REPORT ON FORUMS ON SOIL AMENDMENTS

Project Save the World/Canadian Pugwash Group considered several ways to enhance the capacity of the world's soils to increase the capture and retention of atmospheric carbon dioxide (CO_2). These were:

- Soil remineralization (which provides Enhanced Rock Weathering, ERW)
- Biochar
- Seaweed fertilizer
- All or some of the above approaches used in combination[1]

Soil Remineralization

The growth of plants, including major agricultural crops, is often limited by availability of one or more soil nutrients. Synthetic inorganic fertilizers applied to agricultural soils typically supply nitrogen (N), phosphorus (P), and potassium (K) in various ratios, as these nutrients are used rapidly in intensive crop production. Soil *remineralization* using rock dust has been practised in Europe since the 1960s to increase fertility of agricultural soils and improve the nutritional value of harvested crops, with several other benefits, and some concerns.[2] Possibly in combination with additions of organic matter, and other amendments like biochar, remineralization can restore or enhance the concentrations of P and K along with several essential trace elements in soils in which natural levels of these nutrients have become depleted over decades to centuries of repeated cultivation and cropping.

Rock dust is also subject to enhanced rock weathering (ERW).[3] Natural rock weathering is a geological process by which weakly acidic rainfall (containing dissolved carbon dioxide, CO2) is deposited on rock surfaces causing them to slowly disintegrate over millions of years. The acid solution of silicate and carbonates in rock (notably of basaltic and volcanic origin), produces soluble carbonates which are transported via streams and rivers to global oceans—where some of the carbon is ultimately sequestered for millennia. Pulverizing rocks into dust greatly increases their surface area, accelerating the reaction with acidic rainwater and snowmelt—and providing a greatly increased capacity to sequester atmospheric CO2. Baek et al. (2023) estimate that **10 tonnes of mineral dust applied per hectare every year to agricultural soils globally would capture close to 3 gigatonne (Gt) of CO2 per year** potentially for many years.[4] If implemented on large scale by China, India, the USA and Brazil, Beerling et al. (2020) estimate ERW could remove 0.5 to 2.0 Gt CO2 per year at a cost of $US 80–180 per tonne of CO2.[5]

Relevance of Enhanced Rock Weathering to Canada

Canada produces about 2 Gt of industrial waste annually, including mine tailings[6 7], of which some might be used as rock dust for soil amendments in agriculture and even forestry[8]. Waste concrete material from demolition/construction is also a potential source of calcium silicate. Some mine tailings will contain toxic metals, notably mercury, nickel and chromium, but they might be usable on forest sites where toxicity would be less of a concern.

Canada has extensive areas of agricultural land and contributes significantly to global GHG-emissions. ERW could provide extra income for farmers through sale of carbon credits, although long-term economic benefits of soil remineralization seem clear even without subsidies. Many Canadian growers already use some pulverized rock products; some suppliers mix rock dust with synthetic N fertilizers[9]. In Canada's colder climate, wollastonite evidently performs better than basalt and is marketed as a low-cost alternative to lime[10].

Soil-testing (or vegetation bioassay) is crucial to determining nutrient deficiencies before treating with any soil amendment. Rock dust must be applied responsibly, with monitoring to quantify benefits and carbon costs. Suitable rocks can be located from geological maps, supported by local surveys. It has been suggested that transporting rock dust or mine tailings more than 100 kilometers negates their C benefits. However, future GHG emissions from transport and application could be reduced as electric vehicles replace gas- and diesel-powered transport.

Biochar

Biochar is the charred product of biomass heated without oxygen in a process termed *pyrolysis*[11]. Potential biochar feedstocks include crop residues, forest harvesting residues, municipal solid waste, sewage, and even seaweed. The end product is stabilized (highly recalcitrant[12] and non-reactive). As many as 60 different uses have been identified for biochar[13], ranging from soil amendments to water filtration, and as a component of low-carbon concrete and asphalt. Many of these overlap with the potential to contribute to CO_2 sequestration. This diversity of uses suggests an entire economy could develop around biochar; it has been estimated that **global use of biochar could remove as much as 3 Gt of atmospheric CO_2 annually**[14]. The quantities of other GHGs such as N_2O that could be removed are less well understood; potential impacts of biochar for methane removal could be positive or negative[15 16].

