional smoky destructive burning of field refuse.

B. Composition of biochars:

All biochars consist of some ash (inert minerals that can have agricultural value) and two types of carbon, stable and mobile (see Box 2 at right). The stable carbon percentages are

Box 3: Conversion ratios of C: CO_2 for different percentages of stable carbon in biochars:
Dependent on biomass and technology

Stable C (%)	Ratio of C to CO_2	Multiplier	From typical Biomass
100	1: 3.66…	3.67	(Impossible)
82	1: 3.00	3.0	Woods (75-90%)
80	1: 2.9	2.9	Woods (75-90%)
75	1: 2.75	2.75	Woods (75-90%)
70	1: 2.6	2.6	
68	1: 2.5	2.5	Kenaf (Khiari 2020)
60	1: 2.2	2.2	Sugarcane trash
55	1: 2.0	2.0	Maize stover
50	1: 1.8	1.8	Rice husk (H*omchat)*
45	1: 1.65	1.65	

Box 2: Biochar characteristics and terminology:

Elemental carbon that will remain in soils as graphene sheets for hundreds to thousands of years is considered to be "stable", as is the carbon in the Amazonian Terra Preta soils. Alternative terms of "fixed" and "recalcitrant" are copied from coal terminology for the steel industry that will burn it, which is not the case for biochar.

Biochar carbon atoms (especially in organic compounds) that are not long-term stable are "mobile" because they can be dissolved in soil-water and/or be consumed by organisms. They are seldom "volatile" at ambient temperatures in soil.

Ash can be essentially inert like silica or can have nutrient mineral values such as Potassium (in banana char) and Phosphorous.

For CDR purposes, calculations only refer to the stable carbon that is in the biochar and is measured in laboratory tests.

determined by laboratory testing. The ranges of corresponding conversion factors for calculating carbon dioxide removal (CDR) are displayed in the table in Box 3.

Based on the conversion factors (that will be repeatedly confirmed by laboratory testing), **our project to remove >1000 t CO_2/yr needs to produce and sequester 500 tonnes of dry biochar from sugarcane trash and/or maize stover per year.** Note that cane trash at 2.2 is 10% higher than corn stover at 2.0, indicating a minimal need for only 455 tonnes of cane trash biochar. But that assumes accuracies and precision that cannot be empirically validated by our occasional testing of samples in the initial months. Instead, our calculations are conservative to allow for natural and unanticipated variations.

Box 4: A convenient number: Biochar production of 1.7 to 2.0 t from <u>one hectare</u> of sugarcane field trash can accomplish approximately 3.4 to 4.0 tonnes of carbon dioxide removal (CDR). We only need 260 to 294 ha (less than 300 ha) of participating cane fields to reach the 1000+ tonne CDR/yr. goal. [This number will be reconfirmed or revised with measurements from additional fields during the initial 1000+ t project.]

C. Proven operational CDR capabilities:

Our results are based on hundreds of production runs (using five uniformly-sized RoCC kilns) that have been recorded in a common database since mid-2021. Beginning in January 2023, the results will be recorded in the CERCS™ CharTrac app (See details at https://cercs.io/resources)

1. For our calculations, one unit of operation involves one typical 8-hour workday with one worker and one mobile 2-barrel RoCC kiln working in a field that has appropriately dry cane trash or corn stover. With appropriate loading of biomass in each “run”, the kiln reaches its operational capacity (approx. 55 gallons or 200 liters) with ~25 kilograms of biochar in 3-4 hours. **<u>The combined daily output of two runs of one RoCC kiln is ~50 kg per day.</u>** This is DRY weight, unloaded hot from the kiln and weighed in a steel container (barrel). After weighing, the charcoal is water-quenched and compressed. Note that we do not use volumes or wet/damp weights in our calculations of CDR (long-term carbon sequestration).

