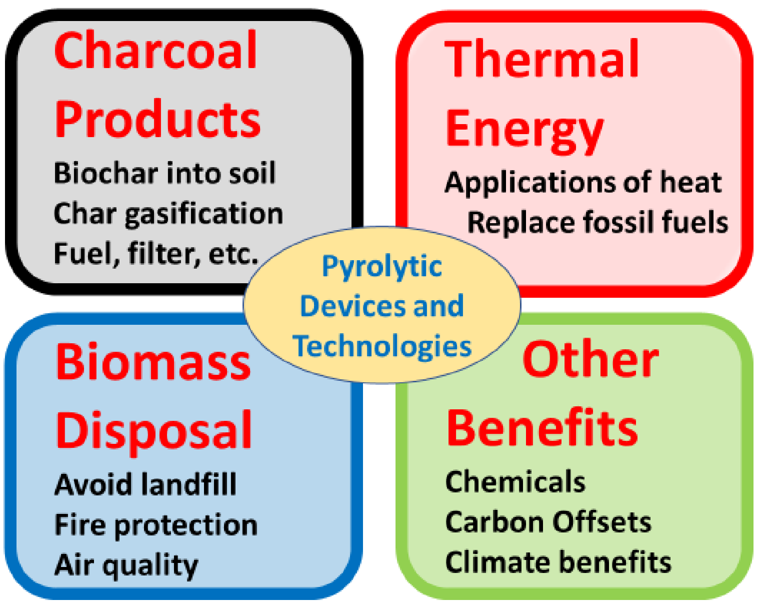
Climate Intervention with Biochar

A White Paper about Biochar and Energy (BC&E) for Carbon Dioxide Removal (CDR) and Emission Reduction (ER)



Paul S. Anderson, PhD
Woodgas Pyrolytics, Inc
www.woodgas.energy

First Edition dated 2020-12-07 (with minimal edits 2020-12-16)

Climate Intervention with Biochar

A White Paper about Biochar and Energy (BC&E) for Carbon Dioxide Removal (CDR) and Emission Reduction (ER)

First Edition dated 2020-12-07 (with minimal edits 2020-12-16)
Distributed from the website www.woodgas.energy

Paul S. Anderson, PhD psanders@ilstu.edu
Woodgas Pyrolytics, Inc www.woodgas.energy
Biochar & Energy (BC&E) Specialist

Paul Anderson is a retired university professor of geography. He has specialized in pyrolysis since 2001, is an international leader for TLUD micro-gasifier cook-stoves, invented RoCC kiln technology, and founded the nonprofit Juntos NFP. A more complete biosketch is at the end of this document.

Table of Contents:

Citizen Summary (less technical) of the White Paper
Climate Intervention with Biochar

Part One: Climate Correction Actions Can Start *Now*

The **climate crisis** is already hurting us and will worsen until we act. To fix the climate, we need **two actions:** 1) stop putting more carbon dioxide (CO_2) into the air (called **emission *reduction* (ER)** to reach Net Zero use of fossil fuels), and 2) take excess CO_2 from the air (called ***carbon dioxide removal* (CDR)** with required sequestration for many centuries). **Both reduction and removal are needed, and both will require numerous contributing solutions.** Reductions will alter your lifestyle; removal does not require much change.

Removal is accomplished in two ways. One is by **living (organic) processes**, specifically photosynthesis, the natural, inexpensive, or even profitable growth of plants that we can encourage in forestry and agriculture. The second way is by **chemical (inorganic) processes** that capture or react with CO_2 to form chemical compounds that are stable in soil or oceans. Chemical processes in nature are too limited to save our climate, and man-made technical accelerations, called Carbon Capture and Storage (CCS), are in pilot stages that are quite expensive. **The growth of trees and crops to change CO_2into "biomass" is our best option for removal.**

Unfortunately, all living biomass will die, and then its decay releases CO_2 back into the atmosphere as part of its natural carbon cycle that is neutral, not carbon negative removal. Even long-lived trees do not live long enough to save our climate, and **we do not have enough land available to keep growing trees** and more trees while also needing cropland to feed our still growing population.

Fortunately, the process called **"pyrolysis" or carbonization** (like making charcoal) transforms 50% of the biomass carbon into highly stable **"biochar" that microbes cannot break down and that does not decay appreciably in many hundreds of years.** To prevent it from ever being burned back into carbon dioxide, we can mix the biochar into soil where it gives **co-benefits for retention of water and nutrients**, resulting in increased plant growth for food, fiber and making more biochar.

Simultaneously, pyrolysis releases the other half of the carbon (along with all of the hydrogen in carbohydrates) as **large amounts of useful chemicals or heat energy that can replace the burning of fossil fuels (therefore, reduction!).** Useful heat is important to us and has major impact on the climate crisis. **About 40% of all fossil fuel usage in the world is for heat** for homes, factories, hot water, and industrial processes.

To emphasize the double benefits because **both removal and reduction are accomplished,** we call these climate-beneficial actions **Biochar and Energy (BC&E or BCE).** When used with BC&E technology, each tonne of dry biomass (such as seasoned wood or pellets from crop refuse) provides:

1. thermal energy that replaces 2 barrels of oil or 0.86 tonne of CO_2 that did not go into the air, and
2. solid carbon biochar equal to about 0.6 t CO_2 permanently removed from the atmosphere, and
3. co-benefits of a soil amendment that helps meet several Sustainable Development Goals (SDGs).

To obtain promptly those advantages of BC&E, proper engineering and investment for BC&E programs can **transform our thermal energy businesses to be not only renewable, but also to be carbon removing.**

BC&E depends on biomass fuel supply; **we know how to grow crops and trees** that can be sustainably harvested and then, through pyrolysis, become useful heat and stable carbon removal **with sufficient quantities to help solve the climate crisis.** The supply of biomass is not limitless, but production can be enhanced and include "refined fuels" (pellets, extracted chemicals, etc.) to supply up to half of the current fossil fuel use for heat.

Coupled with plant growth, Biochar and Energy (BC&E) is uniquely able to help save our climate with both CDR removal and ER reduction in the same projects often with additional co-benefits. BC&E efforts need to be started and sponsored now. Examples of what can be done are in Part Two.

Note: You can assist by discussing BC&E and the Climate Crisis to raise awareness of what is possible.

Part Two: Gigatons of CO_2 Removal and Reduction via Biochar

A. The major opportunities to remove many millions of tonnes of stable biochar for sequestration are **all linked to diverse primary objectives that are *not* about the climate crisis,** meaning that there are non-climate reasons to do (and to pay for) the BC&E efforts.

B. Two of those efforts focus on helping the most impoverished people on Earth to have better lives. Helping them could be paid for by humanitarian efforts, national government programs, regional development banks, carbon funding for climate, or some combination, even with repayment.

1. Advanced micro-gasifier **BC&E TLUD biomass cookstoves produce biochar** equal to approximately 1 t CO_2e removal per stove per year. The poorest 20% of humanity **could sequester 250 million tonnes (0*.25 Gt)* CO_2*e every year*** *and enjoy many* ***SDG benefits (health, income, women empowerment)*** *with* ***a decrease*** *in the consumption of biomass fuel, which is* CO_2 *reduction.* Sect. XII of white paper.

2. Horrible air pollution from the annual field burning of crop residues in India, China and across Africa could be greatly reduced by cleaner pyrolysis that could yield soil enhancing biochar **equal to a full Gt of CO_2e removal each year**. The laborers needed to achieve this CDR could reap benefits from appropriate wages that come via carbon funding. Sect. XV.

C. As in #2 above, here are three other cases where excessive biomass has negative consequences unless there is payment for disposal. Use of BC&E methods can bring needed funding because of CO_2 removal.

3. **Underbrush clearing and disposal** via pyrolysis would help with **fire safety,** as needed in California and Australia. This could permanently remove millions of tonnes of CO_2 per year while saving billions of dollars of needless losses. Governments, insurance companies and landowners could sponsor this. Sect. XVI.

4. Commercial forestry has major amounts of **no-value slash in harvested forests** that could be pyrolyzed instead of being burned to ash or left to rot. Carbon finance for CO_2 *removal* is logical. Sect. XVI.

5. Cities around the world pay millions of dollars for **urban tree waste removal and disposal of organic waste** of which some could be pyrolyzed with CDR benefits. Capture of the heat is an option. Sect. XVI.

D. In the transition to Net Zero emissions, modern societies will wean themselves from fossil fuels. When switching to renewable biomass, there can have extra co-benefits of carbon dioxide removal if using BC&E technology instead of simply burning the biomass to ash**.**

6. Conversion where possible away from **fossil fuels for electricity production** to pyrolysis of biomass **produces both emission reductions and millions of tonnes of CO_2 removal.** Sect. XVII.

7. Transformation to **pyrolytic heat for housing** will yield gigatons of removal and reduction while rebuilding the economy and creating quality jobs. This should not be delayed. Sect. XVIII.

8. The business of providing **industrial process heat** can provide perhaps another gigaton of CO_2 removal if BC&E technology is used. Sect. XIX.

E. The **co-benefits of biochar** and the financial value of CDR via BC&E are substantial. Sect. XXI & XXII.

F. A **blockchain-secured carbon accounting and verifiable biochar sequestration recording and mapping system** for ER and CDR is operational. Sect. IX and XX.

Part Three: Conclusions and Actions

A. Projections for CO_2 removal (CDR) via BC&E are as high as **9.2 Gt/yr by 2050.**

B. CDR does not substitute for the need for emission reductions to Net Zero.

C. Supporting graphics, calculations and discussions can be found in the white paper *"Climate Intervention with Biochar"* that shows that BC&E helps both removal and reduction.

D. The time for climate-saving action is now. You can help by explaining and promoting BC&E efforts to people with influence and money.

"If we cannot promptly implement these comparatively easy, benefit-rich Biochar and Energy (BC&E) initiatives, we will lose the battle to save our planet."

Paul S. Anderson, PhD, Woodgas Pyrolytics, 7 December 2020 (psanders@ilstu.edu)

Executive Summary (more technical) of Biochar White Paper

Elevator Speech:

Major impacts to **fight the climate crisis** are possible **now** with the economical use of **biochar and energy (BC&E)** as a negative emissions technology (NET) for **millennial sequestration of gigatons** of atmospheric CO_2e as a **soil enhancement** while also being an emission reduction (ER) source for **valuable needed heat**. Opportunities for practical, prompt actions are in Part Two of the white paper.

* * * Part One: Biochar among the NETs * * *

A. Carbon dioxide removal **(CDR) involves two separate actions: *remove* CO_2** from the atmosphere and ***sequester*** it for at least hundreds of years. Of the recognized Negative Emissions Technologies (NETs), **only one good combination is functional *now* for gigatons of CDR.**

B. **Natural photosynthesis** by plants in forests, fields, wild lands, and oceans (as associated with AR, SCS, and OF) can do at low-cost massive amounts of **CO_2 removal** by creating biomass that is abundant and can even be increased.

C. **Pyrolysis of that biomass can produce highly stable carbon for sequestration** while also providing vast amounts of valuable heat, being the NET called **Biochar and Energy (BC&E).**

D. Other technical solutions (DACCS, BECCS, EW and OF) are still in development stages involving sorbents and inorganic chemistry for expensive carbon capture and storage (CCS).

E. It is time to recognize pyrolytic biochar from biomass as a practical way get CDR started immediately.

* * * Part Two: Gigatons of CO_2 Removal and Reduction via Biochar * * *

F. **Nearly 0.2 Gt CO_2/yr currently is being made worldwide into stable carbon:** But it is charcoal produced to be burned for cooking for 2 billion people, not for sequestration. Section XI.

G. Micro-gasifier **BC&E TLUD biomass cookstoves produce biochar** equal to approximately 1 t CO_2 removal per stove per year. With carbon offset support, sustainable and even profitable f**expansion could sequester *0.25 Gt* CO_2*e/yr with many SDG benefits for the bottom quintile of socio-economic families*** *with* ***a decrease*** *in the consumption of biomass fuel.* Section XII.

H. Recent (2020 patent application) **advances in lower-cost mid-range BC&E char making technology** help make scalable CDR solutions possible. Section XIII.

I. **Cleaner air is a benefit while sequestering a Gt of CO_2e/yr from pyrolysis of crop residues**, with co-benefits for SDGs. Section XV.

J. Biomass disposal via BC&E for **fire safety, forestry slash and urban waste**. Section XVI.

K. **Biomass pyrolysis and electric power production.** Sections XVII.

L. Heat for housing and industrial process heat. Sections XVIII and XIX.

M. Co-benefits of Biochar and the financial value of CDR, by biochar Sections XXI and XXII

N. **A blockchain-secured carbon accounting** and verifiable biochar sequestration recording and mapping system **for ER and CDR is operational**. Sections IX and XX.

* * * Part Three: Conclusions and Actions * * *

N. Summary of CO_2 removal via BC&E, reaching **up to 9.2 Gt/yr CO_2e**. Section XXIV

O. A call to action. ***"If we cannot promptly implement these comparatively easy, benefit-rich Biochar and Energy (BC&E) initiatives, we will lose the battle to save our planet."*** Paul S. Anderson, PhD, Woodgas Pyrolytics, 7 December 2020 (psanders@ilstu.edu)

Climate Intervention with Biochar

A White Paper about Biochar and Energy (BC&E) for
Carbon Dioxide Removal (CDR) and Emission Reduction (ER)

Paul S. Anderson, PhD, President of Woodgas Pyrolytics, Inc.   7 December 2020

Section I. Preamble and our climate problem:

A. Our urgent climate crisis is caused by the heating of the atmosphere and oceans because of excessive carbon dioxide (CO_2) from land use change and especially the burning of fossil fuels for our past and present energy consumption. The solutions involve both 1) the **emission reduction (ER) (mitigation) of our current annual emissions of ~40 gigatons (Gt)** of CO_2 that must go down to Net Zero by 2050 at the very latest, and 2) the **carbon dioxide removal (CDR) with millennial sequestration of up to 1000 Gt** of excessive CO_2 in the atmosphere and what the oceans will return to the air. The removal of CO_2 is no longer an alternative; it is an imperative. Virtually all climate authorities agree that CDR must be accomplished as well as the reduction to net zero use of fossil fuels, with separate recognition, tracking and financing of each.

B. There are two white papers about biochar.

1. The European Biochar Institute (EBI) released in October 2020 its white paper about biochar-based carbon sinks: www.biochar-industry.com/wp-content/uploads/2020/10/Whitepaper_Biochar2020.pdf **It is highly recommended.** The EBI presents excellent documentation about the broad issues, with an authoritative bibliography. Its recommendations for action appropriately include calls for major macro-level efforts for R&D, market programs, recognition of both biomass and its pyrolysis as a key CDR technology, and establishing standards and certifications,

2. This second whitepaper confirms and extends beyond the EBI document with no substantive disagreement. Differences include that Part One of *Climate Crisis Actions with Biochar* more forcefully differentiates Biochar and Energy (BC&E) from the other Negative Emissions Technologies (NETs). Also, in sharp contrast to the EBI, Part Two **presents with quantitative data specific examples of several recent innovations and projects ready for immediate actions which could tally to several gigatons of CO_2e sequestration per year by 2030.** Included are discussions of:

a) how such CDR actions can be **sustainably financed** if societies decide to become active, and

b) how the energy component (the &E of BC&E) of biochar production can accomplish ***reduction*** **of many Gt of CO_2 emissions from fossil fuels**, greatly offsetting the costs of implementation of BC&E solutions.

> This whitepaper presents **new, innovative affordable biochar technology** for scalable removal of kilos and tons of CO_2 that can become gigatons of CDR/yr by 2030. These are **realistic, plausible actions. We are discussing "…the here and now – short term - at the intersection of urgent need and lasting impact.** (JB, 2017)."

In order to cover the full scope of topics, most sections are intentionally short, being brief introductions to major topics that merit detailed reports and practical actions in the near future.

Part One:
Biochar among the NETs

Section II. 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.

True CDR must present solutions to two distinct tasks, 1) the **capture of CO_2** from the atmosphere and 2) the **prevention of that CO_2** from returning to the atmosphere for many centuries or millennia. The two tasks are not one single step or process; combinations of processes can be utilized if each step is functional.

Box 1: The Seven (7) Prominent Negative Emission Technologies (NETs) for Carbon Dioxide Removal (CDR):

EW	Enhanced Weathering
DACCS	Direct Air Carbon Capture and Storage.
AR	Afforestation and Reforestation
SCS	Soil Carbon Sequestration
OF	Ocean Fertilization
BECCS	Bioenergy Carbon Capture and Storage
BC&E	Biochar and Energy

NOTE: Some listings including ones by U.S. National Academy of Sciences (2019), European Academies Science Advisory Council (2018), and Carnegie Climate Governance Initiative – C2G (2019), erroneously combine SCS and biochar as if they were the same. The reasons to separate them are the fundamental differences between elemental black carbon and organic carbon in biomass. See Section III and Table 1 in this white paper.

B. The **capture of gaseous atmospheric CO_2** is by **two processes:**

1. **Technology-based inorganic chemical conversion (Sorption)** of gaseous CO_2 into liquid or solid compounds that can be collected, transported, and eventually stored. (EW, DACCS, and BECCS).

2. **Nature-based organic growth of plants** (**Photosynthesis)** to create biomass, mainly as carbohydrates (foods, fuels, and fibers). (AR, crops associated with SCS, wild plants, and OF).