Schmidt et al. (2018) see pyrogenic carbon capture and storage (PyCCS) – the collective process by which production of biochar and other materials (notably bio-oil) and their utilization contribute to direct

CO_2 removal – as a major opportunity for global GHG mitigation[17]. Pyrolization produces combustible gases that can be captured for heating or power generation. CO_2 emissions resulting from combustion of pyrolized material can be considered C-neutral[18]. Wood waste pyrolized at the correct temperature will generally create a superior biochar product[19].

In Canada, millions of tonnes of dead forest biomass – from logging activities, and increasingly from natural disturbances (fires, insect attacks, storm damage), are left to rot every year. This material could be an important biochar feedstock for much of Canada's western boreal forest where large wildfires are increasingly frequent. While decomposition is important for releasing nutrients to maintain site productivity, large accumulations of dead tree material create a major hazard as fuel for wildfires.

A Québec company, Suez, aims to use sawmill residues to produce 350,000 t of biochar per year by 2035, claiming this will lead to annual sequestration of 800,000 t CO_2[20]. The US Forest Service is investigating on-site pyrolysis of dead and decaying timber left after pine beetle infestations in Colorado to create biochar, which can then be returned to the forest floor to restore site productivity[21] [22]. Zimmerman *et al*. (2011) found positive and negative effects of biochar "priming" of forest soils, but generally long-term C benefits[23]. Pyrolysis on-site could become part of required forestry practices to reduce fuel build-up on sites that have been harvested or salvage-logged. Tools for on-site biochar production include the Tiger Cat 6050[24], and the KonTiki, a portable, cone-style kiln that can be used for yard or farm wastes and small dimension woody residues[25].

A common concern is that biochar made from some potential feedstocks will be contaminated by heavy metals, or various organic compounds, including polycyclic aromatic hydrocarbons (PAH) and dioxins[26] [27]. These have the potential to affect soil biota, poison wildlife, and cause possible human health hazards through food contamination. Concerns about plastic contamination of biochar feedstock may be overstated[28], however, and other research suggests there is considerable potential in using biochar to filter out microplastics[29].

Research in Tennessee has found that biochar can be a superior binder for roadway asphalt[30] which increases its flexibility and durability, particularly in cold climates; testing the benefits of "BioAsphalt", including GHG removal, is in progress in Alabama[31]. Stockholm has pioneered use of biochar from multiple sources to create "structured soils" – mixtures of gravel and other materials including biochar to create beds along sidewalks and medians for urban trees. Some have been very successful, with trees growing very rapidly compared to conventional plantings[32].

Seaweed fertilizer

Seaweed has been harvested for centuries as food for humans and livestock, and as a soil amendment and fertilizer[33]. Industrial cultivation has increased rapidly over the last few decades, mainly in east Asia[34], with global yearly production of 35 Mt in 2020 according to FAO[35]. Seaweeds can be processed into liquid bio-stimulants to increase crop yields and reduce the need for synthetic N fertilizers. This approach reduces nitrate runoff and N_2O emissions; seaweed cultivation is sometimes claimed to be a negative GHG emitter (i.e., net CO_2 removal) but a comprehensive review suggests otherwise[36].

Conceivably, seaweed could be harvested or farmed to produce biochar feedstock[37]. Biochar made from seaweed could be beneficial, particularly if used in combination with other soil inputs (see "integrated approaches" below). In many coastal regions the environmental impacts of converting seaweed would be small. In some cases, blooms of invasive species such as *Sargassum muticum* in the western Atlantic, driven in part by a warming climate, can pose a significant threat to human health[38]. Conversion of *S muticum* (and other invasive plants) to biochar could offset control costs while benefitting ecosystems (and even public health).

Integrated Soil Amendment Approaches

Schmidt et al. (2018) estimate global potential removals of ~6 Gt CO_2 per year from PyCCS (i.e., biochar and other pyrolysis products, and increases in crop and forest productivity due to their use)[16]. Baek et al. (2023) estimate ERW could provide up to 3 Gt CO_2 removal per year on agricultural soils alone[4] (application in reforestation sites might bring additional C benefits.) **The total removals of ~9 Gt CO_2 per year would be about 25% of current global CO_2 emissions[39].** (As noted, the potential CO_2 sequestration benefits from seaweed are likely to be minimal at best.) There may be opportunities to integrate these different technologies to achieve greater benefits for crop production, while increasing CO_2 sequestration.