2. Based on five workdays per week (because of holidays and some rainy weather) and only 50 weeks per year, we calculate a total of 250 workdays of biochar production yielding 50 kg of biochar per day. **That represents 12.5 tonnes of biochar per RoCC kiln in operation for one year processing sugarcane field trash biomass.** Therefore, to reach 1000 t CDR per year, we need 40 RoCC kilns to produce the necessary 500 tonnes of biochar . We can exceed that amount by any of the following variations:

a) Increase the workweek to 6 days or 52 weeks, increasing biochar output by about 20%. (Feasible because the workers generally request extra days.)

b) Prove with laboratory testing that our percentage of stable carbon is higher, corresponding to a multiplier greater than 2.0. (Likely a 10% increase.)

c) Use different types of biomass, especially biomass that is more woody. This could qualify for a higher multiplier AND have a higher charcoal yield (by weight) per run. We already know that hedgerow trimmings yield close to 60 kg per day (20% increase) and could have a multiplier of at least 2.5 (25% increase).

d) Increase our daily runs to three (3) per kiln, raising the total per-kiln charcoal production to ~75 kg/day, a 33% increase. This has been successfully trialed but is "stressful" and presents scheduling issues with other workers, such as when weighing the biochar with supervision.

e) Alter the equipment (such as with larger RoCC kilns) or the procedures (for easier loading or unloading or weighing) to accomplish greater throughput per day to reach (for example) 30 kg/kiln/run, or 60 kg/kiln/day, a 20% increase.

D. With 40 RoCC kilns in operation each producing 50 kg biochar production per day, the total yield is 2000 kg/day (2.0 tonnes/day). Operating 250 days each year, the annual yield is 500 tonnes of biochar, representing an equivalent 1000 t CO_2 removal/year. This is (40 x 250 =) **10,000 "RoCC kiln days" of 50 kg/day during one year.** This level of production requires roughly 300 kg sugarcane field trash per kiln (or worker) per day and 3,000,000 kg (3,000 tonnes) of raw biomass per year coming from approximately 400 hectares.

E. Proposal: We seek funding to conduct the above-described project with 40 RoCC kilns in Kenya with sugarcane field trash (and some maize stover).

The next section presents the financial issues for this proposal.

Section VIII. Financial analyses:

A. Income (funding the project):

1. Funds from sponsor(s): There are at least two approaches:

a) Flat-rate payment: Request and obtain reasonable funding to accomplish the goal of having a true demonstration trial to achieve the proposed CDR First Goal. Let the "value per tonne of CDR" be a secondary (derived) calculation, not the basis for the project budget. For example, an award of one million dollars can be given to a reasonable prospect for accomplishing the 1000+ t CDR goal, which would be $1000 per t CDR. [Two such prizes have been awarded for other projects involving pyrolytic CDR.]

In addition to labor, equipment and basic administration/supervision expenses, there are additional essential costs associated with demonstration projects, including:

1) special and more frequent testing of biochar qualities,

2) first time MRV, (There can and should be extra confirmation(s) of the validation, with additional care, longer on-site visits, and potential use of two independent third-party reviewers with comparisons of their results.)

3) certifications, (It is possible and could be requested to use multiple certifying entities that have different sets of standards. Of course, even if certified numerous times, the CDR units can only be sold once and retired.)

4) initial capitalization for hardware that lasts for multiple years, and

5) some allowance for "the learning curve" to demonstrate which of different variations (such as kiln size) should be replicated with lower costs or greater benefits when we proceed to scaling the project for much larger quantities.

Using this flat-rate approach, our requested budget for the proposed Kenya First Goal project would be between $250 k and $400 k, depending on the sponsor's expectations on issues such as certification(s). That would be $250 to $400 per t CDR, a bargain when compared to some other R&D and demonstration projects for initial CDR results.

b) Known-costs payment plus extras: Knowing that the expectations are eventually to attain a price as low as $100 per t CDR, use that number ($100 x 1000 t = $100,000) as the baseline (target for replication projects) and point out which expenses will need extra support for the demonstration pilot project. This is the approach presented below in **Section II.B. Funds needed for CDR calculated on operational expenses**

2. Funds from sources that are not Sponsors: Each of the four additional sources of income discussed here can incur additional expenses, so our comments are generalizations subject to analyses and what we will learn by actual experience.

a) The value of the physical biochar: A market value for biochar is not yet established in Kenya (nor in most other places). However, the expected value should be close to being a "break even" amount to cover the post-production costs for storage, preparation, marketing, sales and documented dispersal to ensure that the biochar does go into the soil for its intended purposes (carbon sequestration and soil amendment). Each step incurs costs for MRV. For a flat-rate payment, the project sponsors need to financially cover or guarantee for at least three years the value of the physical biochar, to include all costs for and including placement of the biochar into the soil in demonstration plots with documentation in the CERCS CharTrac MRV system.