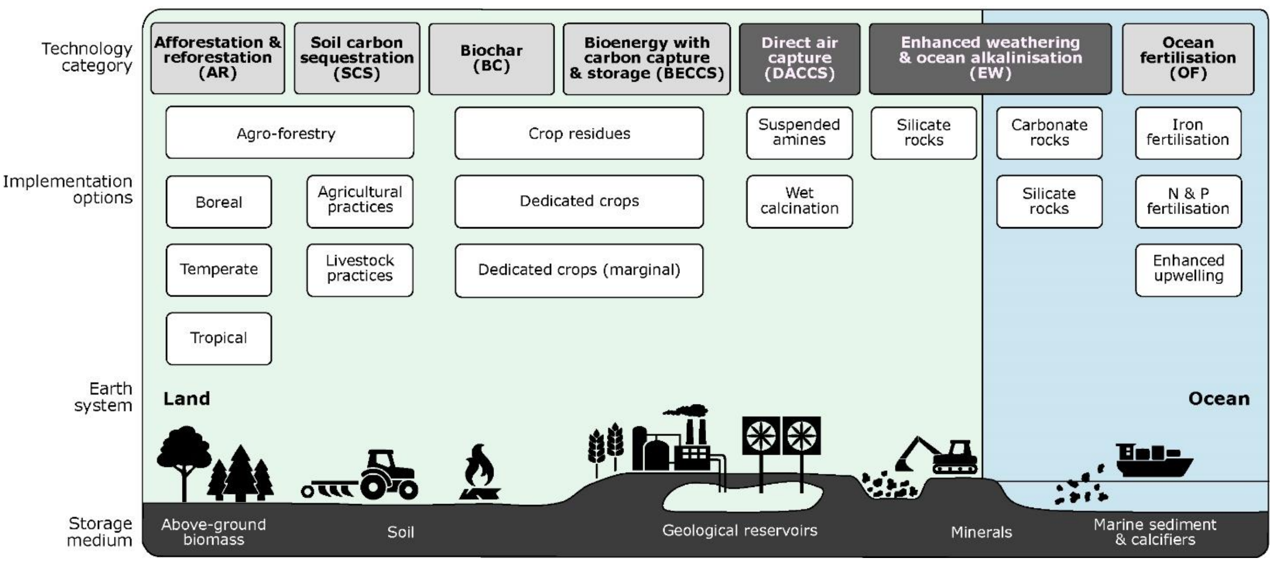
C. After capture, there are **three processes for the long-term holding** or sequestration of that converted CO_2 in "carbon sinks"**:**

1. **Secure the inorganic compounds** where they cannot revert to CO_2 gas, such as by injection into deep geologic structures or by creating rocks, minerals in fields, cement, or other building materials. (EW, DACCS, BECCS, and some OF).

2. **Hold the created biomass in its living forms or with continual renewal (as with living microbes in soils) or preserving it** to avoid decay and decomposition that emit CO_2, CH4 (methane) and other greenhouse gases (GHGs). (AR, SCS and some OF).

3**. Convert 50% of biomass into stable elemental carbon,** commonly referred to as char (of which cooking-charcoal, biochar and activated carbon are variations related to low, medium, and high temperatures, respectively). The process is called **pyrolysis**, and it forms stable solid carbon structures while liberating 70% of the energy content of the biomass as in condensable and non-condensable combustible gases. (The 20% energy boost from 50% to 70% is from the hydrogen in the carbohydrates.) The duration of the carbon sequestration as biochar into soil is measured in multiple centuries (discussed in Sections VI and IX). We prefer to use the designation **Biochar & Energy (BC&E or BCE) to emphasize both the stable char and the available energy.**

Figure 1. Major types of CDR (Minx, et al., 2018, Fig. 2)
(https://iopscience.iop.org/article/10.1088/1748-9326/aabf9b/meta#erlaabf9bf2)



D. Neither BECCS nor BC&E actually removes CO_2 from the atmosphere. Both are totally dependent on the existence of the CO_2 incorporated into biomass by photosynthesis. These two NETs have been called "hybrid CDRs" or "combination CDRs" to give recognition also to forestry and crops for their essential roles for CO_2 removal but inadequate roles for long term sequestration.

BECCS: CO_2 gas → biomass → CO_2 in chimney → CCS to liquid CO_2 → transport → burial

BC&E: CO_2 gas → biomass → biochar → transport → burial

Both BECCS and BC&E can provide energy that should / could replace some energy currently provided by CO_2-positive fossil fuels. Both depend on thermochemical degradation of biomass to release energy stored by photosynthesis. Both of both depend on their carbon life cycle, e.g. they may be negative if the feedstock comes from deforestation or regrowth is too slow for sustainability. But in one way they are fundamentally different:

1. **BECCS burns the biomass all the way to ash**, thus being carbon neutral. Its capabilities for CO_2 removal (CDR) depend on the chimney-based processes of CCS (carbon capture and eventual storage) which are not well developed and nowhere near viable commercial implementation as of 2020. (A US$ 1.4 billion commercial project is announced for Norway to remove 0.4 Mt CO_2/yr starting in 2023/2024. https://www.fortum.com/media/2018/11/full-scale-carbon-capture-and-storage-ccs-project-initiated-norway)

2. **Biochar & Energy (BC&E) utilizes pyrolysis** to release 70% of the biomass energy content while retaining about 50% of the carbon atoms in the form of elemental, solid stable carbon known as biochar. Biochar has a CO_2 equivalence (CO_2e) that is 3.66 times the weight of the carbon fraction of the biochar. The investment costs of BC&E projects could be covered by (and have profit from) the value of the heat released. Any additional expense for the sequestration of biochar in soil is more than covered by the commercial value of the biochar. BC&E is also known as CHAB, meaning combined heat and biochar.

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).

A. OF (Ocean fertilization) is unlikely to contribute much CO_2 removal during the next 50 years. Major implementation of OF is subject to the London Convention (1972) for protection of the oceans.

B. EW (Enhanced weathering) via pulverizing specific rocks plus transportation to and spreading on agricultural fields or shorelines is not a trivial nor inexpensive venture but is possible.

C. AR (Afforestation / Reforestation and including restoration) and crops (associated with SCS) are to be encourage for their efficient, low cost (usually profitable), widespread, environmentally adapted production of biomass that is natural CO_2 removal and short-term storage. Wood is like a battery of stored energy. Crops are essential for our food supply. The enhancement / recovery of soil fertility is desirable and can result in SCS. The risks of decay, disruption by tillage and chemicals, or destructive fire are noted threats to longevity. The issues of needed biodiversity and competition for arable land for food production need to be addressed but can be resolved with careful actions.

D. DACCS and BECCS are dependent on capabilities for CCS (carbon capture and storage). CCS certainly exists in theory, laboratory, pilot projects, and entering into substantial demonstrations attempting to bring costs down to levels acceptable for scale up. Amounts of CDR are measured in Mt (millions), not in needed Gt (billions). They are capital intensive for both construction and operation.

E. All except two of the NETs require the input of significant energy or human effort. In sharp contrast, BECCS and BC&E release significant amounts of potentially useful energy that was initially captured in the biomass of forests, crops, and other plants (including invasive species). That released energy could be used to reduce the consumption of fossil fuels (being emission reduction (ER)). That is why the preferred name is Biochar & Energy (BC&E) and not simply Biochar (BC). [Note: Although there is much energy stored in forests, the standard release of that energy as "renewable energy" (by burning) is only carbon neutral, not CDR negative.]

F. BECCS has received an enormous amount of attention, especially in Integrated Assessment Models (IAM) used by scientists in the preparation of the IPCC documents (2018) on 1.5 degrees C of global temperature rise. The rationale for this focus on BECCS is that it can be modeled (presumably because of available data on biomass supply (including AR), as opposed to hypothetical data for DACCS, EW, OF, and SCS). But the IAM projections are based on hope of what CCS for sequestration MIGHT accomplish in the coming decades **<u>if</u>** CCS becomes financially viable. In contrast, BC&E already has the sequestration issue resolved as stable biochar from essentially the same sources of available biomass.

This white paper contends that BC&E is a better, more realistic NET than BECCS for use in IAM calculations about the future of our planet. See supporting information in Section VIII.

G. Costs of NETs: Using the data from the New Climate Institute (NCI) (2020), except for BC&E.

1. OF is currently a non-starter because of the London Conference of 1972 for protection of the oceans.
2. EW requires the crushing of hard rock and placement onto fields. Large variation of estimates.
3. DACCS requires industrial constructions, electricity and water. Estimates across literature of US$ 30 to $1000 per t CO_2/yr.
4. AR estimates are US$ 2 to $150, but with medium duration and potential land conflicts.

(List continues on second page, after Table 1.)

Table 1: Types of carbon sequestration processes, status, expectations, limits, duration, and associated notes. (This draft version is dated 2020-11-28.)

Process and Associated NETs	Status of Technologies	Deliver Gt/yr at What Time	Limitations	Duration and Likely Impact	Additional notes
Nature-based Inorganic Chemistry **EW** Enhanced Weathering with ocean alkalization	Mechanically and chemically possible, but major applications are still mostly conjecture. Proposals for experimentation.	2020 Negligible 2035 Projections to reach 10 Gt/yr 2050 2075 Unknown	**EW** requires energy to make rocks into powder. Ocean applications are regulated by the London Convention of 1972.	Long-term stability. Possible implementation is questionable. Applications in soil could be compatible with biochar.	If applicable someday, it would be expensive. An "affluent world" approach.
Technology-based inorganic sorbents for CO_2 capture and storage **DACCS** Direct air CO_2 capture	Experimental and expensive demos; some for injection to assist fracking for fossil fuel increase.	2020 Negligible for 7 years 2035 DACCS 3 Gt/yr; claims of 10 Gt: at great expense. 2050 2075 Unknown	**DACCS** (and the CCS part of BECCS) are now functional only in expensive pilots. Transport and deep underground disposal add great costs. Always with induced storage.	Potentially with long-term stability; caution with leakage issues. Possible impact is low in near term and moderate in long term.	If CCS works at scale, it would be comparatively expensive. Requires affluent societies to pay the bill. Requires energy. An "affluent world" approach.
Increase Growth of Organic Carbon WITH NATURAL STORAGE **AR** Afforestation and reforestation. **SCS** Soil carbon sequestration. - - - - - - - - - - - - **OF** Ocean fertilization	Photosynthesis is already part of nature. Optional to support BC&E or BECCS with biomass. **Both AR and SCS** are well established but not well practiced in some regions. Good agro & forestry practices have financial returns to offset CDR expenses - - - - - - - - - - **OF** Theory and laboratory. Natural "seaweed" could be biomass for **BECCS and BC&E**	**Both AR and SCS** 2020 Net increase is zero or negative 2035 Perhaps 4 Gt on a revolving yearly basis because of short permanence. 2050 2075 Unknown - - - - - - - - - **OF** Not active.	**AR** must be careful not to compete with food and fiber. Slow growth makes **AR** susceptible to reversal by fire or cutting. **SCS** takes time to accumulate and needs changes in agricultural practices. - - - - - - - - - **OF** requires nutrients, especially iron or calcium;	**AR** biomass mostly decomposes back to CO_2 in forests several decades; Impact is in potential volume. Most organic / living **SCS** decomposes back to CO_2 in a few years. However, if it can be maintained in a healthy living state, it can be sequestration for long periods. Biochar can assist to maintain that level. - - - - - - - **OF** impact unknown, could cause ocean disruption.	**Both AR and SCS** If without guidance and support, this is likely to be forestry and soil management as usual, which does not solve the climate problem. Worldwide rich and poor societies can participate. Helps meet some SDGs. Potential for plant growth is unknown. - - - - - - - - - **OF** Prohibited by the London Convention of the Sea in 1972
Hybrid CDR Types Dependent on Growth of Organic Carbon but with TRANSFORMATIONS FOR STORAGE **BECCS** Carbon capture and storage with chimneys - - - - - - - - - **BC&E** Pyrolysis to produce elemental carbon (biochar) and energy.	**BECCS** has experimental and expensive demos that lack realistic CCS. - - - - - - - - - - - **BC&E** is ready for scale-up with new methods; need increased R&D for more improvements. Traditional charcoal currently produces gigatons/yr but should be phased out.	**For BECCS:** 2020 Negligible, Speculative to reach 1 Gt/yr by 2050 - - - - - - - - **For BC&E** 2020 Demonstrations. Scale up to 0.5 Gt/yr by 2030. 2050 5 Gt/yr 2075 Stable at 2050 level.	Both **BECCS** and **BC&E** are limited by plant growth that could be increase by management for growth. **BECCS** lacks feasible CCS. - - - - - - - - - - New **BC&E** pyrolysis technologies need scale up funding, especially for use of "waste" heat that could pay for the processing. Needs to develop the market for biochar.	**BECCS** limits are similar to DACCS'. - - - - - - - - - **BC&E** has multi-century or millennial storage. Required protection from burning is natural when put into soil where there are additional benefits for soil, water, and food. Strong impact in short term.	Both **BECCS and BC&E** intercept organic carbon before it decomposes. - - - - - - - - **BC&E** liberates 70% of useful biomass energy. Decentralized. Safe. Worldwide participation by both rich and poor societies. Helps meet several SDGs. Potential to be self-sustaining.

Notes: CCS from chimneys would help fossil fuel business for electricity generation to be almost carbon neutral, but never to be carbon negative.
References for this Table: https://energypedia.info/wiki/Charcoal_Production#Earth_Pit_Kilns http://www.fao.org/3/y4450e/y4450e10.htm
[Note: Advocates of each NET are encouraged to present their rebuttals and data and to refine the characteristics of all NETs.]

5. SCS can be profitable for as much as US$ 45 or have cost of US$ 100 per t CO_2/yr, but short duration with notable monitoring / verification issues.

6. BECCS estimates are US$ 15 to $400.

7. BC&E is estimated by others to be US$30 to $120. (Evidence supporting more favorable (lower) costs is presented in future sections while also contenting that the market value should be higher, perhaps US$100 t CO_2e.)

Section IV. The scientific basis of BC&E is pyrolysis

A. Science: Pyrolysis is the thermo-chemical transformation of biomass that is heated with a deficiency of oxygen to become solid carbon (biochar) and combustible gases that can be condensable (the tarry gases and any water vapor) or non-condensable (composed mainly of CO, CH4 and H2) (the synthesis gas) and any non-combustible gases passing through the system (CO_2 and N2 from air). Both the solid chars and the gases can have differing compositions depending on the biomass and the conditions of pyrolysis. The tarry gases collectively called "woodgas" (even if not from wood because "biogas" refers to gases from anerobic digestion of biomass) can be promptly burned or captured and cooled for collection of diverse chemical compounds. The solid carbon has Important variations (in % fixed carbon, % volatile or mobile compounds, and % ash) that occur because of the highest attained temperature during char production, commonly being called charcoal (@~350 to 400 deg C) or biochar (@ ~450 to 650 deg C) or approaching activated carbon (@ >800 deg C).

Pyrolysis is a natural process that occurs in match sticks, forest fires, gasification devices, etc. Cave dwellers intentionally made and saved char to draw on walls and to carry hot embers for starting fires elsewhere.

Scientific techniques exist to analyze char and also the pyrolytic gases that can be 1) combusted, 2) saved as chemicals, or 3) released into the air as undesirable "smoke". Monetary values (or negative costs) of each can be determined and can vary with different circumstances.

B. The carbon cycle: (Figure 2). In general and referring to dry weights (that exclude the moisture in biomass), if a plant takes in 400 units (kilograms, tonnes, etc.) of atmospheric CO_2 during photosynthesis, it utilizes 200 units to sustain its biological life, being carbon neutral. The other 200 units are retained as carbohydrate growth (wood, leaves, and roots) and that, too, will eventually be carbon neutral if it decays or is combusted (burned) back to greenhouse gases (GHG). But if 200 units of wood are pyrolyzed, approximately 100 units will become solid, stable graphene sheets of elemental carbon (biochar) that are highly resistant to decay or digestion by microbes, etc. Thus, based on dry weight of biochar and its CO_2 equivalence (CO_2e), the CDR value of the biochar is about half of the weight of the plant biomass that was pyrolyzed or one quarter of all of the carbon dioxide that ever entered into the plant. As an example, **for every**

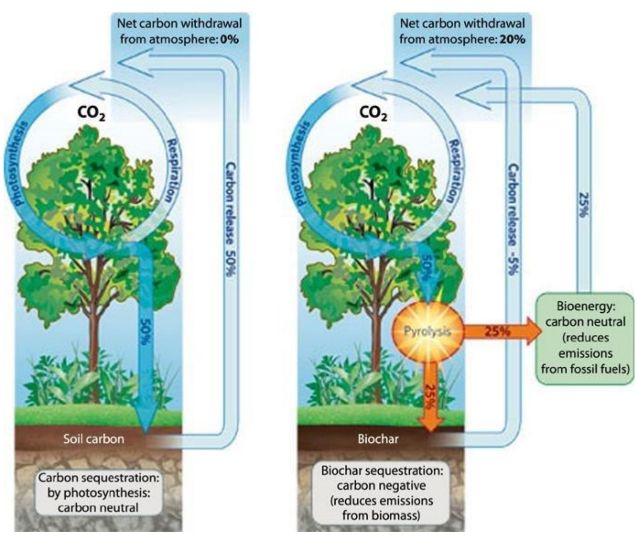


Figure 2: Comparison of normal and biochar carbon cycles (Lehmann, 2007)

100 kg of wood that is pyrolyzed, the resultant 20 kg of biochar for sequestration represents 50 kg of CO_2 sequestered (50 kg CDR), of which ~80% (40 kg) will have millennial sequestration if protected from burning such as if mixed into soil.

Similarly, about 25% of the CO_2 that is captured in biomass exits the pyrolyzer as gases that can be captured or burned or simply returned to the atmosphere (including "smoke") to become carbon neutral and simply part of the carbon cycle.

In terms of actual dry weights of biomass being pyrolyzed, one tonne is about half of a cord of split wood (4 x 4 x4 ft or 1.2 x 1.2 x 1.2 meters). Being less than 1% ash (inert minerals), the dry wood contains 1000 kg of mainly carbohydrates (cellulose, lignin, sugar, etc.), of which approximately 500 kg are carbon atoms, of which about 250 kg will become biochar if pyrolyzed, of which about 80% (200 kg) will be fixed, stable, "recalcitrant," carbon. Of the 250 kg of biochar, the amount of equivalent CO_2 would be 915 kg., or at the 80% fixed carbon level, that would be 730 kg of CO_2 available for millennial sequestration if it is made "un-burnable" such as by mixing it into soil.

C. The energy value: Pyrolysis releases about 70% of the energy stored in the biomass in the form of combustible gases.

> The original ton of wood contains energy expressed as any of the following: 17 million Btu; 18 GJ (giga Joules); 5000 kWh (thermal); 170 therms; 6700 horsepower-hr.; or the fuel equivalents of 3 barrels of crude oil; 626 kg of coal; or 18,000 cubic feet of natural gas.
>
> Because the biochar produced represents energy that is not released (30% of the total), the energy actually released is equivalent to 11.9 million Btu; 12.6 GJ (giga Joules); 3500 kWh (thermal); 119 therms; 4690 horsepower-hr.; or the fuel equivalents of 2 barrels of crude oil; 440 kg of coal; or 12,600 cubic feet of natural gas.
>
> Using 2020 values of these energy units, the commercial value of the energy present in the pyrolysis products of the wood would be $82 based on (subsidized) oil or $26 based on coal, fossil fuels that are not paying any carbon tax for their CO2 emissions.

Section V. Biomass supply for pyrolysis.

A. The USA has available every year between 1 and 1.5 billion tonnes of dry biomass equivalent without upsetting the production of food and fiber.