Vanacore (2022) suggests a "whole systems approach" to integrate ERW and biochar into regenerative agriculture to reduce dependence on synthetic fertilizers[9]. When mixed with rock minerals, biochar greatly expands the surface area for moisture and nutrient retention; this causes nutrients to be released more slowly through weathering. Combining rock dust with biochar and compost evidently stimulates soil microbial communities; adding biochar to soil media increases mycorrhizal activity in crop plants[40]. Lambert (2022) advocates "nature-based" climate solutions including holistic grazing management, no-till agriculture with cover crops, and agroforestry all making use of composting and biochar[41].

At present, global and regional supplies of biochar are limited, whereas supplies of rock dust are plentiful. Other than basalt, several types of alkaline silicates and placers are widely available, including stockpiles of previously pulverized materials that can be repurposed. In the future, electricity generated from renewable sources could be used to pulverize local rocks, before combining with biochar. Vanacore thinks production of biochar will expand rapidly to meet the demand for "bio-mineral" fertilizers. (This could be an economic opportunity for Canadian biochar in the North American marketplace.)

Specific research questions

Existing Federal government laboratories have capacity to assess mine tailings, biochar and other potential soil amendments for effectiveness, toxicity, etc. Contracts can also be negotiated with university soil science departments. Possible research areas include:

- National surveys of rock dust resources, including mine tailings and demolition/construction concrete waste, with assessments of chemistry (including potential soil contaminants such as heavy metals), carbon capture potential, and transport distances to potential end-users.
- Literature review and/or original research to determine whether soil remineralization can stimulate N-fixing bacteria and fungi, to reduce the need for repeated synthetic N fertilizer applications.
- Assessments of potential biochar feedstocks available in Canada (waste wood, crop residues, sewage sludge, seaweed, etc.) to assess contamination with heavy metals and other environmental and public health hazards.
- Research into use of on-site pyrolysis systems to create biochar from wood waste on logged areas and burn sites, and to determine its effects on site nutrient cycling.
- Literature review and/or original research on contamination of biochar feedstock with plastics and potential use of biochar as a filter for microplastics.

RECOMMENDATIONS

The Government of Canada, which already maintains agencies and research laboratories to support agriculture, forestry and mining, should develop a program to expand testing, and develop product specifications for technologies to increase yields obtained from sustainable agriculture, including organic and regenerative farming and permaculture, while aiming to maximize CO_2 sequestration in soils and other growth media.

Potential technologies include:

- Use of rock dust obtained as by-products from mining and quarries, and pulverized waste concrete from demolition and construction projects, to be used for soil remineralization.
- Use of biochar created from agricultural crop residues, forest harvesting and wildfire residues, food waste, sewage, etc.
- Increased commercial harvesting or cultivation of coastal seaweed species, both as an organic soil fertilizer and as a biochar feedstock, subject to rigorous environmental impact assessment.

Programs of support could include:

- Promoting Federal and/or Provincial/Territorial specifications, standards, and regulations for large-scale sustainable production of biochar and rock dust, and their use in agriculture and forestry Canada-wide
- Providing development grants/loans for industrial start-ups.
- Incentivizing farmers through subsidies and technical transfer. A voluntary or government-regulated carbon market could offset the costs and finance CO_2 removal schemes.
- Creation and support of professional associations and academic outreach programs.
- Support and collaboration to international agencies to develop these technologies at global scale.

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[1] Nature based solutions (NBS) were also included in the original report of panel discussions on soil amendments. We have chosen to omit NBS from this summary, however, because it is a much larger topic that already receives much attention as a climate mitigation approach. While we fully support use of NBS, soil amendments are fundamentally human technology and are arguably not "nature-based", though their effectiveness typically depends on natural processes; soil amendments may be important components of NBS techniques.

[2] Other expected benefits of rock dust application to soils include reduced problems of pollution and eutrophication; basaltic rocks are also useful as an economical alternative to lime on acidic soils (See: https://content.ces.ncsu.edu/lime-equivalence-of-fine-ground-basalt-rock). A new review cautions that applications of basaltic rock dust can bring toxic levels of copper and nickel, and sodification (excessive sodium concentration). Increased fertility stimulates earthworm activity—and higher soil respiration rates—increasing CO_2 emissions (See: https://www.sciencedirect.com/science/article/pii/S0048969724064532). Rock dust does not provide essential nitrogen (N) compounds. It is possible that improved soil conditions due to remineralization will stimulate N-fixing bacteria and fungi. In Brazil, over 5 million hectares of soil have been remineralized, reportedly to grow soybeans as a strategy to reduce Brazil's dependence on ammonium fertilizer imported from Russia. (Soybeans harbour *Rhizobia* N-fixing bacteria. See: https://www.topcropmanager.com/nitrogen-fixation-trends-in-soybean/) If this effort proves successful, larger areas of degraded land in the Amazon basin might be restored with remineralisation (See: https://www.remineralize.org/2022/04/rock-dust-to-the-rescue-for-brazil-during-europes-geopolitical-crisis/ and https://www.researchgate.net/publication/227262700).