b) Payments by biomass owners: Currently, the landowners simply allow us to remove their excess biomass. They could be asked to pay for the service. Alternatively, they could charge us for the biomass or claim partial or total ownership of the biochar. Market forces and contracts will impact what eventually happens, but it is likely to be a neutral draw with some non-monetary trades of biomass and services/labor and biochar.

c) Emission Reduction (ER) Carbon Credits: Quite possibly 2 to 6 or more ER credits could be earned per year per RoCC kiln in regular usage. The expenses (such as baseline studies) for establishing that income stream are too high at this time to make ER funding viable as income of any significance for this project in the near future. If a sponsor desires the ER credits, they must factor in the cost of establishing additional MRV (+ certification and sales).

d) Subsidies / incentives: Although it would be logical for the host country or community to financially encourage the development of this (and other) project(s), we consider it to be highly unlikely that such resources would be forthcoming. To the contrary, the realities of taxes, licenses, costly regulations, requested bribes, or other disincentives can also be legitimate concerns. Again, we treat this as a neutral (unknown) factor in our current discussion of financing a 1000+ t /yr CDR demonstration project.

B. Funds needed for CDR calculated on known-cost operational expenses:

We present estimates **as if** the business model has been established for replication and can operate **on the assured price of US$100 per t CDR.** [Assured prices of $140 or $180 or higher could also be considered by funding sources.] We provide notes about expected demonstration costs. Note that 1000 t CO_2e @ $100/t = $**100,000 as the baseline budget,** which is also expressed as **$10 per each of 10,000 "RoCC kiln days" of operation.** Determining the costs for labor, administration, and hardware is fairly straightforward. The main variables are the extra costs associated with MRV and certification.

1. Labor (70%): There is a sufficient supply of laborers willing to conduct the above-described operations for the payment of US$7 per day for one worker per kiln. That means that 70% of the $10 budget per "RoCC kiln day" goes directly and immediately into the local economy.
Each worker would earn at least 250 x $7 = $1750 per year, a modest but reasonable income for a rural worker in western Kenya. Income for 40 workers becomes $70,000, an acceptable and known cost for producing 1000 t CDR (as biochar) in one year. We do not seek to reduce the needed labor nor to pay less for labor services. We would like to advocate for $8 per day (a 14% wage increase), but that is not part of our proposal. Appropriate, stable job creation has specific, non-monetary value for the communities.

2. Project administration (20% local & 5% international):

a. Local: The experienced project administrator, Gilbert Mwangi, will oversee all operations. He will select and pay more per day to a team leader in each of 10 teams of 4 RoCC kilns. Team leaders do field operations work and also biochar weighing and reporting, similar to what he (Gilbert) has been doing since mid-2021. We propose that each team leader be paid an additional $2 per day for 250 days, which becomes $500 per year times 10 leaders, totaling $5000 additional per year. Gilbert earns $1000 /month base salary, being $12,000 /yr, plus a proposed budget for admin/supervisor transportation ($1500/yr) and $1500/yr for admin materials / office costs. The administrative costs would total $20,000 /yr, so we allocate 20% (being $2 per RoCC kiln day) for these essential administrative and quality control tasks.

b. International: Dr. Anderson continues as the overall project developer and leader for project integration, innovation, and R&D. He is to receive $5000/yr ($0.50 per RoCC kiln day) for his efforts and for discretionary spending to benefit the project, including kiln innovations, project promotion, and website efforts.

3. Hardware (kilns and other equipment) (5%): We budget 5% per year ($5000) for hardware, with the expectation of having 3 years' funding ($15 k for start-up) available and expended at the very beginning to acquire 40 RoCC kilns, pitchforks (we make our own in Bungoma), weighing scales, gloves, maintenance, and repairs. With modest maintenance, the kilns should remain functional for at least three years.

4. The three known cost expense categories above can be fully funded at the $100 /t CDR rate, even in a small project. The crucial unknowns are discussed next.

C. Funds needed from the sponsors for unknown costs of CDR operational expenses:

1. Physical biochar expenses:

It is essential to cover the post-production costs of the biochar all the way to its dispersal into soils. Our project requests a guarantee of support by the sponsor(s) of a minimum price for the biochar for at least three years so that its market value can be established with a) demonstration field plots, b) agricultural education about biochar issues, and c) promotional pricing to initiate sales. There are too many variables (soil quality, current fertilizer use, types of crops, socio-economic conditions, etc.) that overly complicate an accurate estimate of these expenses before the project starts. Details should be discussed with sponsors in relation to specific geographic locations. Eventually the sale of the biochar should cover those costs and provide sufficient profits to sustain biochar-based businesses, excluding the CDR funding.