B. Worldwide estimates are less reliable because of they may or may not include protection of rainforests and other habitats. But 15 to 25 billion tonnes per year would seem to be a reasonable estimate. See Box 2 (next page).

C. The pyrolysis process in various types of pyrolyzers can be quite adaptable to receive biomass in many sizes, shapes and qualities, so additional sources of supply can probably be found, especially when modern forestry and agriculture industries put effort into faster growing plants on less desirable ground while building up the soil and ecosystems with biochar and permaculture.

D. All of the calculations for AR as a NET eventually encounter limitations when the surface area required for further growth and maintaining the trees alive begins to infringe on the land needed for food, feed, fiber, and fuel. When using biochar as the means for long term sequestration, harvesting in sustainable manners will allow more growth of trees and energy crops (instead of holding them in their mature but space-occupying locations). [Note: When managing for increased photosynthesis of forests and crops for CDR, great care must be taken to protect the biodiversity and refuge habitats.]

Box 2. Available biomass supply:

A. "Every year, plants convert 4,500 EJ (exajoules) of solar energy and 120 Gt (gigatons) of carbon [= 439 Gt CO_2] from the atmosphere into [~240 Gt of new] biomass – eight times as much as the global energy need." (World Bioenergy Association (2016)). About half of that plant growth is in oceans, and [as an assumption] about half to three-quarters of the land-based growth is inaccessible in current conditions of terrain and location, which would means leaving 30 to 60 Gt of biomass accessible for many uses, including pyrolysis into biochar if society decides that climate change can be combated with BC&E and decides to manage the biomass.

B. That same document identified the annual global supply to be 56 EJ of biomass energy [about 2.9 Gt of biomass] in 2012, with an expected near tripling to 150 EJ by 2035 [~8.5 Gt of biomass]. This indicates there can be decades of increasing CDR by actively employing BC&E drawdown before we reach the planetary limit of annual biomass supply.

C. There are further considerations:

1. Much of biomass growth in current situations is too remote, too dispersed, too sensitive for habitats, too difficult to process, too wet, or too "something" to be utilized for convenient pyrolysis. Human ingenuity and engineering can certainly overcome some of these situational limitations when circumstances arise.

2. Biomass supply is capable of being increased via scientific advances in agriculture and forestry in the coming decades. With BC&E in mind, decisions about plantings could favor faster growing species that could be harvested more frequently.

3. Biomass growth is not in isolation. It relates to food supply and natural habitats. The limited supplies of land area, soils and water all require appropriate management and protection and some regeneration. There is no "free ride" of unlimited biomass. The best practices of environmental science must be followed.

4. "Excessive" amounts of "liability biomass" can be detrimental or dangerous.

a. Intercept / collect and pyrolyze the "refuse or residue" from fields where burning causes great air pollution, as in India and northern Thailand. (Considered in Section XV).

b. Pyrolyze the cleared understory and thinnings from forests to reduce forest fire danger. (Discussed in Section XVI).

5. With reasonable separation efforts, municipal solid wastes could become a supply of organic matter for pyrolysis instead of an urban liability often sent to landfills. (Section XVI).

6. Stop the focus on BECCS that burns biomass all the way to ash but lacks viable carbon capture and storage (CCS) (See Section VIII).

E. Human ingenuity can devise better ways to utilize more biomass. Taking into consideration costs for equipment and energy, biomass can be processed to improve its characteristics. Chipping can make large pieces more manageable, while pelletizing and low- and high-density briquetting consolidates small and tiny pieces to create fuels with added utility and value. Such processing is rather simple and less expensive than the refining that is done to oil.

An innovative approach to biomass processing is the Chip Energy Biomass Conversion Facility (BCF) in Goodfield, Illinois, USA. (See Figure 3.) The building itself is made of repurposed shipping containers which are no longer seaworthy. It is a highly efficient and economical structure with a small footprint and a low impact on the surrounding community. The BCF will process up to 100 tonnes per day, turning raw material into densified biomass fuel, mulch, and other products. Most of this material would otherwise have gone into a landfill.

Figure 3. Chip Energy Biomass Conversion Facility.

F. Much land has been degraded by erosion and past agricultural practices including application of carbon-positive chemical fertilizers. Utilizing biochar, the progressive recovery of millions of hectares will increase the biomass supply because of improved soil physical, chemical and biological properties, aka soil fertility, soil organic carbon, water retention and productivity.

G. If climate change sufficiently disrupts our ecosystems, the prospects of biomass production by forestry and crops for BC&E sequestration could be seriously jeopardized, further limiting our prospects to correct the CO_2 problems. That would be a devastating tipping point of no return.

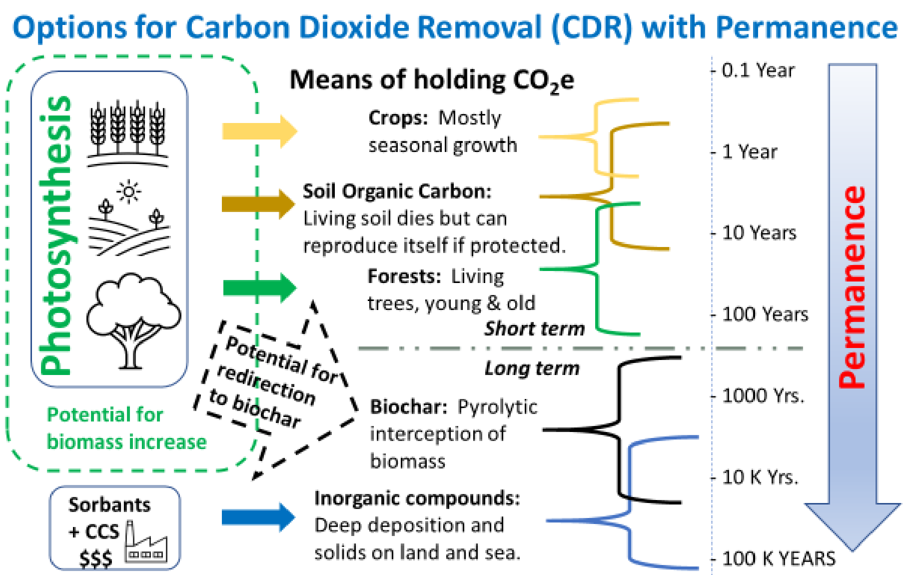
Section VI. Additional considerations

We cannot ignore some major issues. Full discussions will involve many experts from a multitude of disciplines. The EBI white paper (2020) discusses each of these. The two white papers are mutually supportive. Briefly, these additional considerations include:

A. Permanence: Duration is measured in months, years, decades, centuries, and millennia, essentially five orders of magnitude of temporal impact. Some authoritative publications (*e.g.* New Climate Institute, 2020, Fig. 2) have given biochar a rather low rating on how well and for how long the carbon sequestration will last. Such perceptions appear biased or poorly informed, perhaps with old data. Figure 4 is a more accurate representation.

Studies of biochar permanence require time to be conclusive. And the climate crisis allows no spare time. Based on observations of *terra preta* black soils and the EBI Whitepaper (2020, p. 22 with numerous bibliographic references), biochar has "… an annual degradation rate of 0.3% … [which is] … a conservative

Figure 4:



estimate." and "When biochar is added to agricultural or urban soils, … its carbon is stable for centuries." That might be the best that can be stated with strong confidence. And the key word is "centuries" when we are today trying to pull our climate back from the brink of tipping points during the next 30 years to 2050. And to make it to 2100, a mere 80 years away, is within the life span of today's children. If the half-life of stable (80% pure) biochar is 200 or 500 or 1000 years might not matter a few generations from now.

Box 3: Biochar for long term sequestration
******* On a dry weight basis, each ton of wood or similar biomass can yield about 200 kg of solid carbon (biochar) which represents the removal of 730 kg of atmospheric CO2. Of that, ~80% (580 kg) can be sequestered for many hundreds of years by placing biochar into soils. Every 1.7 billion tons of biomass can yield enough biochar for the long-term removal of 1 Gt CO2e. And there would be potential for up to 7 Gt CO2e removal per year derived from the world's estimated 15 Gt of accessible available biomass. *******

B. Additionality: Additionality is the concept and requirement that a desired climate benefit would not be done without the encouragement of financial assistance via carbon markets. In that regard, the total lack of advancement of BC&E for CDR in recent years suggests that any progress for biochar for CDR could be recognized as being additional. In fact, no sequestration of any kind was recognized in the pre-2015 UNFCCC regulations, and the Paris Agreement has not yet formalized sequestration as an authorized part of carbon accounting. Repeated searches in the past five years by Carbon180 (https://carbon180.medium.com/in-search-of-carbon-removal-offsets-42abf71b3ccc) have failed to find true CDR units. This will change. Recognition of additionality regarding CO_2 *removal* in any culture (not just in impoverished areas) is critical.

C. Governance: The examples of BC&E projects and prospects presented in Part Two indicate that BC&E could largely occur within the confines of individual countries and would not require external governance. For example, where charcoal production is currently illegal (but still occurs), it is because of traditional, inefficient production methods and the intended burning of the char for cooking. Modern pyrolysis to make biochar for sequestration must not be a restricted action. Some governance efforts should be appropriate for the stimulation of BC&E and because impacts eventually touch the climate of everyone.

D. Social Justice and Inclusivity: Of all the negative emission technologies (NETs), only AR and SCS (soil repair) and BC&E are viable in all nations and all socioeconomic sectors. They are not the exclusive high-tech, high-prestige, high-budget "techie treasures" with large grants and profit expectations from DACCS and BECCS, favored by wealthy nations. Biomass growth and BC&E in developing societies can be grassroot efforts for which the affluent nations should be grateful and willing to be financially supportive. *[This issue is likely to be expanded into an editorial and a "slam-dunk" "open and shut case" about how the wealthy societies should assist the truly impoverished people to fight excessive* CO_2 *caused by developed countries, but that is not our focus now.]*

E. Rapid feasibility and maturity of each NET: Each NET's technological readiness level TRL) (theory, laboratory, pilot, demo, scale-up and maturity) can be estimated at key benchmarks such as 2020, 2030, 2050 and 2100. Any comparison today will put BC&E clearly in the lead.

F. Delivery time for sufficient quantities: It matters how fast and for how long each CDR methodology can provide results in quantities of 1 to 5 Gigatons per year. Delivery times can be measured in months, years, decades, and centuries, with varying degrees of effectiveness. Again, BC&E is far ahead. (See Part Two).

G. Interrelationships with other extremely important issues: While dealing with our planet's future, BC&E can impact favorable major progress for several other issues:

1. Help accomplish the Sustainable Development Goals (SDGs)
    a. Household Energy and Health: (See Section XI about BC&E cookstoves.)
    b. Food supply: (See Section XXI about Biochar for soils and agriculture.)
2. Increase renewable energy supply: (See next Section VII.)
3. Reduction of CO_2 emissions from fossil fuels (See next Section VII.)

H. Confidence about truth of actions taken and data collected: Records need to be as error free as possible. Liars, cheaters, corruptors, and careless persons can spoil the records, resulting in over payments, double counting, or deficient recording of actual impact. This is especially true when societies in the future need to have confidence about actions, events, and data from decades earlier, including protection against tampering with the records such as numbers in spread sheets or dates of transactions. Modern information technology (IT) provides us with immutable tracking of contemporaneous data via blockchain. Examples for CDR purposes are in Sect. IX and XX.

I. Suitable and sufficient ultimate destination of the removed carbon. The "storage" of CO_2 via CCS in specific geologic formations poses some questions about location (including transport costs) and sufficiency of capacity to put the material far out of circulation. For biochar, the main destination is literally beneath our feet in the soils that we cultivate for our food and fiber. Biochar is desired, not something to be disposed. Soil science and agriculture experts will give guidance to optimize biochar placement, but in general, there is no shortage of relatively close destinations for biochar.

Section VII. Focus on energy and NETs

The worldwide consumption of energy is in three major categories. Electric power is king because of the great versatility and cleanliness of electric motors. Electric power can come from hydro, solar, nuclear, and large thermoelectric installations using mainly fossil fuels and some biomass. But electricity is only 17% of our energy consumption, split between 12.5% from fossil fuel and 4.5% from renewable sources. (See Figure 5.)

Liquid fuels for transportation (32% of energy consumption) are the queens of power, coming mainly from fossil fuels. The intense interest in hydrogen-powered or electric vehicles points to solutions, but only if enough hydrogen or electricity can be created by renewables.

As in any monarchy, beneath the top royalty are the masses, the lowly, the often forgotten. Simple thermal energy is a full 51% of energy consumption , but it receives less attention (fewer and smaller research grants,

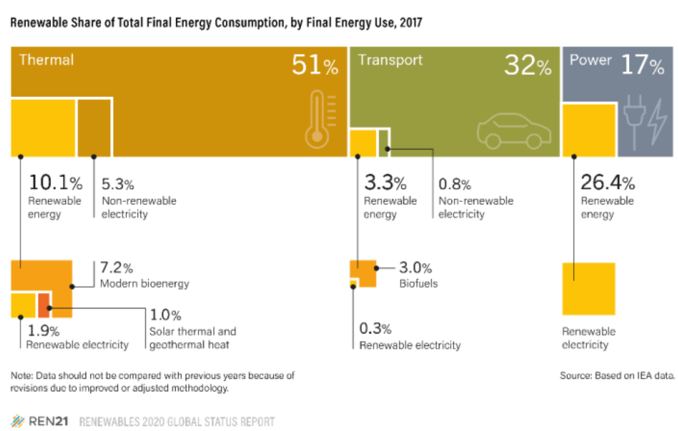


Figure 5. Major categories of energy consumption

etc.). About 40% of **all** energy production / consumption is from fossil fuels for industrial process heat, steam / hot water, and simple warming of buildings at modest temperatures required for human comfort.

That 40% of all thermal energy consumption is half of the world consumption of fossil fuels, so it is equal to about 20 Gt CO_2 increase each year. To help mitigate (replace or eliminate) that amount of fossil-origin heat is a worthy emission reduction (ER) goal for the lowly thermal energy from pyrolysis of biomass (as discussed later in this white paper). (That is separate and not to be confused with the simultaneous biochar production for carbon dioxide removal (CDR).)

This thermal necessity matches extremely well with the "&E" part of Biochar and Energy (BC&E). No other NET can complete. EW, OF, and DACCS require energy. AR and crops associated with SCS do accumulate and store energy but lose it with decay or, if used to replace fossil fuels via burning, are carbon neutral, no CDR. Even **IF** CCS were functional, BECCS could not be a strong candidate because it requires large installations, in contrast to widely distributed need for thermal energy and the spread of biomass.

BC&E provides CDR <u>**and**</u> ER thermal energy. And it does those tasks exceptionally well. BC&E is only at the fringes of making electricity or transportation fuels. But it is at least a prince or princess in the royalty of energy for providing essential heat from renewable sources while also doing the long-term sequestration of atmospheric CO_2 that plants pulled out of the air.

Box 4: What politicians do not do but could do to help:

In America and probably in other countries, when politicians declare their support for renewable energy, they name "wind, solar, hydro, geothermal, and biofuels (referring to liquid fuels for transportation)." Period. Full stop. They never acknowledge "biomass" that is so evident and appropriate for the thermal energy needs of societies. Thermal energy is 51% of our energy consumption, so perhaps it is worth mentioning.

[Be sure to applaud and vote for the politicians who eventually connect with this message and actively include and provide funding for biomass energy along with the other renewable energy sources that they advocate for future energy transformation, economic growth, job creation, and serious efforts to resolve the climate crisis.]

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

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

1. Different technologies: BECCS <u>*appears*</u> to have the advantage because it starts with technology for releasing 100% of the energy by burning biomass all the way to ash, and the intention that nearly 100% of the created CO_2 could be captured and stored via proposed functional CCS technology. In contrast, BC&E <u>*appears*</u> 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 (or 40% for long-term sequestration).

2. Different levels of readiness: For BECCS, of its two components, BE and CCS, the CCS capability is grossly lacking as of 2020 and is dependent on assumptions and speculations for solutions that will be costly because they are industrial, and not natural. In contrast, for BC&E, both the BC and

&E components are already functional or awaiting the existing business sector for heat capture to adjust to and commercially promote some BC&E systems of heat delivery and usage for homes, etc.

3. Sizes of units: BECCS focuses on large (expensive) facilities and has no expression as small, decentralized capabilities. BC&E springs from and thrives in small units, as in cookstoves, but also can have major capabilities for much larger facilities where heat can pay the bills while biochar is a desired co-product. (See Part Two.)

4. BC&E devices are, in general, significantly less expensive, allowing for more units to be placed in more locations closer to the sources of biomass and the destinations of the sequestration of the biochar. Lower costs and moderate sizes combine for these advantages for BC&E:

a. Different sizes of facilities allow BC&E to be much more accommodating to use diverse types of biomass, with the result that the potential pool of biomass is larger for BC&E than for BECCS.

b. BC&E locations will be much more numerous and located closer to the sources of biomass and the destinations for the heat. Local ownership is more likely.

c. BC&E has worldwide appeal to and potential involvement with all socio-economic strata. BECCS is directed toward wealthy societies.

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.

C. The focus on electricity production via BECCS is misleading, as was pointed out in Section VII about heat and energy. When BC&E becomes well established and is providing useful thermal energy, there will be minimal biomass available or affordable for expensive BECCS installations that require massive amounts of biomass with significant transportation costs.

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

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

Section IX. Documenting multi-century sequestration

For recognition and any financial reward for carbon dioxide removal (CDR) of any type, all stakeholders must have confidence in the process, and that begins with rigorous accounting. Each CDR unit of biochar sequestration must be derived from data captured during the process, from biomass sourcing, optional biomass transportation, pyrolysis, optional biochar transportation, and posit (soil sequestration of biochar).

The rigor of documenting each part of the process is what makes or breaks stakeholder confidence. Anecdotal evidence including word of mouth or scraps of paper is not sufficient.

A combination of mobile applications (used by field agents) and IoT devices (optional) can provide the data to create a credible record of sequestration events. These records can be compiled and coded in near real time as immutable transactions on a blockchain from secure (encrypted) data transmissions that are digitally signed and timestamped,, possibly including GPS coordinates, still images, and video.

With guidance and early investment from the nonprofit, Juntos Energy Solutions NFP, Bitmaxim Laboratories has developed an app ecosystem under the Woodgas Impact initiative that implements this strategy. (See further information in Section XX.)