2. Expenses for MRV, certification, and project profits:

Having explained above the major issues of biochar production and dispersal into soil, a key issue involves the sale of the CDR credits at $100 /t CDR <u>or more</u>. The expenses of any MRV (or MRV+ if including full certification) need to be covered by a sale price that is ***above*** the $100 /t CDR price. That is, if 1000 CDR units (tonnes) are sold for $140 each, the budget to accomplish MRV+ would be $40,000 per year. If the required MRV+ expenses are $240,000 over a 3-year period, then the CDR price must equal or exceed $180 / t CDR.

2. MRV+ (broadly defined and including certification) (additional funds): When eventually there are many projects to help cover the MRV / certification expenses, we expect that 10% of the budget will be needed to cover the costs of using the CERCS CharTrac app and engaging third parties for review and certification. But now, at our very early stages (prior to reaching one million t CDR/yr), even 10% is grossly insufficient, as is certainly expected by the sponsors who are appropriately interested in well-documented CDR efforts. The amount of $200,000 or even much more is commonly mentioned to get MRV / certification for almost any common (ER) carbon credit project, usually to be expended prior to starting any in-field operations. Our estimate of 10% is only in reference to expected expenses when RoCC kiln projects are widely implemented following well-established procedures. By whom and how the MRV+ expenses are covered is a topic for discussion in each project.

3. The "break-even" discussions above leave no direct project profits. The plans are that the overall efforts will become profitable from multiple small margins created by exceeding the stated expectations, including the possible improvements named in Section VII.C.2. Also, as is discussed in Part Three, the expectation involves proceeding to larger projects that will have better economies of scale. Also, some profit for the project owners / organizers can come from the MRV+ activities.

D. Summary of financial topics:

Based on more than one year of real-world experience in Kenya, the goal of >1000 t CDR/yr can be accomplished:

1. with the technology and methodology of modest-cost RoCC kilns,

2. with the extremely low-value / no-value biomass residues of sugarcane field trash and maize stover,

3. in a developing country where there are extra benefits of
    a) job creation with reasonable wages,
    b) biochar for improvements of soils, water-retention, and food production,
    c) improved air quality (reduced smoke) when clearing/burning waste biomass.

4. with financial viability showing
    a) the eventual price of only \$100 per t CO_2e when further scaled up, and
    b) the ability to scale to 100,000 or even millions of t C02 CDR/yr via biochar from agricultural field residue within a few years.

Proposal: We seek funding to conduct the above-described project for the First Goal of 1000+ t CDR/yr with 40 RoCC kilns in Kenya (or elsewhere if sponsored) that will process sugarcane field trash (and some maize stover).

5. Comments and provisional (draft) budget: (not included in this initial document.)

* * * * * *

Conclusion of Part Two

A. Thus far and current status:

1. We have explained above how we are currently producing over one tonne of biochar per week (~2 t CDR/wk = 100 t CDR/yr) in four RoCC kilns in fields where dry sugarcane field trash is conveniently and abundantly available.

2. We have provided calculations for increasing from 100 t CDR/yr to accomplish the First Goal of 1000+ t CDR/yr.

3. We have provided options to be discussed about financial arrangements, especially the need for minimal price support for the produced biochar and for the assured sale of the CDR units for at least $100 /tonne.

4. We will utilize the rigorous MRV capabilities of CERCS CharTrac (https://cercs.io/resources).

5. We have scalable, demonstrated experience that assures the accomplishment of the 1000+ t First Goal in 12 months of operation at our location in Kenya. To shift to a different location is possible but would incur additional start-up expenses.

6. We request funding.

B. Yet to come. Moving further forward:

1. In Part Three we offer prospects for scale-up by 10X, 100X and even 1000X to reach one million tonnes CO_2e removal per year by 2027.

2. Part Three also points out additional opportunities to accomplish that First Goal in other very different projects that use pyrolysis and biochar for carbon dioxide removal (CDR).

3. The realities of Part Two for achieving the First Goal in Kenya or in any other country must be accomplished if there is to be hope for reaching those further Goals.