Part Two:
Gigatons of CO_2 Removal and Reduction via Biochar

Section X. Overview of CDR Capacity via BC&E

Our attention turns to the practical and implementable actions that can help resolve the climate crisis using the existing and near-future scalable BC&E technologies. The targets are 1) carbon dioxide removal (CDR) of gigatons of CO_2 and 2) emission reduction (ER) of gigatons of fossil fuel CO_2 emissions. The specific actions presented in individual Sections are:

Section XI. Clear demonstration that basic pyrolytic **production of stable carbon is already possible at scale** with over 100 million tonnes (100 Mt = 0.1 Gt) of CO_2e (removal of carbon dioxide equivalent) per year in the 2020s.

Section XII. **Carbon dioxide removal (CDR) of 0.25 Gt** CO_2 **per year by 2030** can be accomplished by Advanced Cookstoves (BC&E technology) with **0.5 Gt** CO_2 **emission reduction** because of ***a decrease*** *in the consumption of biomass*, with co-benefits for SDGs, while being affordable and sustainable.

Section XIII. Issues that impact the prospects for biochar production to reach high volumes of CO_2 removal

Section XIV. Introduction to recent and ongoing **advances in BC&E technology** for CDR so that scalable solutions become possible.

Section XV. Biomass disposal and clean air via pyrolysis of crop residue
Section XVI. Biomass disposal of excessive tree growth via pyrolysis for fire safety
Section XVII. Pyrolysis and electric power production.
Section XVIII. Residential heating with BC&E
Section XIX. Industrial process heat with BC&E
Section XX. Confidence in Sequestration via biochar
Section XXI. Co-benefits of BC&E
Section XXII. Financial value of CDR

Part Three Conclusions with action plans.

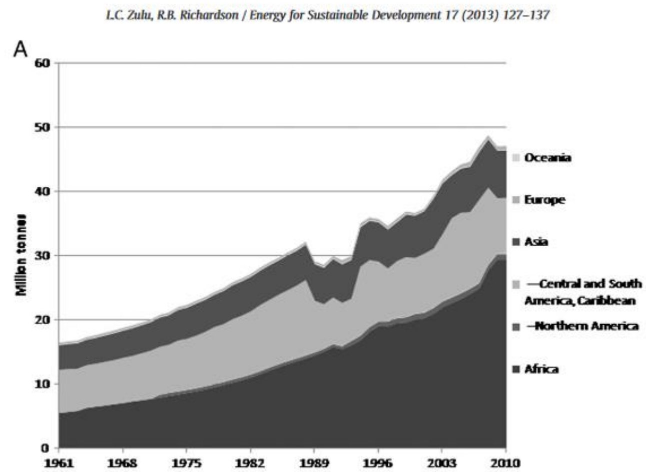
Section XXIII. Overview
Section XXIV. Summary of proposed CDR efforts based on BC&E:
Section XXV. Issues
Section XXVI. Calls for actions

There are no Gigaton solutions. There are only small solutions of 1 kg or 1 tonne of CDR per day or hour that can be scaled to reach the necessary millions of replications to reach gigaton status. That is the approach of Woodgas Pyrolytics. Many small exceed a few large. It is important to get started now and keep scaling up as fast as possible.

Section XI. Pyrolytic production capacity of 0.18 Gt CO_2e CDR per year already exists.

Making stable carbon out of biomass is not difficult. Humans have been doing it since they started using fire in their caves and campsites. Worldwide charcoal production in 2014 was over 50 million tonnes, which would be 180 Mt CO_2e removal per year if it would be sequestered. And that amount is accomplished mostly with rudimentary or "traditional" charcoal production methods that can certainly be improved.

Figure 6: World Charcoal Production



However, that charcoal production is burned each year as the primary energy source for over one billion people (over 200 million households) cooking with charcoal stoves. The stable carbon in that charcoal is not available for carbon sequestration. Burning that much charcoal would be essentially carbon neutral except for the carbon positive (unfavorable) annual net loss of forests that is to be discouraged and stopped.

The replacement of charcoal stoves with modern pyrolytic gasifier stoves (see the next Section XII) would stop the inefficient traditional (10% yield) charcoal production that consumes 500 million tonnes of trees per year. Instead, the families could have equivalent but cleaner cooking on pyrolytic stoves using less than 100 million tonnes of biomass that includes direct crop residues (e.g. maize cobs) and processed pellets from rice husks, stems and other "agricultural refuse," not from trees. This possible change should have great appeal to WWF and other organizations wanting to halt deforestation and sponsor habitat and species protection in addition to protecting the climate.

(Reference: https://www.researchgate.net/figure/A-Charcoal-production-by-region-of-the-world-1961-2010-millions-of-tons-B_fig1_257434437)

Section XII. The removal of 0.25 Gt CO_2 per year by BC&E cookstoves **[This is by far the longest, most detailed Section. Do not get stuck here. Maybe skim it fast.]**

A. Need and opportunity

Approximately 500 million households (HH) (the poorest 40% of world population) still cook their daily meals with solid fuels of biomass, charcoal, and some coal. Hundreds of millions cook on 3-stone fires of pre-historic origin; others use a range of basic and intermediate (sub-optimal) "improved cookstoves – ICS" designed mostly in previous centuries and not considered to be adequately clean burning. The consequences include health issues (respiratory diseases, eye problems, pre-mature births, etc.), environmental damages of air pollution and ecosystem depletion, and socio-economic limits to income, drudgery fuel collection, and hinderance of female education. There has been some scattered progress in this century, but so little that the population growth keeps constant the number in need of adequate cooking methods.

On the positive side, the Energy Sector Management Assistance Program (ESMAP) of the World Bank, has identified some truly “Clean Cooking Solutions” to be promoted for the poor. The stoves are associated with types of fuels, each with its own pros and cons: 1) “modern fuels” of electricity, LPG, and natural gas; 2) “renewable fuels” of solar ovens, alcohols, and biogas; and 3) “advanced ICS” of biomass gasifiers stoves, also known as **woodgas or TLUD stoves that use true BC&E technology.** drtlud.com/wp-content/uploads/2017/04/Stove-Classification-2017-04-10.pdf In other words, the best cookstove technology that uses the same solid biomass fuels that the people are currently using is the type that makes its own cooking gas (woodgas) while also producing biochar. Question: Can the BC&E stoves contribute significantly to CO_2 removal?

B. BC&E cookstove technology and current char production

1. Woodgas stoves are the smallest examples of BC&E pyrolytic technology; literally, they make charcoal while producing the woodgas for cooking a meal. And because of efficiencies, the cooking is done using *less* of the same fuels that the poor people are currently using, which means emission reduction (ER).

2. TLUD (“tee-lud” = Top-Lit UpDraft) micro-gasification (or micro-pyrolysis) is functional BC&E in a variety of **gas-burning cookstoves that make their own clean-burning gases while leaving charcoal behind.** (see Box 5 and Figures 7 and 8.)

Box 5: TLUD gasifier stoves are BC&E technology.

For technology, terminology, video, history and usage of TLUD stoves, there are twelve key publications available in the “Quick Picks” section at drtlud.com.

Concerning usage, the key document is “Case Study of Acceptance … Deganga”, also directly available at drtlud.com/deganga2016.

An innovative project with carbon offsets is outlined at JuntosNFP.org/projects . [Dr. Anderson is the founder and executive director of this 501(c)(3) nonprofit.]

FIgure 7. Indian woman cooking food on a Champion TLUD BC&E pyrolyzer cookstove (conceptually designed by the author in 2005).

Figure 8. The most advanced and exceptionally clean burning TLUD stoves use pellet fuel and have small fans for forced air. Shown are FabStove and Mimi Moto models.

3. Proven acceptance by tens of thousands of dedicated users is already established. Over 35,000 households in West Bengal use the Champion (Figure 7) with consistent daily usage, some since 2013. Another 55,000 have been added in 2020. Scale up by further hundreds of thousands during 2021 would be a significant accomplishment.

4. Cooking with a TLUD stove uses less (about 50%) of the same biomass fuel currently consumed for daily cooking in traditional cookstoves. In 2018, traditional biomass provided nearly 7% of the world total energy consumption, mostly for household cooking in developing countries (see Figure 9). BC&E stoves and the increase of pellet fuels from forestry waste and crop residue can saves trees and habitats.

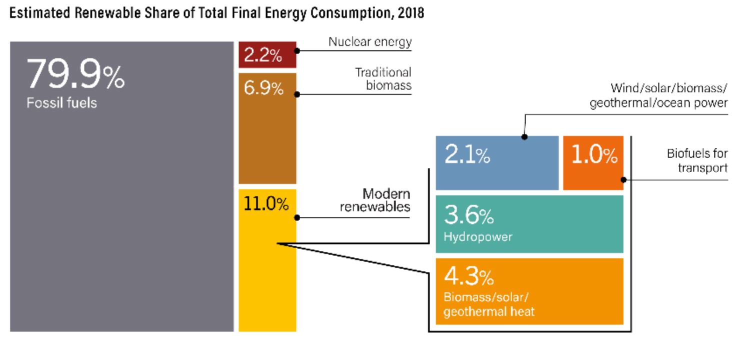


Figure 9. Fuel type shares of total energy. Proposed BC&E initiatives should greatly increase modern biomass use while significantly reducing both traditional biomass, and the need for fossil fuels. [Source: REN21 Renewables 2020 Global Status Report.]

5. One TLUD stove in one day makes approximately 0.8 kg (2 pounds) of good quality biochar while cooking meals on approximately 5 kg of the same fuel that the family has been using, **earning two ER carbon credits per year, each for 1 t CO_2 reduction.** The West Bengal exemplary project with 35,000 stoves produces approximately 27 tonnes of biochar per day (equivalent to almost 100 t CDR/day). However, procedures established for official certified UNFCCC CER and Gold Standard carbon credits require that the char be sold to industry (mainly for production of incense sticks), replacing traditional inefficient charcoal production and earning an additional two carbon credits per stove per year. Only rule changes (governance) and appropriate financing are needed to allow biochar production to be multi-century sequestration in the form of biochar into soil with the co-benefit to improve crop yields.

6. The TLUD stove activities in West Bengal and Assam are expanding, but not at rates fast enough to alter our climate because of lack of financing. Massive efforts of scaling are quite within society's industrial, organizational, and socio-economic capabilities to bring millions of BC&E stoves to India and to expand across Asia and into Africa and Latin America.

1. Each day each household (HH) with a TLUD stove produces 0.5 to 1.0 kg of biochar (@ ~80% fixed C). Multiplied by 365 days, it becomes between one-quarter and one-third ton of stable solid carbon per year/HH as a byproduct of cooking the family meals.

2. Using a conversion ratio of C to CO_2 of 1:3.6, each HH could sequester (via biochar into soil) approximately 1 t CO_2/yr., or almost **1 Mt CO2/yr per million families who are the poorest in the world as carbon dioxide removal (CDR) in addition to the two ER carbon credits for reduction of use of biomass fuel.**

3. The poorest 40% of the world is 500 million households. Half of that would be 250 million HH (20%). **250 million families could sequester 0.25 Gt CO2/yr as a "by-product" of cooking daily meals while using less of the same biomass fuel that they currently use in traditional biomass stoves, or over three times more wood savings if the household transitioned from charcoal stoves.**

That merits repeating:

> **Box 6: 250 million families could sequester 0.25 Gt CO2/yr as a "by-product" of cooking daily meals** while using less of the same biomass fuel that they currently use in traditional biomass stoves, or even three times greater wood savings if transitioned from using charcoal stoves. This can be reached before 2030.

C. Based on established projects, the potential for CO_2 removal by the poorest millions of the world's households can be calculated (and put into IAM projections).

D. Financial options for the initial 0.25 Gt CO_2/yr. sequestration via 250 million TLUD stoves:

1. Hundreds of millions of the poorest families on earth will gladly sequester 0.25 Gt CO_2/yr. if the affluent world (which has caused the climate crisis) would provide a decent, modern, pyrolytic char-making cookstove for each house. Impoverished households aspire to have such stoves that are cleaner burning and can create micro-income (such as US$ 3/month, based on the Deganga project) from the sale of the charcoal they produced while saving money (average US$110 /yr.) by using less fuel than they currently do.

2. Providing TLUD stoves would contribute significant progress toward meeting eight of the UN's Sustainable Development Goals. [SDG's 1, 2, 3, 5, 6, 7, 13, and 15, as listed in Box 7.]

3. The price tag for each stove is between US$30 - $50. That adds up to about $10 billion for one-time direct assistance (but not all at once) to the poorest 20% of the world's families. (See Box 8.)

4. Any combination of funding sources in Box 8 could do the job, and a bit of help from the national governments would also be appropriate. [Additional ideas and help would be appreciated.]

5. The money is not needed all at once. But exponential growth of projects into over fifty independent countries is likely and few will want to wait, so a trickle of money is insufficient for them or for the climate-repair efforts.

6. Perceptions of what these efforts mean become more realistic when dealing with a million BC&E gasifier stoves to sequester 1 Mt CO_2e. The amount is only $40 million dollars, well within the range of development banks and other funding sources. For comparisons about what actions can accomplish 1 Mt CO_2 CDR / yr., see Box 9.

7. Alternatively, a million stoves would be only 1000 projects of 1000 stoves each (for $40,000 per project). Each sponsor would accomplish CDR ***removal*** of 1000 t CO_2 each year while the

> **Box 7: The Sustainable Development Goals (SDGs)**
> (as listed in Wikipedia)
> 1. ***No Poverty***
> 2. ***Zero Hunger***
> 3. ***Good Health and Well-being***
> 4. Quality Education
> 5. ***Gender Equality***
> 6. ***Clean Water and Sanitation***
> 7. ***<u>Affordable and Clean Energy</u>***
> 8. Decent Work and Economic Growth
> 9. Industry, Innovation, and Infrastructure
> 10. Reducing Inequality
> 11. Sustainable Cities and Communities
> 12. Responsible Consumption and Production
> 13. ***Climate Action***
> 14. Life Below Water
> 15. ***Life on Land***
> 16. Peace, Justice, and Strong Institutions
> 17. Partnerships for the Goals

project itself continues with self-sustaining funds from the sale of two carbon credits for the ER ***reduction*** of fuel consumption by each stove.

Box 8. A total of ten billion dollars is not a lot of money for directly helping the poorest 20% of the world's households:

a. Half of one percent (0.5%) of the annual global military expenditures of two trillion dollars.

b. Two and one-half percent (2.5%) of the $400 billion pledged to be given away by the over 200 billionaire signers of the "Giving Pledge" that was initiated by Gates and Buffett, who each could do the entire amount.

c. The entire amount or a significant starter fund to get the ball rolling could be covered (or loan guaranteed) by Jeff Bezos who in 2017 was seeking projects for "…helping people in the here and now – short term – at the intersection of urgent need and lasting impact." [Direct contact with Bezos or his staff has been tried and is still requested. Somebody please give this message to him.]

d. Loans from the World Bank and the Regional Development Banks, with repayment via the commercial sale of the carbon dioxide removal (CDR) credits and emission reduction (ER) credits that would also finance the maintenance and replacement of the stoves for decades.

e. Because the reduction of fuel consumption generates carbon credits with financial value, the funding could come from thousands of individualized, focused million-stove projects (or 100,000-stove projects) by NGOs, non-profits, or "social businesses" with the stove-user communities sharing in the profits.

Box 9. Comparisons of three NETs for the proposed annual removal of 1 Mt CO2e:

The source for A. and B is Sir David King and Rick Parnell on Sept. 17, 2020.
https://www.washingtonpost.com/outlook/climate-change-intervention-cost/2020/09/17/c6715db6-f784-11ea-89e3-4b9efa36dc64_story.html

A. DACCS: *"The Canadian company Carbon Engineering is building the world's largest DAC plant in the Permian Basin in Texas. It will be able to capture one megaton (1 million tons, or one-forty-thousandth of our global output) of CO2 annually at a cost of $94 to $230 a ton."* [Mid-point cost would be about $160 million for each Mt of removed CO2e.]

B. AR: *"An average tree can absorb 48 pounds of carbon [dioxide] per year, so it would take 1 million trees about 42 years to remove the same [1 Mt] of CO2."* [Planting @ $2/tree is only $2 million, which is not the problem, but limitations include the forestry care needed and space occupied while waiting 42 years to about 2062, and then the continuing but ultimately insufficient permanence of sequestration if kept as trees occupying land, compared to millennial sequestration if made into biochar.]

C. BC&E: The BC&E TLUD stove comparison is 1 M impoverished households receive and use 1 M stoves at a cost of $40 million (including stove maintenance) paid once to accomplish the removal of 1 Mt CO2e (about 270,000 tons of biochar). The long term continuation is accomplished by the sale of the charcoal, for which these impoverished families are paid about $40 per ton of CO2e (during one year of stove use) or the equivalent of about $0.15 per kg for biochar that can be resold commercially at a higher price as a valued soil amendment for increased crop yields. Up to two ER carbon credits for reduction of fuel use (CO2 savings) are also earned each year.

D. CONCLUSION: BC&E is the obvious choice for prompt attention. All of the other CDR methods are to be encouraged because they could be useful someday, but not at the expense of support for BC&E actions that should be started immediately.

The successful removal of CO2 does not replace the essential reduction of ongoing CO2 emissions. Cookstoves for the poor do not justify fossil fuel consumption by the affluent.

E. Speculations / projections for Gigatons of CDR/yr via BC&E cookstoves

The discussion above has been about stoves for the poorest 20% of the world's people who live in 250 million households (HH). The next poorest 20% are in almost similar conditions. Serving them with TLUD stoves for BC&E CDR is totally conceivable, especially when carbon prices, fuel supply chains, and financial resources are being established. That would raise the annual CDR to 0.5 Gt while accomplishing more co-benefits for several SDGs.

For civilization to go to net zero emissions by 2050, the remaining 60% of the world's households will also need to cook without fossil fuels. The most affluent 20% could probably cook with electricity, but electricity will likely be needed for higher priority purposes.

The further development of pyrolytic cookstoves capabilities in the coming decades of this century could quite possibly include features that could make BC&E stoves acceptable in many households in middle-income and affluent societies.

Alternatively, larger pyrolytic / gasifier installations might include production and cleaning of combustible gases that can be stored for perhaps 3 days at local facilities and safely distributed by pipes within neighborhoods or across cities. This would have similarities with the 1800s era of gas lighting but with 21st Century materials and technology, while still producing the necessary stable biochar for sequestration.

Such developments could bring the CDR just from cooking to a full 1 Gt CO_2/yr by involving 80% of the world's households. Then, in each 50 years, 50 Gt of CO_2 could be removed. That would be 5% of the world goal of removing 1000 Gt of atmospheric CO_2 to bring the ppm of CO_2 down from 410 to pre-industrial levels of 280. This is speculation, but it is as least as plausible as some of the speculations presented about other NETs that have not yet developed their foundation processes or viable costs but are the bases for projections for limiting global warming to 1.5 deg C.