To keep all of the Kenya Biochar Pamoja information together, I have decided to provide the Preface and two Sections IX and X from Part Three that explains the plans for scaleup to accomplish one million tonnes of CDR/yr by 2027 in Kenya and 100 Mt from sugarcane agriculture worldwide.

<u>**Preface and Sections IX and X from Part Three:**</u>

Scale to one million tonnes of CDR

[Subject to revisions in the final release of the full Part Three.]

Preface to Part Three of the 2023 Roadmap:

It is one thing to accomplish the 1000+ tonnes CDR/yr First Goal at some reasonable price, as shown in Part Two for Kenya with pyrolysis of sugarcane field trash. It is a different challenge or goal to do it 10X larger, being the **"Second Goal" of 10,000 t CO2 removal/yr.** And then to do that Second Goal another 100X larger, reaching what we call the **"Third Goal" of one million tonnes of CO2 removal per year, written as 1 Mt CDR/yr.** An acceptable price is essential, as presented in Section IX. We present in Section X the details of how to increase the Kenyan Biochar Pamoja results by three orders of magnitude (to one million t CDR/yr) within five years (by 2027). And we do it all with affordable pyrolysis and biochar:

Section IX Price
Section X Replication: Kenyan RoCC Kilns with Sugarcane Field Trash

The full release of Part Three will include five additional different ways to reach that Third Goal of one million tonnes (Mt) CDR/year.
Part Four deals with reaching gigatonnes (Gt) of CDR/yr with pyrolysis.

Section XI Kiln Size: Large RoCC Kilns with Waste Wood
Section XII Biomass Type: RoCC Kilns with Distinct Biomass
Section XIII Micro-pyrolysis Technology: Champion TLUD-ND Cookstoves
Section XIV Electronic Enhancement: Fabstove TLUD-FA Cookstoves
Section XV Application of Thermal Energy: Essential Carbon Negative Heating

Section IX: The right price

Before we even reach the 10K tonnes First Goal, the price should drop to the widely-recognized target of $100 /t CDR. As reported in October 2022 in https://www.protocol.com/bulletins/carbon-removal-cost-per-ton , "Carbon dioxide removal service buyers and sellers [and Frontier, Carbon Plan, and US DOE] are focused on one metric: $100 per ton." The same article quotes Shuchi Talati, a senior visiting scholar at Carbon180, as saying "$100 per ton is an extremely ambitious 10-year target, likely probably more of a 15- to 20-year target," But she thinks it's "important to be ambitious," and "there's a lot of momentum around CDR and getting these technologies to scale."

We agree with her except the time estimate to reach that target. We present how to reach that target low price and do it for one million t CDR/yr in five years, by 2027. But we reject from the start any efforts to have the price per tonne be below $100, even if there is an abundance of biochar-based carbon sequestration activity. Irrespective of the location or production method of these activities, each tonne of CDR ultimately has the same value in the fight against climate change. To pay less for CDR accomplished in the Global South or Third World Societies would be a form of Carbon Colonialism.

It can be argued that true CO_2 removal (CDR) ***created in impoverished societies*** should receive a higher, premium price because these people were not the ones that caused climate change. Also, simple methods of growing plants (agriculture as well as forests) and the production of biochar are more natural and elegant than methods of engineered construction. And CDR via biochar can be accomplished in quantity with relatively low investments today when we need to get stated, not waiting years or decades for promised breakthroughs that require high capital investment for relatively less CO_2 removal.

Section X: Replication: Kenyan RoCC Kilns with Sugarcane Field Trash

A. Replication implies (or actually requires) that what is to be replicated should have been already successful. We refer to our project for 1000+ t CDR/yr that is presented in Part Two above and is assumed to be accomplished in the year 2023. Only the lack of financial support is preventing the attainment of that First Goal.

B. Accomplishing an initial Second Goal 10 K tonnes CDR/yr project.

To scale up the 1000 t biochar project (Part Two) by a factor of ten, we propose the following actions, primarily for the years 2024 through 2027.

1. Document well (during 2023) all of the steps and actions in order to have standardized, replicable procedures suitable for process control and quality assurance measures. This documentation will also facilitate the production of training materials (web, print, and video) with translations into other languages where needed.

2. Start as soon as possible (late 2023?) an identical, second project site with another 40 RoCC kilns and 40 workers in a nearby similar geographic area with cooperating sugarcane farmers. Resolve any replication issues within three months to reach double the initial number of operational kilns (2X). [Note: We will have been thinking about this and preparing even during 2023 while reaching the First Goal. Commitment to provide the financial resources also needs to be planned.]

3. Use the first and second project sites as training grounds for 120 additional workers and managers who are identified from three other cooperating project areas. Hands-on training will enable the workers and managers to be immediately productive when transferred back to their home areas and provided with the required hardware. Total scale-up is 5X within six months.

4. In the next three months, repeat step 3 above for 200 workers and managers who are identified from five additional cooperating communities. We will have reached the 10X goal in about 9 or 10 months, but we allow a full year.

5. To accomplish this rapid expansion requires some expenditures for recruiters, trainers, and additional supervisors (earning the 2022 income level of Gilbert Mwangi). This initial expense is not covered by any funds coming from the $100 t CDR that can be expected to apply later when the projects have become established in each area.

6. Most of this is probably within 50 kilometers of Bungoma City. It is one order of magnitude increase in one year.

7. At a minimum, this involves 10,000 t X $100 /t = $1 million for the basic operational costs, plus another estimated one million dollars for the training and other expansion expenses, including MRV.

8. We can also allow for the inclusion of quality biochar produced from other biomass-residue feedstocks, including maize stover, agro-straws, and weed clearing. This assumes that there has been at least moderate support for the R&D requirements when adding activities that are outside of the established pattern with First-Goal cane trash pyrolysis.

C. The increase from 10 kt (kilotonnes) to 100 kt CDR/yr:

1. The next 40 kt (kilotonnes) will come from four similar projects of 10 kt each, all beginning about one year after the first 10 kt project is smoothly operating, but with pre-planning in the first years (2023-24). Sugarcane fields owned by sugar mills should also be considered.

2. These projects will be located in four other sugarcane areas of Kenya, each selected carefully according to the resident leadership in each area and involving NGOs and public agencies to assure acceptance in each local area. The leaders will receive training at the level of project organizers, even in the first year at topic-specific conferences and training sessions.

3. These initial startup costs must not be charged against any carbon removal financial arrangements. It is reasonable to assume that the Kenyan Ministry of Agriculture would participate with experienced, skilled representatives and leadership to assist with mapping, training sessions, coordination of resources, etc. Assuming success for the initial 50 kt CDR/yr efforts, there is no restriction in year three (of five that are allowed) on further replication efforts in Kenya to reach the 100,000 t CDR/yr goal. See Box 6 for statistical projections of Kenyan sugarcane trash available for CDR via biochar.

Box 6: Kenya's annual sugarcane production is 4.6 M tonnes of cane. Cane trash yield is 10 – 20%, becoming 460 k to 920 k tonnes. At a conservative ratio of 7 trash to 1 biochar unit, that would be 65 to 130 kt biochar that at 1:2.0 conversion to CO_2e would be 130 to 260 kt CO_2 removal (CDR) per year via biochar from Kenyan cane trash. Our goal is 100 kt CDR/yr.

By area, the cane fields cover 72,000 hectares that each yield 1.7 to 2.0 t of biochar. This represents an annual potential of 120 to 144 kt of biochar that is equivalent to 240 to 288 kt CDR/yr.

By both calculations, perhaps 50% (and certainly less than 70%) of Kenya's sugarcane fields would be sufficient for achieving 100 kt CDR /year. This would generate $10 million/yr in CDR payments with $7 M going to local rural workers.

Source of base numbers:
https://www.atlasbig.com/en-us/countries-sugarcane-production

4. Additionally, other biomass-residue types could be used to meet the 100 kt Kenyan national goal.

5. The above Sections X.C.1 and 2 and 3 propose reaching 100 kt CDR/yr within the country of Kenya. This is another order of magnitude increase that is accomplished within three years, but we have allowed up to five years if necessary. Why the extra years? Because the availability of funding to accommodate such a rapid pace of accomplishments is questionable.

D. The increase from 100 k tonnes to 1000 k tonnes (1 Mt = one million tonnes) CDR per year by 2027.

1. Simply stated, the goal is to replicate the Kenya success story in ten (10) similar countries or be only half as successful in 20 countries. And we have five years to do that by 2027.