Note that this is ONLY discussing BC&E for purposes of residential cooking using less biomass than is now used for those people to cook their food. Much more CDR via BC&E is possible, as discussed in the next major Sections.

F. Reconciling vastly different calculations of $10 billion versus $1.5 trillion for cookstove solutions by 2030

1. Cookstove specialists can quickly point out the vast difference between the above described proposals for TLUD BC&E cookstoves (US$10 billion total spread over a decade with carbon credit financing) and the authoritative "estimates that $150 billion is needed annually to reach universal access to modern energy cooking services by 2030", as stated in the *"State of Access to Modern Energy Cooking Services"* report that was produced by the World Bank's Energy Sector Management Assistance Program (ESMAP) in collaboration with Loughborough University and the Clean Cooking Alliance (CCA, the successor to the GACC and the PCIA organizations with cookstove efforts that go back about 15 years). https://www.cleancookingalliance.org/about/news/09-24-2020-new-report-lack-of-access-to-clean-cooking-costs-the-world-2-trillion-annually.html Why the difference?

a. CCA and ESMAP include "$103 billion [that] would come from household purchases of stoves and fuels [annually]". Cash flow for fuel purchases by 500 million households presumably includes LPG, electricity, and other "modern" fuels that cannot be locally obtained. Those costs are not included in the TLUD proposition because the families are continuing to use their same biomass fuels (wood, crop residues, perhaps locally made pellets), but with better fuel efficiency that reduces their fuel expenditures.

b. CCA and ESMAP are "stove and fuel neutral", meaning acceptance of lesser (not advanced) quality stoves than TLUD micro-gasifiers and also the inclusion of other advanced / modern clean cooking stoves (biogas, solar, alcohol, LPG, NG, and electric). Some advanced stoves are more costly or require purchases of non-locally sourced fuels. Even worse, included are LPG stoves and fuels that are often imported and are fossil-based carbon positive. For CDR objectives, this is a step in the wrong direction and to the disadvantage of all people on Earth, especially the poorest.

c. The CCA focus (and main approach for obtaining funding) is on the worthy goal of better human health (less smoke in kitchens) and not on the health of the world climate.

d. Although use of other "advanced cookstoves" can also generate carbon credits for CO_2 ER emission reductions (and generate funds to offset some expenses), only the TLUD micro-gasifiers are able to accomplish significant carbon removal. The funds for CDR are massively important to keep down the costs for the establishment of BC&E stove usage by hundreds of millions of impoverished households. If CDR credits generated by cookstoves for the poorest families cannot be sold at reasonable prices, there will be no hope for carbon financing to fight the climate crisis.

2. This is not a criticism of ESMAP or CCA. It is a clarification as to why this author disagrees about cost estimates given by these powerful organizations that have great influence over the advancement of cookstove efforts. Dr. Anderson is a faithful attendee since 2007 at the biannual meetings sponsored by CCA and its predecessors and he is certainly well known to the leadership and rank-and-file of the CCA. There is every expectation that the CCA and ESMAP will embrace the issues of carbon dioxide removal (CDR) and the CDR role of TLUD BC&E cookstoves so that the CCA goals can simultaneously be accomplished. Dr. Anderson is certainly not neutral about stove types. And CCA can remain neutral while being recognizing that only the BC&E micro-gasifier stove technology can accomplish significant carbon dioxide removal.

Section XIII. Issues that impact the prospects for biochar production to reach gigaton volumes of CO_2 removal

Although the BC&E cookstoves in the previous section are a worthwhile effort for both climate and humanitarian objectives, they are not sufficient to resolve the climate crisis. They would pyrolyze less than 5% of the available biomass. To be able to favorably impact the climate crisis, we need multiple gigatons of true CDR sequestration every year and significant replacement of fossil fuel use. For that, we will consider in the next sections the answers to several issues / questions:

A. How can we get greater or additional value from pyrolysis?

Biochar itself is only one of four profit categories of BC&E tasks, presented in Section XIV and Figure 10. And we will see in Section XIV that the additional values of thermal energy, biomass disposal, and climate care can drive or sustain the biochar production.

B. Is there a full range of BC&E technologies to do the tasks of pyrolysis?

There are seven orders of magnitude in the sizes of pyrolyzers based on quantities of biomass to be pyrolyzed per day. And there are many types of pyrolyzers that relate to the different quantities. We do know that appropriately sized BC&E devices can be built with known technology. Important variations such as portable vs. permanent installation, degree of automation vs. manual labor, differences of biomass types and sizes, and ownership vs. lease/rental can all be decided in each project and shared for replication in similar circumstances. The options will keep getting better in the coming decades of trying to solve the climate crisis. Some key ones are primarily from the 21st Century. See Section XIV.

C. What could be the impact of BC&E on the climate crisis? We have already presented in Section V. that there could be 15 to 25 Gigatons of biomass in the world, especially when the quantities can be increased by forestry and agricultural efforts. In general terms, when used with BC&E technology, **each tonne of dry biomass** (such as seasoned wood or pellets from crop refuse) provides removal, reduction, and adaptation:

1. **Removal**: solid stable carbon biochar equal to about 0.6 t CO_2 permanently removed from the atmosphere. Ten (10) Gt biomass pyrolyzed each year could **remove** 6 Gt CDR per year, or 300 Gt removal between 2050 and 2100 and onward. If we could be with sustained pyrolyzing of 25 Gt per year by 2050, and if we started soon with some build up in the 30 years until 2050, the cumulative carbon dioxide removal (CDR) could reach over 850 Gt by 2100.

2. **Reduction**: thermal energy that replaces 2 barrels of oil or 0.86 tonne of CO_2 that did not go into the air, ten (10) Gt biomass pyrolyzed each year could **replace** 20 billion barrels of oil per year, which is about 8% of the world energy consumption each year. Perhaps we could increase that to 25 Gt biomass and 20% of our current fossil fuel energy consumption, focusing on the half of all fossil fuel consumption that is used for heat (see Section VII and Figure 5). There would still be 80% of current fossil fuel consumption to be reduced to Net Zero by changes in our lifestyles.

3. **Adaptation**: co-benefits of a soil amendment for increased food security helps meet several Sustainable Development Goals (SDGs) and should be included as a BC&E impact.

To obtain promptly those advantages of BC&E, proper engineering and investment for BC&E programs can **transform our thermal energy businesses to be not only renewable, but also to be carbon removing.**

D. But how do we get to such amounts? What are the types and circumstances of biomass in the real-world impact actual situations and operations?

1. Perspective: **There are no Gigaton solutions.** There are only small solutions of 1 kg or 1 tonne of CDR per day or hour that can be scaled in number (not size) to reach the necessary millions of replications to reach gigaton status. That is the approach of Woodgas Pyrolytics**. Many small can exceed a few large. All sizes of BC&E pyrolysis units can be useful. It is important to get started now and keep scaling up as fast as possible.**

2. Specific situations: Specific examples are presented in Sections XV through XIX, with estimates of how much CDR is possible in each situation. The estimates total to a range of 5 to 9 Gigatonnes/yr. The final numbers will be determined during the coming decades when specialist engineers and scientists seriously focus on BC&E technology instead of burning biomass to ash.

Section XIV. Old and new technologies for BC&E

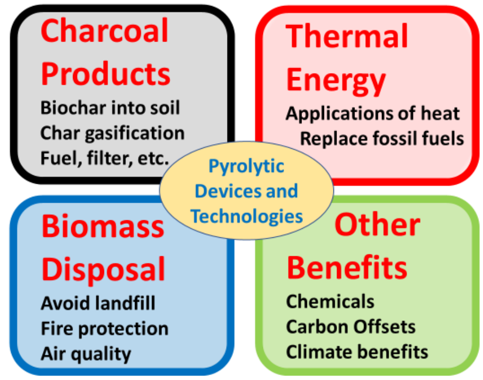


Figure10. Four major ways to have income from pyrolysis

A. Variety and innovation in BC&E.

Biomass combustion of a matchstick or forest fire is a natural process and leaves behind some but relatively little charcoal. To increase the char production, the principles of pyrolysis via limiting access to oxygen can be applied in devices from laboratory test tubes to gigantic industrial complexes for combined heat and power (CHP). Figure 10 shows the four products or services that can make pyrolysis financially viable, especially if at least two of the four are operational in devices at the same time. To maximize these incomes, optimize costs of equipment and operations, and match with available biomass types and sizes, there are many variations of pyrolytic technologies, devices, costs, and sizes. See the "Examples" column in Box 10 and note that they are classified by the amount of biomass input in a 10-hour period with a range of **seven orders of magnitude** from less than 1 kg to over 100 tonnes per 10-hour period.

Box 10. Classification of "modern" biochar production technologies by orders of magnitude of <u>the amount of biomass that is pyrolyzed</u> in a 10-hour workday. (This is not a classification based on yield of biochar.):

Scale/Quantity	*Objective*	*Examples*	*Generalized comments*
• Laboratory (< 1 kg)	R&D and testing of qualities	Matchsticks and other demonstrations	Science to be taught in school
• Micro (1 to 10 kg.)	Cooking (biochar is a bonus)	Char-making cookstoves (TLUD mainly)	Since 1990s; See Section XII.
• Small (10 to100 kg)	Making Biochar (loss of heat)	Barrel-size TLUDs, retorts, open flame-cap kilns	Labor intensive; do not readily scale.
• *Midi (100 kg to 1 ton)*	*Making Biochar and Heat*	*Rotatable Covered Cavity (RoCC) flame-cap kilns*	*The focus of this Section XIII.*
• *Medium (1 t to 10 t)*	*Making Biochar and Heat*	*Rotatable Covered Cavity (RoCC) flame-cap kilns*	" " " " " ".
• Large (10 ton to 100 t)	Char/chemicals/power	Retorts, heated screws, air curtain, incinerators	Expensive; large; with multi-objectives
• Industrial (> 100 t)	CHP (char is secondary)	Combined heat and power (CHP) facilities.	Big business; competition from fossil fuels

Introductory and review comments of these size levels have been presented previously by the author and are readily available on several formats: A video summary in 100 seconds is from 0:40 to 2:20 minutes in a 4-minute video about RoCC kilns at the website: **www.woodgas.energy/resources** . More details are in the deck of webinar slides numbers 6 to 13 and in the webinar oral presentation about those slides (minutes 4:06 to 8:50).

The Micro scale with TLUD cookstoves is new since the 1990s and started gaining recognition after 2010. Their strength is in vast numbers, as discussed in Section XII.

Except for old style retorts for charcoal making, there has been a general lack of modern pyrolytic methods and devices with moderate costs [under US$50,000] in the three sizes of the Small, Midi, and Medium ranges. To fill that gap or "missing link," in the past ten years the "flame-cap" technology for open-top cavities (cones, pyramids, troughs, pits and trenches) shows that biochar can accumulate in the oxygen-starved lower cavity levels. The cap of flames consumes the oxygen above the biomass and sustain the pyrolytic temperatures radiating downward onto biomass that keeps being added. (See Figure 11.) A disadvantage is the need for labor to keep gradually adding fuel but to avoid burying the fuel, which would prevent proper pyrolysis.

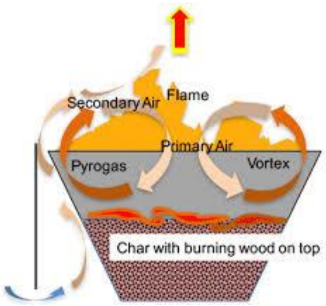


Figure 11. Flame cap processes in open top cavity kilns

A "covered cavity kiln" was devised in 2014 by Anderson (author), but it too suffered the requirement of gradual fuel feeding until late 2019 when he added the ability to rotate or roll the kiln. (See Figure 12.) With the capabilities for mixing the biomass even when in much larger quantities that are loaded in bulk instead of gradually, the Rotatable Covered Cavity (RoCC™) kiln was invented. It now has patent (pending) protection and is being developed by Woodgas Pyrolytics, Inc. Although the author's comments here could be viewed as biased, they are an expression of the vision of what RoCC kilns can accomplish. Participation by others and funded projects will influence the designs, kiln capabilities, additional features, and business directions of RoCC kilns. If interested, contact the author and (eventually) see results announced at www.woodgas.energy .

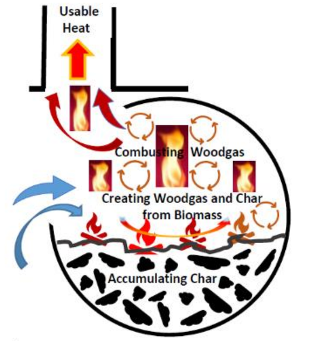


Figure 12. Flame cap processes in covered cavity kilns

The ability to rotate, roll, or tilt the RoCC kilns when desired by the operator or by a programmed mechanical routine is the key to assuring adequate mixing of all the biomass for exposure to the necessary pyrolytic temperatures.

B. Core design and variations of Rotatable Covered Cavity (RoCC) kilns. There are four variations of RoCC kilns. The first or core design consists of a cylindrical kiln with one large portal (doorway), a rack with wheels to support the cylinder, a hood with chimney(s), and a frame that holds the hood separate from the cylinder, all of which are visible in Figure 12 and in the 4-minute video at www.wooodgas.energy/rocc .

Several barrel-size units have been built and successful tested. The unit in Figure 13 was demonstrated near Chico, California on 28 February 2020. Two weeks later the Covid-19 pandemic hit the USA and most activities came to a stop. Even into November, the progress is slow, in part because of California forest fires. But there is progress in South Africa, India, USA (several sites), Colombia and Australia.

Figure 13. 4-ft diameter RoCC kiln, rear view, preparing to unload biochar. 28 February 2020

The RoCC concept is to be tested with adjustments at much larger diameters, even using 10-ft (3 m) diameter railway tank cars and 16-ft diameter corrugated steel pipe (culverts) of lengths appropriate for long biomass fuel. This will be serious R&D requiring specialists and sponsors.

A second variation is to have the cylinder (kiln) roll horizontally on a frame or rails, with two positions for loading, one for emptying by gravity, and rotation positions through more than 200 degrees of arc for mixing. One with a 6-ft diameter and 7-ft long (42 sq ft of pyrolytic area) is being built inside of a 20-ft shipping container. Heat capture at the chimneys could be nearly 2 GJ (1.8 M Btu) per hour.

Figure 14. "RoCC n' Roll" kiln (R&R) for biochar production. Prototype for R&D, October 2020.

A third variation (see Figure 14) has angular or circular wheels at both ends that allow the RoCC kin to be tilted or rolled into desired positions, earning its name "RoCC n' Roll"™ kiln (R&R). This is a very inexpensive and convenient way to have relatively small-scale biomass disposal with appropriate biochar production. One operator could attend to several units.

The fourth variation is similar to the third and is to be pulled through harvested fields to pyrolyze the excessive crop residue instead of having open burning. It is discussed in Section XV. The objectives are essential biomass disposal, better air quality, addition of biochar to the fields, and possible carbon funding. The heat is normally discarded but would be available when a use is determined, perhaps for pre-drying more biomass.

C. Sizes and capacities of RoCC kilns

Because of varying project objectives and fuel characteristics, many different sizes of RoCC kilns could be needed. When fuel is long and reasonably straight (such as bamboo, miscanthus, hemp, poplar, pine, and fir), lengths of 10, 20 and even 40 ft could be appropriate for easy manual or fully automated loading. Or when the fuel is small but uniform (such as nut shells, maize cobs, or woodchips), the unit could be shorter (perhaps 5 to 15 ft long) with fuel feeding by augers or manual means to assure pyrolysis.

Before the Corona virus restricted most activities, one carefully weighed batch of tree branches and cut wood was pyrolyzed in a RoCC kiln made with a standard barrel (200 liter or 55-gallon with ~ 2 ft diameter and 3 ft length). The quantitative results in Box 11 could be doubled or tripled by increasing the length to 6 or 9 ft (about 3 meters).

Box 11. Results of use of a small RoCC kiln

Quantitative data show pyrolyzing of wood branches of about 25 kg per hour during several hours in each batch. That is about 4 kg of biomass input per square foot of the 6 ft^2 of flame cap pyrolytic area. The biochar yield at ~20% is ~5 kg/hr.

The thermal energy output was estimated to be 12 MJ/kg/hr, which is 70% of the total energy with 30% remaining in the biochar. That means 300 MJ/hr or 83 kW-h/hr or 284 k Btu/hr. That heat is not trivial, but so far there is no attempt to use that heat.

Extrapolations for larger diameters becomes too speculative because a larger diameter increases the volume more rapidly than the surface area that is exposed to pyrolytic heat. Engineering can be applied to control the air flows, emissions (for capture or burning), and tonnes of biochar that become available from, for example RoCC kilns made from the abundantly available recycled thick-walled railroad tank cars (10 ft D x 50 ft L) using biomass of almost every imaginable size and type.

RoCC kilns development is in its infancy and the business should grow exponentially in the next few years. Even greater growth will be in the related industries that produce boilers for heat capture, the supply chain for biomass, the biochar-use industries (discussed later), and for CDR transactions.

Box 12: Patents and business:

Patents give legal monopolies for limited time in exchange for the open sharing of details. The RoCC kiln patent (pending) is intended to stimulate many to participate in business ventures and to prevent abuses by the problematic few. Usage of the patent rights can be granted by contracts in exchange for reasonable returns when a business or person is making a profit.

If an alternative BC&E technology is equal or better, that will be wonderful for the world. Until then, RoCC kiln technology from Woodgas Pyrolytics, Inc. appears to be the only game in town in the Midi and Medium scales with basically simple, low-cost pyrolytic technology. Looking forward to working with you. We have a great deal of CDR and CO2 mitigation to do. PSA

Section XV. Biomass disposal and clean air via pyrolysis of crop residue

As pointed out in Section XIII.A and Figure 10, the production of biochar is only one reason for pyrolysis of biomass. The other three major reasons (heat, biomass disposal, and misc., including climate) are more likely to drive forward the actions that fortunately produce biochar. Here our focus is on biomass disposal while producing biochar.

A. Background:

After harvest, many fields have an overabundance of crop residue or refuse (such as hard stems) that need to be reduced, removed, or incorporated into the soil before the next planting season. Industrial societies have turned to mechanical agriculture for plowing, disking, chopping, bailing, etc. to have fields ready for the next planting season. In the less developed world that heavily depends on human or animal labor, when sufficient physical removal of residue from the fields is too troublesome, burning is a common "solution" that results in excessive removal, nutrient loss and serious air pollution.

A far better solution would be to pyrolyze an appropriate amount of that crop residue. Pyrolysis would put 50% of the carbon atoms of the processed residue into the soil while having cleaner combustion of the emissions, meaning less air pollution.

The fourth variation of RoCC technology is the “RoCC Field Pyrolyzer” kiln that can be rolled through fields. (See Figure 15.) It is still experimental, and maybe some other biochar devices could be better. But for CDR objectives, some pyrolytic solution would result in the permanent sequestration of nearly 25% of the carbon (not CO_2) of the pyrolyzed biomass, or the CO_2equivalent that would weigh about 60% of the original weight of the biomass.

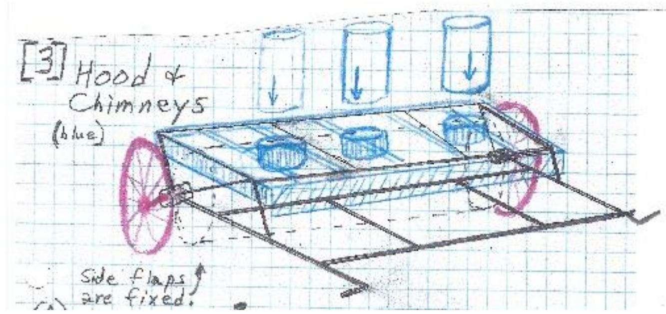


Figure 15. RoCC Field Pyrolyzer. The cylinder is shown only with dashed lines. The fuel feeding shelf will be on the handles. Suggested width 6 ft to 2 meters.

The “Asian Brown Cloud” is annual massive air pollution that spreads from the Punjab beginning in late November to Beijing in July. Similar hazy skies are in Central and South America in August and September, then resume in West Africa, stretch across that continent, embrace, Iran and start again in Pakistan and India. In India, vehicles and industrial emissions cause about half the emissions, with the rest from “smoke” from traditional inadequate cookstoves (see Section XII) and especially from the open burning of crop residue in harvested fields.

B. India example: A case study with India data of annual crop residue

Data source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6427124/ and agricoop.nic.in/sites/default/files/NPMCR_1.pdf

National total = 502 Mt of crop residue from 77.7 Mha; 360 Mt used; Surplus = 141 Mt, of which 93 Mt are burned, being an average of 1.2 t/ha.

Punjab total = 51 Mt of crop residue from 6.4 Mha; 26 Mt used: Surplus of 24.8 Mt, of which 19.7 Mt are burned, being an average of 3.1 t/ha. (See Box 13 on next page)

The point is that it should be financially feasible because of the climate crisis to sequester CO_2e, improve the soil, ,increase crop yields, have cleaner air with better health, and create employment in conditions such as in Punjab. If the demand for such carbon sequestration credits is not sufficient for an adequate price, then the affluent world is not yet motivated enough to fight climate change, and tragedy awaits us. And if any of this crop residue would be made into pellets for use in BC&E gasifier cookstoves, the heat would have been used for cooking while replacing some tree-based biomass or carbon positive LPG fuel that is more expensive and imported.

The total cost is possibly less than \$200 million for kilns for all of India to achieve nearly 30 Mt of multi-centennial CDR sequestration per year just by cleaning up some of its air pollution. **If implemented by 2030, the CDR accumulation from pyrolyzed crop residue in India alone by 2100 would total about 2.1 Gt CO_2e removal.** Note that this uses existing annual growth of biomass and does not compete with agriculture but could actually improve soils, food production and SDGs.

[Note: Funding should be available at least for a significant trial in India. For years 2018 and 2019 US\$177 million were earmarked for subsidies in India to farmers to buy farm equipment to dispose of crop waste without burning. And in the 2020-21 fiscal year, US\$746 million were allocated for farm equipment subsidies. https://w ww.reuters.com/article/india-pollution/india-aims-to-cut-crop-waste-burning-in-punjab-and-haryana-by-80-idUSKCN26D1XJ]

Box 13 For Punjab only: These calculations are estimates and each variable could be possibly doubled or half of its stated value, but probably balancing out.

a. If two (2) workers with a RoCC Field kiln can cover 3 ha per day for 80 days during the burning season (which becomes ~250 ha/season/kiln), Punjab would need ~25,000 kilns, totaling about 4 million work-days. The char would be deposited in shallow trenches and covered to smother. A few days later the char could be spread or collected.

b. Intentionally leaving 25% of the residue untouched in the fields for SCS and for soil conservation, and using a 15% weight-yield of biochar, then 15 Mt of residue would become about 2.2 Mt biochar/yr, which at 80% fixed carbon would represent **almost 7 Mt CO2e permanently removed per year** from the atmosphere from Punjab, which has 8% of India's crop residue.

c. If the cost is ~US$600 per kiln, the total expenditure for kilns would be under $15,000,000 for Punjab, being a one-time cost (but kilns with repairs or replacement parts might only two or three years). The kilns could be available during other months for processing collected or other feedstocks.

d. If the carbon value of 1t CO2 removed and sequestered were to be US$30, the financial breakdown would be $30 x 2.2 million Mt = $66 M. Subtracting $15 M for equipment and $5 M for administration, that leaves $50 M to pay 4 million workdays, becoming $12.50 per day per worker. Current Punjabi agricultural workers earn about $4.50 per day, so their wages could certainly improve.

<u>Reemphasizing</u>: Every number in these calculations could be higher or lower: kiln price; number of kilns; number of workers per kiln; number of days for clearing; hectares per day that can be serviced; and especially the monetary value for true CDR removal with long-term sequestration that should be substantially higher than $30 1t CO2e. Furthermore, there should be some ER emission reduction carbon credits for reducing the pollution of the air each year.

C. Global calculations about annual crop residue:

(With thanks to Dr. Michael Shafer of Warm Heart Foundation, Thailand, for much of this content.)

The topic of annual crop residues and biochar is gaining importance. In 2020 there are the studies in China by Liu, et al. on "straw biochar amendments" https://onlinelibrary.wiley.com/doi/abs/10.1002/ldr.3495 and in Brazil by Lefebvre, et al. on "Modelling the potential for soil carbon sequestration using biochar from sugarcane residues in Brazil" https://www.nature.com/articles/s41598-020-76470-y . Statistical data are available from around the world.

According to FAO compilation of statistical data, in 2017, farmers in the developing world grew 10 billion tonnes of crops. Based on standard ratios of edible crop to waste, these 10 billion tonnes of food also left 21 billion tonnes of waste. Some became fodder, fuel, mulch, etc. How much of this was burned in their fields is open to discussion, but a conservative estimate is 50% (**10.5 billion tonnes).**

If just 25% of this crop residue that is currently burned is converted to biochar at a 20% conversion rate, then small farmers in the developing world could produce **525 million tonnes of biochar *per year*** from crop residue. That would be over **1.5 Gt CO_2e/yr** going into multi-century sequestration. From 2030 to 2100 that would be over **100 Gt CDR**, one-tenth of the total world goal of removal.

Of additional note are these considerations:

1. There still remains 75% of that crop residue biomass available for more pyrolytic CDR with BC&E.
2. There are co-benefits regarding SOC and food production, t
3. There should be some compensation for the avoidance of the following GHG emissions that impact global warming: **CO** (EF 102 g/kg) **~0.25 billion tonnes; CH_4** (EF 5.82 g/kg) ~1**5 million tonnes; NH_3** (EF 2.17 g/kg) over **4 million tonnes; NOx (**EF 3.11 g/kg) **~8 million tonnes; and $PM_{2.5}$** (EF 6.26 g/kg) **~ 16 million tonnes.**
4. There could be attempts to utilize the heat directly or delayed with pelletizing of the biomass, but it is an option wherever the benefits offset the additional costs of equipment, labor, transport, etc.

Section XVI. Disposal of excessive tree growth via pyrolysis

(A constructive review and corrections by forestry experts would be appropriate and appreciated.)

A. Undergrowth (understory) in America's western forests is infamous as a major factor in fire hazards. Paradise, CA burned to the ground in 2018, and in 2020 was threaten again with a resultant four-day evacuation. Fire breaks are not a guarantee against forest fires reaching houses, but every resident in those endangered areas is interested in the reduction of biomass in and around their communities. Preston Englant has launched a small business to help protect Paradise and other communities by clearing excessive biomass. Regulations require him to transport the biomass to a landfill and wood chipping site ten miles away.

As an alternative, Englant intends to use the first large RoCC kiln (the 4-ft diameter one in Figure 13) in late 2020 after the current fire season has passed. It will not be big enough for the task, but it could prove the point that RoCC kilns can make a difference and be safe to use locally during most of the year.

If successful, a larger unit could be demonstrated, specifically one that is 8-ft in diameter (maximum size for standard transport on US highways) by up to 20 ft in length for long biomass. Similar in size to a 20-ft shipping container, its projected biomass intake is to approach 1 tonne per hour, which in a 10-hour workday is about equal to three mature pine trees or a lot of undergrowth. That would yield about two tonnes of biochar/day, equivalent to 6 t CO_2e per day, or up to 1500 t CO_2e per yr per large RoCC kiln. Some of the thermal output of perhaps 10 M Btu/hr might be of use for centralized heating and air conditioning in the rebuilt center of the Paradise. But neither the heat no the biochar is the rationale for this effort. Rather, people want to be reasonably safe while living in a mountain paradise, so disposal of much understory is important every year or two.

To protect the town (or another town that was not burned down), a fire hazard biomass clearance plan would be appropriate, to include a community-determined amount of undergrowth and some number of full trees to be handled. Assuming the task should be done promptly (and not linger for years and years), there can be an estimate of the labor, equipment, and transport, etc. to do the job. If 6 months, then so much. If in 12 months, then so much. This is serious biochar production with the purpose of biomass disposal.

Numerous RoCC kilns of different sizes could be needed, along with other actions such as log extraction to larger facilities such a biomass power plants (see below). Just within the built-up area of Paradise, there are over 200,000 dead trees to be removed. One unsubstantiated calculation is that at a rate of two trees per kiln per day working 200 days per year, 100 kilns would be needed for five years.

There are thousands of American communities that want to avoid the fate of flames. For every 10,000 large RoCC kilns in regular use (and they can be transported to where the biomass is located), that could permanently remove 15 Mt CO_2e per year as biochar, or 1 Gt by 2100. Of course, all of this remains to be proven. Perhaps some assistance to Preston Englant will come soon so we can move forward based on real world data.

B. Slash from forest logging operations or natural forest disturbances

In a typical logging operation, roughly half of the biomass leaves as logs and half stays at the site as slash. Some slash should stay on the ground for habitat purposes, but much that is often piled and burned could be converted into biochar. If logging equipment can reach the forest site, large 8-ft diameter RoCC kilns (see Section XIII.B.) could be brought in, moved around the site, used and later retrieved. The site could be appropriately uncluttered, the created biochar could remain to improve the soil during replanting, or extracted for commercial sale, or used with C2P char gasifiers (see Section XVII.D) to provide electrical energy (and avoid diesel usage) for the logging and chipping operations. In the USA, over 3.2 million tonnes of forest consumption could leave 3 Mt of slash available for pyrolysis on site at the forest. That could become almost 10 Mt (0.01 Gt) CO_2e/yr (or 0.1 Gt CDR/yr globally) while improving soil and avoiding considerable emissions of methane and/or smoke. https://www.fia.fs.fed.us/library/brochures/docs/2012/ForestFacts_1952-2012_English.pdf . A similar approach could be useful in the forests that are severely damaged by hurricanes.

C. Most urban wood waste is not a fire hazard, but it still must go!

"… assuming an average national [USA] tipping fee of $38/tonne, the 29.6million tonnes of urban wood waste disposed of annually represent more than $1,124 million in annual disposal costs. … Assuming a landfill density of 1,000 lb./yd3, the 29.6 million tonnes of wood waste disposed of annually consume about 59 million yd3 of landfill space each year." [Source: https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr133.pdf dated 2002, so current numbers would probably be higher.] And landfills emit methane.

Converting any portion of this urban wood waste into biochar and useful heat should be called an "opportunity" for each community and a bonus for CO_2 removal. 30 million tonnes becomes 6 Mt of biochar that is 18 Mt CO_2 removal and sequestration per year. Being implementable by 2030, that accumulates to 1.3 Gt by 2100 from only the urban areas of America. Would the worldwide estimate be 20 times higher? And the heating value would be worth many millions of dollars that could all be utilized locally.

Urban areas are also noted for their overabundance of organic matter in municipal solid waste. At least some significant percentage could be appropriate for BC&E disposal, but the calculations will be left for professionals in those fields to determine.

Box 14: Confidence in the numbers

A. All of the above situations in Part Two (Sections X through XVI) have involved only biomass that is either already destined for such use (e.g., biomass cookstove fuel) or is considered to be residue, waste, refuse or hazardous. None has negatively impacted production of food or fiber. In fact, it can be declared that the biochar will improve soils and food production. The quantitative data above are, in the author's understanding, quite reasonably correct. His specialty is small systems. All calculations should be verified, and the author regrets any errors.

B. This is the transition point for the author's knowledge of usage of biomass and of heating and power issues. Below this point is essentially where engineering, accounting, and established businesses take over, and also where the sizes and costs of equipment and systems become much larger. The sections that follow will be made more rigorous by experts in updates of this document. For now, "best estimates" are presented.

Section XVII. Pyrolysis and electric power production.

A. California case of biomass power plants. Electric power production with biomass is in the size range of Large and Industrial scales of installations [Box 10 in Section VIII.]. California currently has about two dozen biomass power plants with an installed capacity over 500 megawatts. None were built for producing biochar, just for burning all the way to ash to maximize energy generation potential. Some are still operating, some are idle, and some have closed. One CDR approach is to convert them into pyrolytic power plants. Josiah Hunt of Pacific Biochar has already been working with such facilities to produce biochar and he has a plan to scale this up by modifying eight active power plants in 5 years as biochar producing, carbon negative efforts. Idle plants and closed plants can be modified and brought back online later, as needed.

The eight power plants would consume 16% of California's "Technical Forest Biomass Resources" total of 14,300,000 BDT (Bone Dry Tonnes) per year. That is 2.28 M BDT of biomass to yield 228,000 tonnes of biochar (@ 10% yield) valued at over $50 million /yr plus 192 MW of electrical energy generation. For climate purposes, that becomes about 0.7 Mt CO_2e sequestration per year. These numbers should be of interest, especially because they are only one-third of what could be done with only conversions. Modifications to existing infrastructure, as presented in this case, can leverage existing machinery, trained staff, and standing contracts to get to work quickly with relatively low capital and following the "reduce, reuse, recycle" principles. [Source: https://pacificbiochar.com/wp-content/uploads/The-Big-CA-Biochar-Model_Version-1.1_9.23.19.pdf]

This is an excellent example of how California can transition to pyrolytic renewable electrical power that is also carbon negative. America has 178 biomass power facilities with total capacity over 6,000 MW, and several hundred coal-fired plants that could be considered for conversion instead of shut-down. The biochar yield from dry-weight biomass could possibly be doubled to 20% with some R&D funding.

B. The UK initiative at the Drax power plant is quite different from the California example. It came online as a coal fired power plant in 1986, and by 2010 it was co-firing biomass. Between 2012 and 2016, three generating units were converted to solely biomass consuming 7.5

million tonnes/yr. of imported pellets from the United States and Canada (but that is a separate issue). A fourth unit converted in 2018, and the final two coal units are to be gas turbine operations. Total planned output is about 4,000 MW.

Burning biomass all the way to ash is not CDR. The acclaimed plan is to use BECCS, but the CCS technology is not viable yet. And what is currently being evaluated for CCS might have possible capabilities of 300 kg CO_2/day, which is only 0.1 Mt/yr., 1/10,000th of a Gigaton.

It would make more sense for Drax to use BC&E technology to have biochar for sequestration. If pyrolyzed, ten million tonnes/yr would yield 70% of its thermal energy to make electricity and 2 Mt of biochar, with a CDR value (80% stable) of 6 Mt CO_2e. The engineering and financial experts can determine which of these three options is best: a) current operations are carbon neutral sending the CO_2 up the chimney, or b) *someday, maybe* capturing that CO_2 via CCS, or c) using the BC&E option. [Note: It is possible that because of the BC&E removal of biochar (with 30 % of the energy) that the fuel input could be increased to 14 Mt per year to attain the maximum thermal energy output for the power system, with a corresponding increase in the biochar output to 2.8 Mt/yr, or almost 0.2 Gt CO_2 cumulative by 2100.]

C. One estimate of world CDR with BC&E technology for biomass power plants might be 0.1 to 0.3 Gt CO_2e/yr, but that is a "guess" and does not take into account what engineering could accomplish to raise the biochar yield to 20%. IAM specialists can study and model this to get better results.

D. Creating power via char gasification

To transform biomass into "engine-quality gases" (EQGs) can be done in two ways:

1. Full-fledged gasification of "raw" biomass, with persistent challenges of removing impurities (tars, particulates, etc.) that could foul the engines except for filters, etc. that add cost, operational complexity, and some pools of nasty waste, or

2. the gasification of charcoal, which is essentially biomass carbon with the tar-making volatiles already removed. Char gasification is appropriate for small engines in remote locations, such as direct shaft power to water pumps or electricity generation up to 20 to 40 kW. (see Figure 16.) Creating 1 to 2 kW per kg of charcoal, these units are carbon neutral and can be quite useful in remote locations where engine power is crucial and when char production is easy or abundant. C2P (Char to Power) initiated by Gary Gilmore offers solutions in two sizes. Char gasification is not recommended for vehicles that would travel beyond the charcoal supply chain.

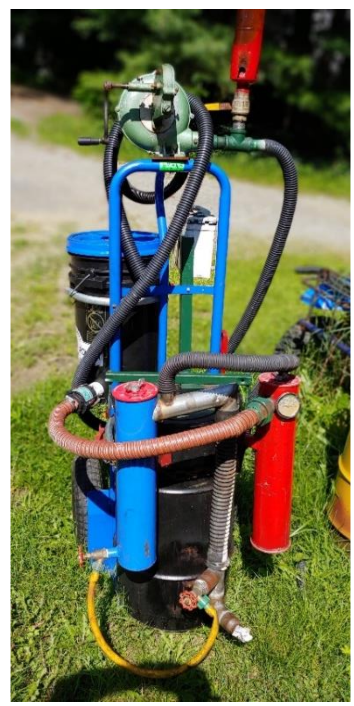


Figure 16: Mobile C2P char gasifier, small size for 3 to 10 HP engines.