2. Our initial First Goal project for 1000+ t CDR/yr with low-cost pyrolysis for biochar will attract attention and will be open to observers locally, within Kenya, and from beyond. Among the first interested will be other countries with similar sugarcane operations that could promptly replicate what is being done already in Bungoma in the 100 t CDR/yr Biochar Pamoja enterprise.

3. Depending on the availability of financial resources and supportive entities (NGO or governmental), the proposal is for three other countries to be selected to be the initial replicators. They must have appropriate and sufficient support, including markets at least at the $100/t CDR level and for the guaranteed biochar purchase. Very practical training and mentorship would be provided, sometimes at Bungoma and other times with Kenyan trainers going to the international target areas.

4. The successful demonstrations in Kenya and three other countries to reach each of the milestones might gain interest in 10 to 40 countries, each with its own resources of funds and quality personnel and entities. In such a case, there is no "selection" or preference of countries. A pooling of some resources (or help from international development banks, etc.) could result in

a) Informational communications and meetings,
b) Conferences for those who work in air-conditioned offices,
c) Hands-on training workshops for those who make things happen in fields,
d) Sharing of results between all involved throughout the five years allowed.

5. By replication of what is presented in this Section X.D, repeated progress in numerous countries is quite possible. Some would be more successful than others.

6. With world sugarcane harvest at nearly 2 billion tonnes per year, the target of one million t CDR/yr could be reached ***easily*** using low-cost pyrolysis technology that already exists and is ready to be implemented with sugarcane field trash. As documented in Box 7 (next page), the sugarcane industry could accomplish over 100,000,000 tonnes (100 Mt) of CDR/yr, without including possible CDR via biochar with the bagasse that is at the sugar mills, not left in the cane fields.

E. Some important considerations for 1 M t CDR/yr as discussed above

1. Because 40 of the 2-barrel RoCC kilns are sufficient for 1000 t CDR/yr, then 1 M t/yr would require 80,000 barrels. Annual world production of 55-gallon (200 liter) drums is over 150 million, so there should be no serious shortage even though many are plastic that cannot be used as kilns.

2. The above discussion does not include likely improvements in RoCC kiln sizes and procedures that can increase the production speed, quality, quantity, and biochar usage methods. RoCC kiln technology and designs are still young (invented in late 2019) and evolving to better serve the needs of the users. In the next few years, we can expect some enhancements.

3. A million tonnes of CDR per year (the Third Goal) is really a very small amount. In Part Four we discuss the prospects and implications of scaling up by 1000 X to accomplish pyrolytic CDR at gigatonne (Gt) quantities (the Fourth Goal). But prior to that discussion, Sections XI through XV provide five other examples and ***proposals*** for pyrolytic conversion for attaining not only the 1000+ t CDR First Goal but also their prospects for the Third Goal of quantities of one million tonnes per year (1M t CDR/yr) even within the coming five years.

Box 7: The world annual sugarcane production is almost 2 billion tonnes of cane. Cane trash yield is 10 – 20%, becoming 200 M to 400 Mt (when manually cut, not pre-harvest burned). At a conservative ratio of 7 trash to 1 biochar units, that would be 28 Mt to 57 M t biochar that at 1:2.0 conversion to CO2e would be 56 Mt to 114 Mt CO_2 removal (CDR) per year as biochar from cane trash. This does not include the millions of tons of CDR that could be accomplished from the bagasse that is at the sugar mills and could be pyrolyzed to obtain the useful heat from woodgas as well as the physical biochar and CDR.

Africa by itself produced in 2020 nearly 100 M tonnes of cane, which could become 2.9 Mt CDR/yr. That capacity is nearly three times our 1 Mt CDR/yr goal at this stage of the discussion.

Our calculations are realistic and do not require any additional land for biomass growth..

Source of base numbers:
https://ourworldindata.org/grapher/sugar-cane-production?tab=table

Author's notes:

A. I am a technical resource person with limits on what more I can do.

B. If you see value, your participation is requested and will be appreciated.

1. Send comments and corrections to psanders@ilstu.edu .

2. Tell others about this "Roadmap for … Biochar" document that is available at https://woodgas.com/resources along with the 2020 white paper.

3. Seek replication in other countries.

4. Influence the leaders and funding sources that you know to participate in CDR via biochar. Offer how you could participate in these CDR efforts.

5. Please provide assistance according to your talents, interests and resources. The climate crisis is already at hand. CDR via Biochar is ready for use.