Section XVIII. Residential heating

A. In less-than-affluent housing in cool and cold areas around the world

Dwellings are of so many sizes and types around the world that many BC&E solutions are possible, each with millions of replications. At one extreme are uninsulated drafty huts and shacks heated by open fires or metal fireboxes that also serve for cooking. For these, the previously discussed TLUD char-producing cookstove technology could be modified to include moderate space heating capabilities. Better sealed dwellings with insulation could also switch to char-making heaters when they are developed and available. This could add perhaps another 0.25 Gt of CDR while heating homes with less of the same biomass fuel than is currently being consumed.

B. In affluent housing in cool and cold areas around the world, plus in hot areas where space cooling is the expected norm

Residents in temperature-controlled housing in North America, Europe and other affluent societies spare no expense to heat or cool their living space for maximum comfort, plus hot water at every faucet. Affluent people have low tolerance for thermal discomfort. To attain Net Zero status, there must be some serious revision of "home heating and cooling", or else Net Zero could be at risk of failure because of space heating. This is not about CDR for climate issues. This is about changes in lifestyle that could be difficult to accept. Some of the need for residential heat will be solved by better construction, more insulation, solar collection, geothermal, and simple combustion of biomass, none of which are carbon negative. But BC&E technology is available, and variations could be incorporated into the millions of homes and apartment buildings. To meet the Net Zero Emissions goals of 2050, focused engineering ingenuity will find solutions but at prices that may or may not be acceptable / affordable. Some examples of where solutions (and business opportunities) might come include the following:

1. There is progress for better biomass fireplaces and inserts for home heating, but thus far biochar production is not a sought or available feature.

2. Modern pellet burning heaters are efficient and clean, but they burn the pellets to ash. We can expect there will eventually be pellet stoves that are carbon negative with BC&E technology, perhaps a larger variation of the previously mentioned TLUD FabStove.

3. As a replacement to outdoor wood boilers that do not make biochar and are criticized for smokiness, the Chip Energy Biomass Furnace (Figure 17.) operates cleanly and safely with pellet fuel or wood chips. The biochar quality is good and automatically collected. However, it provides enough heat for four American houses in cold winter areas and costs over $12,000 because automation is costly (but could be scaled down). However, mini-heating districts of 4 to 8 homes or apartment complexes might be candidates when the mindsets finally embrace Net Zero heating and when electricity is too expensive to be used for space heating.

4. Systems with more heat could include the RoCC kiln technology with heat exchanges and systems of shared thermal distribution, as in business districts.

Figure 17. Chip Energy Biomass Furnace.

Any success for Net Zero by 2050 must include non-fossil heating and cooling for affluent people. "Together, home heating and cooling is responsible for roughly 441 million tonnes of carbon dioxide annually." (https://www.c2es.org/content/home-energy-use/) This is a non-trivial 1% (0.4 Gt out of 40 Gt) of world annual emissions by the USA alone, so imagine the combined impact with Europe and everywhere else that has modern heating and cooling and would like to continue with that basic comfort. Much of this annual potential emission reduction will be accomplished by previously named changes, including some full combustion of biomass to ash. That transformation will not be inexpensive, but will create jobs, economic activity, and financial savings for families, communities, states, and nations. One unknown is if BC&E technology will be utilized, especially where easily serviced by biomass supply chains. If used, the CDR could be over 1 Gt per year of permanent sequestration of CO_2 from the atmosphere.

Section XIX. Industrial process heat

This topic is beyond the scope of this author's expertise. Suffice it to say that engineers and business owners with experience with industrial process heat (for example, Eng. Tom Miles, current head of the US Biochar Initiative) will have much to contribute about ways to match biomass supplies, heat requirements, and BC&E kiln types and sizes. Efforts could start with the easiest targets such as grain drying facilities and especially greenhouses that 1) need the heat, 2) can use the biochar, 3) can with care use the cleaned emissions to have elevated levels of CO_2 for more plant growth, and 4) can use their own crop residues as fuels. The collective target would be equivalent to two or more gigatons of CO_2 removal, with initial efforts starting immediately. And we note again the substantial simultaneous annual *emissions reductions* (ER) because of replacing fossil fuels.

Section XX. Confidence in CDR sequestration

A. Marketable CDR units tied specifically to biochar sequestration efforts must be backed by rigorous accounting. Biochar sequestration achieves carbon dioxide removal (CDR) that could represent several gigatons per year in this decade. Whether documented or not, every tonne of CO_2e sequestered helps the fight against climate change and should be encouraged. And where those efforts can be validated, financial rewards can be available for the entire value chain, from growth to sequestration. At present, there is at least one initiative, called Woodgas Impact, that is focused on the emerging interests surrounding CDR sequestration. Most notable is its app ecosystem that serves woodgas cookstove projects and biochar-producing kiln efforts. Its central data engine, CharTrac™, is an advanced, multi-featured web application that enables secure data acquisition from IoT devices and/or authorized persons operating in the value chain who are equipped with Woodgas Impact mobile apps (primarily, CharTrac). With authentication and certification from the proposed Woodgas Institute, this data is key to generating a credible registry of marketable CDR units tied specifically to biochar sequestration efforts. Details about CharTrac and the Woodgas Impact initiative can be found at their respective websites, chartrac.com and woodgas.com .<<THIS SECTION IS PRESENTLY INCOMPLETE, AS IT IS BEING DEVELOPED WITH A THIRD PARTY.>>

B. A case study with BC&E for CDR sequestration.

1. The location is the **Jalinga Tea Estate in Assam, India,** and its administrative expansion to a nearby tea estate. The BC&E device is the FabStove (Figure 8) with initially 50, then 500, then 5000 units, using pellet fuel that is prepared at Jalinga. **EVERY action is timestamped and digitally signed, securely transmitted, and encoded to at least one blockchain transaction. H**ere are the broad strokes; details of actions can vary in different situations:

a. (There are prior recorded data about the fuel, cookstoves, etc. for carbon emission reductions that precede the next steps.)

b. Each stove creates biochar that is periodically (at least every 4th week) collected, examined for consistency, and weighed.

c. Collections are gathered at a secure location, with grading and separations.

d. Samples can be gathered for analysis of carbon, etc. at any time.

e. Recorded video and witness declarations confirm the action "to make forever noncombustible" (there is no word for this in the English language yet).

f. Distribution is documented along each step to the final location; record of source, quantity, and specific destination, complete with GPS locations, high-resolution satellite images and GIS database mapping, and geosynchronous contemporaneous documentation, including drones with cameras. The precise documentation of sequestration (and confidence level) could be rated as C, B, A, AA, and AAA.

g. Permissioned online access to cumulative results for continual monitoring, available to all parties according to their need for access.

h. Additional records for land use, crops, yields, average and exceptional weather-related events (drought, floods, etc.) for each parcel of land.

i. Later access to the locations for verification, including soil samples and testing.

j. Review and determination of certification (includes being retroactive to include all allowed transactions).

k. Each CO_2e tonne is retired from the registry but never erased, always available for further review. Blockchain is forever.

l. Be supportive of the authorized officials (UNFCCC, GS, etc.) to find appropriate ways to conduct verification and certification methods.

2. The Jalinga Tea Estate is a pioneer location because of other BC&E activities:

a. 4000 Champion TLUD stoves since 2016 with CER / Gold Standard certification of carbon credits, working through atmosfair.

b. World's first certified organic tea estate and progressing to becoming the first carbon neutral tea estate.

c. Conducting BC&E exploratory studies with RoCC kilns and C2P char gasifiers.

Section XXI. Co-benefits of biochar

A. "Adaptation" is the third leg of the stool (along with reduction and removal) for the fight against climate change. Adjusting what we do and how we live will become increasingly important. Biochar can have important adaptation roles if significant support for biochar R&D is provided to improve, refine for specific soils and crops, and maximize the agricultural potential of biochar. Soils and crops are extremely complex. There is still much to learn, which means that there is much progress to be gained.

B. Biochar in agriculture is increasingly well-regarded (partial list)

1. The water holding capacity of biochar can help withstand increasing droughts and also aid cultivation to be expanded into some current semi-arid areas. This includes savings on irrigation water.

2. Biochar's capacity to hold back nutrients reduces the risk of them being lost to the environment and increases their use efficiency by the plants, resulting in increased yields with less

expenses for fertilizers. (Commercial fertilizers are often carbon positive, meaning further emission reductions when less fossil-based fertilizers are used.).

3. Biochar for filtering and adsorption of some toxic materials can recover some unproductive land.

4. Biochar in soil may stimulate and strengthen SCS, the living and growing organic carbon in the healthiest soils. Whether BC&E or SCS gets credit for the boost in CDR is not an issue.

5. Cattle that consume small amounts (1% by weight) of biochar produce less methane, allowing beef consumption to continue a while longer.

6. After pyrolysis of at least one biomass (banana leaves), the biochar contains significant Potassium, becoming an actual fertilizer and not just a soil amendment. [Research by Dr. Manish Kumar, IMMT, India.] We can expect further discoveries of biochar benefits when more attention is given to pyrolysis of biomass.

C. Biochar in industry

1. Some construction and highway materials can incorporate biochar to replace some fossil fuel ingredients.

2. Biochar has usage and therefore commercial value as a filter of water. Depending on what the contaminates are, the used charcoal can normally be put into fields as normal biochar.

Section XXII. The financial value of CDR

A. Supply and Demand for CDR credits

An insightful November 2020 article by Carbon180.org states: "Ultimately, we didn't believe the carbon removal credits [on the voluntary markets because there is no allowed official UNFCCC certification] that we could find and afford [for $100 or less per 1t CO_2e] on the market today represent the high-quality carbon removal we see as imperative for meeting climate goals." https://carbon180.medium.com/in-search-of-carbon-removal-offsets-42abf71b3ccc The nature-based removals of AR tree growing and SCS soil building fail regarding long-term sequestration. The tech-based (sorption) removals are rare and with actual costs of hundreds of dollars per tonne. And without financial incentives, current biochar placement into soils is for agricultural efforts that do not deposit sufficient tonnage of biochar to attempt the complex, costly processes (including monitoring) to seek carbon credit. This should be purposefully changed. Currently, there are rigorous and affordable CO_2 removal units available, not for a gigaton, megaton, kiloton, or single tonne.

B. Relative value of removals compared to reductions

Based on Section XXII.A. above and referring back to Section XII about BC&E cookstoves, should the $100 per tonne CO_2e value be applied to the approximate 300 kg of biochar (= 1t CO_2e) from each Indian household in West Bengal using a TLUD BC&E cookstove IF it were to be sequestered as biochar with rigorous documentation? This very tangible and highly documented char that is currently destined to be burned in incense sticks and forges, is being credited as *two* tonnes of Gold Standard certified emission reductions (CERs) as replacement of traditionally made charcoal. Stated differently, one tonne CO_2e *removal* equals two tonnes of certified CO_2e *reductions* that are marketed at about $5 to $30 each. That is, 1 t CO_2e removal credit could be priced at $60 or higher! AND the char is still available for sale into documented biochar sequestration sites for soil enhancement. This is an example of the multiple values of pyrolysis shown in Figure 10. The family cooked their food with the heat from combustible emissions, created char for the biochar activities, made possible the financial transactions for carbon credits for climate protection, and possibly used biomass fuel from invasive species or crop residues that needed to be cleared and disposed.

C. The addition of each tonne of CO_2 into the atmosphere will cause harm for its lifetime of 5 to 200 years (IPCC #1 https://archive.ipcc.ch/ipccreports/tar/wg1/016.htm). In contrast, the removal of each tonne of CO_2 can help mitigate climate change impacts for many hundreds of years. T**he climate change costs vs. benefits of each tonne of carbon dioxide removed should be weighted,** with long-duration removal being valued appropriately higher than a one-tonne reduction of emissions for one year that might not be continued in later years or could even be reversed by fires or farmers returning to poor practices that hurt SCS.

Recognition and accounting for CO2 REMOVALS should be kept separate from that for CO2 REDUCTIONS.

Part Three:
Conclusions and Calls for Action

Section XXIII. Overview

A. This white paper opened with a statement about the climate problems. It then positioned BC&E as **the most viable *long-term* negative emission technology (NET)** when used in conjunction with the photosynthetic powers of forestry, crops, and land management. But the bulk of the document is about solutions, what has been done, what is being done, and what can be done.

During the next 10, 30 and 80 years, the NET known as biochar and energy (BC&E or BCE) is poised to grow to accomplish carbon dioxide removal (CDR) in the range of 5 to 10 Gt CO_2/yr. by using current technology and realistic scientific progress. BC&E is not a substitute for other carbon mitigation, nor a single NET solution for the climate crisis. But it could be "The Great Green Hope" that motivates us to take major, impactful steps now to address the climate crisis.

Biochar and Energy (BC&E) is not a silver bullet to solve the climate issues. But it is a bullet, a black bullet in our arsenal, and it is now loaded and ready to help fight climate change.

B. Why has this NET called BC&E been previously overlooked? Seven reasons are prominent:

1. Past lack of understanding or appreciation of the nature of elemental pyrolytic carbon in soils, especially its long-term permanence. Biochar has not been significant in soil science education and was even mis-classified by some specialists to be included in the NET of soil carbon sequestration (SCS) that lacks security for long term sequestration.
2. Biochar enthusiasts have looked at plant growth issues utilizing relatively few tonnes of biochar and did not give much attention to CDR for climate mitigation involving gigatons of biochar.
3. The still-continuing official ignoring (or lack of "allowance") of biochar-into-soils for any carbon credit recognition or financial stimulation. [The Article 6 discussions could rectify this.]
4. Combustion engineering has focused on maximizing the burning of all carbon in biomass. One result is that biomass energy production was seen as renewable but not as also being carbon negative.
5. All NETS have been overlooked because of the low prices of fossil fuels that keep people happy with cheap power while insidiously causing climate warming. The privileged position of fossil fuels, including subsidies and no emission taxes, must end if BC&E or any CDR technology is to have a chance to help restore our climate.
6. Biochar production has lacked profitability. Its volume has been either a) in labor-intensive and quite small units (e.g. barrels) or b) in rather expensive, multi-objective special devices (that are prime for getting large grants and investors), or c) in the waste streams from large furnaces.

7. Only in 2020 did the RoCC kiln innovation fit into the gap for medium size units with comparatively low prices. Although promising but unproven (pending further development), RoCC kilns certainly have potential for fundamental changes to improve pyrolysis at reasonable costs.

C. BC&E as a carbon dioxide removal (CDR) technology is a reality, and it can involve global participation, particularly if there is the political will to do so. If properly sponsored and implemented, BC&E can be an opportunity for multiple benefits, including for climate, soil restoration, water retention, food production, cleaner air, renewable energy, reduction of poverty, and (we hope) greater cultural stability and world peace.

Section XXIV. Summary of proposed CDR efforts (and emission reductions) based on BC&E:

A. CDR projections. Carbon dioxide removal can be physically measured and expressed in tonnes of inert carbon called biochar. There is no baseline. There is only the actual tonnage. Table 1 summarizes the previously discussed plans for action and CDR impacts.

Table 1:

Projections for CDR via BC&E (Version 2020-11-30) **Units = Gt of CO_2 removal (CDR) per year**

Application	**2030**	**2050**	**2100**	**Cumulative during 70 years**	Notes:
Cookstoves (TLUD)	0.1 – 0.2	0.5 – 1.0	1.0 – 1.5	60 – 80	1. All numbers are "best estimates" and are subject to increases or decreases of 50%.
Crop residue	0.2 – 0.5	1.0 – 2.0	1.0 – 2.0	60 - 100	2. Abbreviations: ALIA = Areas of Labor-Intensive Agriculture
Subtotal ALIA	*0.3 – 0.7*	*1.5 – 3.0*	*2.0 – 3.5*	*120 - 180*	3. In 2020, all the BC&E amounts were virtually zero.
Forest safety	0.1 – 0.2	0.5 – 1.0	1.0 – 1.0	40 – 80	4. No double counting. Example: do not count as crop residues or urban tree waste what is collected and counted for cookstove fuel or other heating.
Urban tree waste	0.1 – 0.1	0.2 – 0.8	0.5 – 1.0	30 – 50	
Subtotal	0.2 – 0.3	0.7 – 1.8	1.5 – 2.0	70 -130	
Elect. power gen.	0.1 – 0.1	0.2 – 0.3	0.5 – 1.0	30 - 40	
Home heating	0.1 – 0.1	0.2 – 0.4	1.0 – 1.5	50 - 70	
Process heat	0.1 – 0.2	0.2 – o.4	0.6 – 1.2	50 - 70	
Subtotal	0.3 – 0.4	0.6 – 1.1	2.1 – 3.7	130 - 180	
TOTAL	**0.8 – 1.4**	**2.8 – 5.9**	**5.6 – 9.2**	**320 - 490**	

Observations:

Over one-third of the CDR in Table 1 can be accomplished in "areas of labor-intensive agriculture" (ALIA) that include the least developed countries (LDCs) and the less affluent rural segments in India, China, and other emerging societies.

Another third relates to disposal of excessive biomass by affluent societies, possibly to be redirected to applications for heating or power generation.

In Table 1 the final third of true CO_2 removal relates to transitions of affluent societies from fossil fuels to renewable dry biomass. This segment could grow even further if and when biomass fuel supply is enhanced. The transitions and enhancements create employment and societal wellbeing and should be stimulated in these urgent decades as much or more as has been given for nearly 200 years to fostering the fossil fuel industries.

There is a *close* relationship between biochar production and the availability of appropriate biomass. Developments in the realms of forestry, agriculture, waste management and non-traditional biomass such as seaweed and invasive species could provide substantial increases to the potential for pyrolytic CDR.

These removal benefits plus the possible reduction / mitigation value of thermal energy from pyrolysis have prospects to more than pay for the price of biochar production, resulting in potential profits while accomplishing carbon dioxide removal (CDR) and emission reduction (ER).

B. Emission reductions (ER). In sharp contrast to the direct physical measurements for CDR, ER is dependent on the determination of reductions in sequential one-year periods compared to different baselines for each of diverse scenarios about energy usage which can and should change as each scenario develops. Therefore, the projections for ER are much vaguer and more subject to interpretation.

An attempt to create a table for ER associated with BC&E resulted in statements regarding each of the seven line-items about biochar CDR activities. See Table 2.

Table 2

Estimates of emission reduction (ER) associated with BC&E (Ver. 2020-11-30)

1. Cookstoves (TLUD)	Up to 1 Gt/yr. CO2 ER because of reduced biomass use equal to 2 CC per stove. Minimal reduction of fossil fuel usage.
2. Crop residue	Maybe some ER for less emissions into atmosphere
3. Forest safety	Unlikely any ER credits. (Not counted here if wood is taken for other use.)
4. Urban tree waste	Unlikely any ER credits. (Not counted here if wood is taken for other use.)
Subtotal	Basically no significant impact for reduction of fossil fuel use.
5. Elect. Power gen.	Meaningful reduction of fossil fuel per 1000 MW power produced. (= ~1 – 3 Gt CO2/yr.)
6. Home heating	Meaningful reduction of fossil fuel per 1000 MW thermal produced. (= ~3 – 5 Gt CO2/yr.)
7. Process heat	Meaningful reduction of fossil fuel per 1000 MW thermal produced. (= ~3 – 5 Gt CO2/yr.)
Subtotal	Substantial (perhaps 10 Gt (25%) reduction of annual consumption of fossil fuel

Section XXV. Issues

A. The affluent and the impoverished. Approximately half of the estimated CDR via BC&E in this current decade is in the least developed and developing countries, simultaneously helping meet several of the Sustainable Development Goals (SDGs) while also combating climate change**. It should be done immediately, but not as a substitute for what the affluent societies (including the wealthy people in the developing countries) should do *__immediately__* for BOTH removal and reduction.** There are two insidious dangers of successful CO_2 removal with pyrolytic biochar:

1. The **"moral hazard"** of thinking that some removals now would allow us to not do the urgent transition to Net Zero emissions by 2050, or preferably much sooner. Removal of 5 Gt CO_2e is only 12% of our current emissions. **Reductions are essential!!!**

2. The immorality of **"climate colonialism"** if the affluent would shift the work or responsibility for climate solutions onto the developing nations. [Ref: https://www.canberratimes.com.au/story/6992851/net-zero-emissions-by-2050-leadership-or-climate-colonialism/ Nov 2, 2020, by Ian Dunlop and David Spratt.]

B. Who gets to count the CDR recognition toward their climate goals? Without any double or triple counting, does the carbon accounting go to the person, to the country where done, to the country of "buyer" or to the project sponsor? Does the actual money get to the poor when they are the true doers of carbon removal? Is there equity and fairness? What are the responsibilities that come with different capabilities, capacities, and history of unintentionally causing the climate crisis but now intentionally not working hard and fast enough to correct the climate problem?

C. Reductions. Because of the release of thermal energy, BC&E provides a clear way to have reduction of CO_2 emissions from fossil fuels. In terms of simple accounting of CO_2e units, the contribution of BC&E for emission reduction could equate or eclipse the CO_2e units for permanent removal. That is favorable because there can be major profits in providing thermal energy, and the benefits of CDR could then come more easily.

D. Impact on lifestyles

1. In relative terms, the actions for removal of invisible CO_2 gas via BC&E do not impinge much on our lifestyles and should be done almost solely to fight the climate crisis (which happens to threaten our existence, but slowly, like cancer).

2. On the other hand, the actions for CO_2 reduction very much relate to rather drastic lifestyle changes that should be done for climate purposes but should also be done for so many other valid reasons for improving our lives, such as better health with better diet, cleaner air, fairness and equity of access to resources (such as mass transit), and financial power less concentrated in the hands of fossil fuel entities.

E. Limitations and deficiencies of this white paper

1. This is the work of one person who is clearly biased in favor of BC&E. *Correct. There is no requirement for anyone to accept what is written here, but if this white paper helps solve the climate crisis, these things needed to be presented with urgency regardless of some uncertainties.*

2. The author has potential for personal gains through his possible business ventures. *True. He arrived at this position because of nearly two decades of in-depth involvement with pyrolysis and BC&E issues at the level of inexpensive clean-burning TLUD cookstoves that happened to make charcoal/biochar. That experience shifted to seeing the need for but general weakness of biochar (the material, not the BC&E process) to attain commercial success. Involvement led to insights that led to innovations that led to possible biochar-production solutions at the same time that the world is awakening to the threat of climate disaster and that led to this white paper. Prospects of BC&E being economically viable can benefit many other people as BC&E stimulates the worldwide transitions to Net Zero carbon economics at national, community, corporate and family levels. This prospect of profit could appeal to readers who advocate innovation and free enterprise, even as society is threatened by the climate crisis. There will be many winners in the multi-trillion-dollar transition. That transition must be successful or else the loses will be "existential", as in threatening the existence of acceptable life on Earth. The stakes are super high.*

3. The white paper could have had additional authors. *Yes, but joint authorship would have greatly delayed the release of the document. Future versions of this document or other publication can and should have additional authors, especially in the sections of their expertise. An improved version could come in 2021 with corrections, adjustment and perhaps confirmations of statements in this First Edition.*

4. It is not peer reviewed. *Correct. White papers are not academic articles. And peer review of something this large would have been very time consuming and limiting on the passion of the message. Peer reviews can be included in future editions / versions.*

5. Some of the statements are overly strong. *Perhaps, or perhaps the reader does not yet fully realize the urgency of the climate crisis. This document was not written to be offensive to the alternative positions, but there are serious problems to be confronted directly.*

6. It overlooks the other negative emissions technologies (**NETs).** *Incorrect. Each of the other NETs for CDR have been examined, and they are still to be considered. But millions / billions of dollars for futuristic prospects should not suck up the funds needed for practical implementation of BC&E that is viable now.*

7. The projections of gigatons of CO_2e removal are too optimistically speculative. *Really? Have you looked at the IAM projections about BECCS for the IPCC report? This BC&E white paper could underestimate the CDR potential of photosynthesis for removal and biochar for sequestration. If we do not have a sufficiently large and still reasonable goal, why bother with the small stuff? We really do not have much time.*

F. Reduction can never accomplish removal.

G. Removal is not a substitute for reduction.

H. Removal is not insurance against failure to reduce emissions.

I. Both removal and reduction should have separate accounting and separate incentives.

Section XXVI. Calls to action

A. If this white paper does not prompt serious action within months, there is something wrong either with this document and/or with the moral character of our societies. When BC&E was not being sufficiently recognized for CDR (Section XXIII.B above), there could be arguable excuses for lack of enthusiasm for any NETs because the other NETs are much less developed, more futuristic or with only short-term sequestration. But now, the cat is out of the bag. **BC&E is a serious contender for gigatons of carbon dioxide *removal*. And it offers what no other NET can provide, a simultaneous significant contribution toward CO_2 *reduction* that is frosting on the cake of CO_2 *removal.***

B. Call to action A: Would you like to do something to help save our climate? One call to action is for you to be involved and stay involved. How? One way is to simply spread the word about Biochar and Energy (BC&E). Tell you friends. Discuss this white paper with them. Try to get this white paper and its message to the "movers and shakers" of your community. Do you know people of influence, or people with money for action? Make sure that they are aware of BC&E and the climate crisis. Do you know somebody who knows somebody who knows people with capabilities for action or influence? Reach them. And vote for candidates who actively support the climate efforts.

C. Call for action B: Be informed. Stay informed. Read more and attend more events about the climate. Promote education about climate solutions in local schools. Volunteer to help. Promote BC&E efforts in your community. Be part of the solution, not part of the problem. Make some biochar. Get your hands dirty. Seek to have your home heated with BC&E technology. Use biochar in your garden.

D. One of the remaining big questions regarding CDR is “From where will come the needed money,” even if only as a loan without collateral (except to receive recognition about helping to save our planet). Will the wealthy people and societies continue to be slow to act? At this time of getting started with serious BC&E, the success is basically about money to make and use pyrolytic devices. The gasifier cookstoves should be a “no brainer” decision for action now. To get started, we, the people, are not really being asked for sacrifices in lifestyles by ourselves or our next generations. Those sacrifices will need to be made someday, but right now it is really about money to get started; it is money from those who have plenty, including the middle class in affluent societies, most of us who are reading this white paper. It is about the political will of leaders and the people to take needed actions and allocate the funding, and that means the support of the people for allocation of tax money to fight the climate crisis.

E. The Preamble included a quote from Jeff Bezos about **doing realistic, plausible actions in “…the here and now – short term - at the intersection of urgent need and lasting impact.** (JB, 2017).” BC&E capabilities are poised a that intersection. Bezos, Gates, Buffett, and other billionaires are invited to be leaders. Help get this message to them. And to the political leaders who are seeking ways to make good things happen.

But it is not just about them. Nor just about the millionaires and people with decision-making authority, both political and commercial. It is about us, all of us, the people with homes, education, food, security, and jobs that give us discretionary income for entertainment, travel, and other niceties. **We need to be supportive of government efforts to use some of our collective vast wealth (and tax money) to take serious action for both removal and reduction of greenhouse gases.** We might want to have more comfort for ourselves, but we could live with less if necessary, and those days are certainly coming.

If we, the affluent 20% of this world, will not do promptly the easy stuff that is before us, what will happen when the “heavy lifting” is required for fully confronting climate change? That remains for a further discussion.

“If we cannot promptly implement these comparatively easy, benefit-rich Biochar and Energy (BC&E) initiatives, we will lose the battle to save our planet.”

Paul S. Anderson, PhD, Woodgas Pyrolytics, 7 December 2020 (psanders@ilstu.edu)

Please spread the word and support BC&E for biochar and energy to remove carbon dioxide from the atmosphere and reduce new emissions to Net Zero.

Respectfully submitted,
Paul S. Anderson, PhD, 7 December 2020 Email: psanders@ilstu.edu

Biosketch of Paul S. Anderson, PhD.

Paul Anderson has a broad liberal arts education. (Augustana College, BA in biology; University of California Berkeley, MA in Geography; Australian National University, PhD in Demography (migration studies); and technical training in Remote Sensing).

He is a retired university professor of geography, having had positions in Australia, Brazil, USA, and Mozambique. (Fulbright professor twice, to Brazil and to Mozambique).

He has specialized in pyrolysis since 2001, with the following activities that relate to this white paper, with full disclosures:

1. An international leader for TLUD ("tee-lud") micro-gasifier cook-stoves (Protégé of Dr. Thomas B. Reed). Consultant to many, mainly as a volunteer.
    a. Conceptual designer of the Champion TLUD-ND. (modest royalty receipts for some units.)
    b. Advisor for the FabStove TLUD-FA. (Minority partner in FabStoves International)
    c. Designer of Mwoto, Quad, Troika and Bingwa TLUD-ND stoves for various projects in Africa.
2. Co-founder and former partner in Awamu Energy Ltd, Uganda. (minimal operations now)
3. Co-author of "All Biochars Are Not Created Equal…." (2009) with McLaughlin, Shields, and Reed.
4. Participant in all and co-leader of about half of over twenty week-long hands-on workshops called Stove Camps and CHAB (Combined Heat and Biochar) Camps in USA, Australia, Honduras, and Kenya.
5. Active in organizations with cookstoves and biochar foci, including co-founder of the Illinois Biochar Group.
6. Co-founder with Paul Wever and minority partner in Chip Energy, Inc., developers of
    a. Chip Energy Biomass Furnace
    b. Chip Energy Biomass Grill
    c. Chip Energy Biomass Conversion Facility
7. Founder and executive director of Juntos Energy Solutions NFP, a USA-registered nonprofit focused on gasifier cookstoves and biochar.
8. Originator (with James S. Schoner of Bitmaxim Laboratories) of CharTrac carbon accounting system with blockchain verification of data records.
9. Collaborator with Gary Gilmore for the Char-to-Power (C2P) charcoal gasifier for engine power.
10. Inventor of RoCC kiln technology, with patent (pending) with collaboration by Gary Gilmore.
11. Founder and owner of Woodgas Pyrolytics, Inc. (Willing to work with others around the world.)
12. As a concerned citizen, he has additional dimensions that do not relate to biochar, cookstoves and climate. Some exposures to his socio-economic and political feelings are in two books he published in 2018. They are free as digital (.pdf) books at his other website: www.capitalism21.org. *Nehemiah Papers* contains 14 topical essays. More enjoyable but equally pointed is the novella *A Capitalist Carol* that has a subtheme of cookstoves and climate and brings in themes from the *Nehemiah Papers*.
13. With experience in developing countries and as a grandfather of three who could live to 2100, he is uncomfortable about the prospects of decline, harm, and true tragedy for them and the coming generations.

Limitations and Conflicts of Interest:

Dr. Anderson is not an engineer and acknowledges the need for engineers and other specialists to provide corrections, expansions, etc. for the improvement of the December 2020 “First Edition” of this white paper. All are welcomed to contribute and participate.

After nearly two decades of essentially unpaid full-time efforts and considerable personal expenditures, Dr. Anderson is finally seeing possible financial and intangible benefits from his work with many aspects of what is presented in this white paper. He is therefore to be considered as a biased source. His priorities are to accomplish meaningful beneficial impacts for the planet, impoverished people, cooperating entities, and all others, and to succeed in business, in that order.

Appreciations (Including Peer Reviewers and Contributors)

Although there are no official, blind peer reviewers, several peers have provided valuable and much appreciated comments during the preparation of the first draft (Dec. 2020). They are not responsible for any errors or omissions in this white paper.

Selected References:

This white paper has some broad strokes and statements that can be verified with simple internet searches on referenced terms. Some specific references are imbedded in the document. Some further references are:

Carnegie Climate Governance Initiative – C2G (2019)
www.c2g2.net/project/infographic-governing-carbon-dioxide-removal

European Academies Science Advisory Council (2018). Negative emission technologies: What role in meeting Paris Agreement targets?
www.easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_Report_on_Negative_Emission_Technologies.pdf

European Biochar Certificate (EBC) (201?). The C-Sink Potential of Biochar https://www.european-biochar.org/en/c-sink

European Biochar Institute (EBI) 2020. TITLE www.biochar-industry.com/wp-content/uploads/2020/10/Whitepaper_Biochar2020.pdf

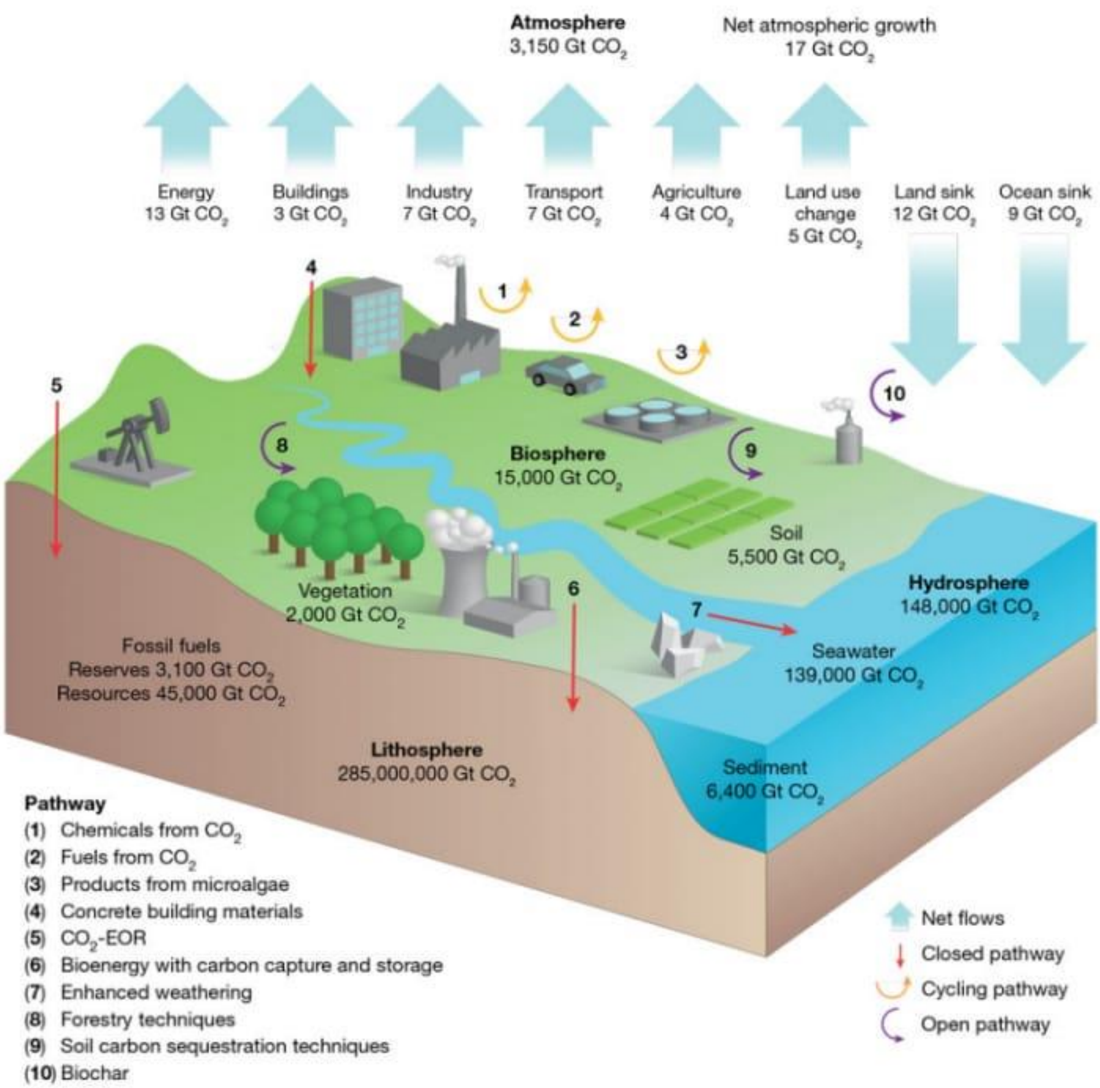
IPCC (2018). Special Report Global Warming of 1.5 ºC. https://www.ipcc.ch/sr15/

New Climate Institute (2020, Fig. 2, p.3). Options for supporting Carbon Dioxide Removal: Discussion paper https://newclimate.org/wp-content/uploads/2020/07/Options-for-supporting-Carbon-Dioxide-Removal_July_2020.pdf

U.S. National Academies Press (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. www.nap.edu/25259

World Bioenergy Association (2016). Global Biomass Potential Towards 2035. https://worldbioenergy.org/uploads/Factsheet_Biomass%20potential.pdf . Some of the WBA numbers come from Svetlana Ladanai, Johan Vinterbäck (2009). Global Potential of Sustainable Biomass for Energy https://worldbioenergy.org/uploads/WBA_Global%20Potential.pdf

Figure 18 (extra): Below is one of several useful representations of carbon in our world. Biochar is included as #10 of the listed Pathways. BC&E should add some Gigatons to the Land sink arrow and help reduce via ER some of the Net atmospheric growth of CO_2.



....