[3] https://www.remineralize.org/2023/01/crash-course-on-enhanced-rock-weathering-for-carbon-removal/

[4] https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023EF003698 Baek et al. 2023. *Impact of Climate on the Global Capacity for Enhanced Rock Weathering on Croplands*. Key points: Enhanced rock weathering (ERW) with fixed annual application rates of 10 tons of basalt dust per hectare on 1,000 global cropland sites sequesters 64 gigatons of CO_2 over 2006–2080; Extrapolated to all croplands, ERW with a fixed application rate of 10 tons of basalt dust per hectare sequesters 215 gigatons of CO_2 over 2006–2080. ERW is resilient to global climate change but is much more efficient over hot and humid environments.

[5] https://www.nature.com/articles/s41586-020-2448-9 Beerling et al. 2020. *Potential for large-scale CO_2 removal via enhanced rock weathering with croplands.* Paper is behind paywall but author's PDF is available at https://eprints.soton.ac.uk/442331/1/Beerling_et_al_2020_Author_final_copy.pdf From the abstract: "Enhanced silicate rock weathering (ERW) deployable via croplands is a prime candidate to be evaluated for atmospheric CDR…. ERW has potential co-benefits for improved food and soil security and reduced ocean acidification. We use an integrated performance modelling approach for an initial techno-economic assessment for 2050, quantifying how CDR potential and costs vary among nations in relation to business-as-usual energy policies and policies consistent with limiting future warming to 2 °C. China, India, the United States and Brazil have large potential to help achieve average global CDR targets of 0.5 to 2 Gt CO_2 yr^{-1} with extraction costs of ~$80-180 t^{-1} CO_2. These targets and costs are robust regardless of future energy policies…. We discuss challenges and opportunities of ERW deployment, including the potential for excess industrial silicate materials (basalt mine overburden, concrete, and iron and steel slag) to obviate the need for new mining, as well as uncertainties in soil weathering rates and land-ocean transfer of weathered products." Includes links to data and code.

[6] https://publications.gc.ca/collections/collection_2019/rncan-nrcan/m38-13/M38-13-79-22-eng.pdf This report produced by Energy Mines and Resources Canada in 1978, reports 800 Mt of mining waste per year.

[7] https://mmsd.nrcan-rncan.gc.ca/prod-prod/ann-ann-eng.aspx Data on Canadian mine production are available here, and updated annually; however data on mine *waste* production are harder to verify.

[8] https://www.remineralize.org/2007/12/information-for-the-application-of-silicate-rock-dust-for-the-amelioration-of-forest-soils/

[9] https://www.remineralize.org/2022/07/moving-beyond-academia-rock-dust-local-founder-promotes-remineralization-research/ **Thomas Vanacore** writes: "…there is enough good science to recommend a whole-systems approach to climate mitigation which includes Enhanced Rock Weathering, Biochar and Regenerative land management as a viable strategy for adaptation and mitigation of the effects of climatic instability." See https://globalcarbonreward.org/ **Ryan Brophy** writes: "[Soil remineralization using rock dust] … will play a large role in our production processes as we onshore our compound fertilizer manufacturing from Europe to Canada. Sustainably-derived basalts and high quality humic substances will be embedded in all of our granular products beginning fall 2024. See https://www.globenewswire.com/news-release/2023/06/14/2688214/0/en/Canada-s-First-Compound-Fertilizer-Manufacturing-Facility-to-Supply-Domestic-Export-Markets.html …We will be commencing the largest yet broadacre deployment of metabasalt over 15,000 acres of Saskatchewan farmland this fall [2023?]. Over 2 seasons, the product will be mixed with low pH phosphate rock and elemental sulphur (oil-sand byproduct) to …increase reactivity in alkaline prairie soils, …[and] to boost the agronomic value of the application process for the participant's soils and on farm ROI. The project will be closely monitored by …[experts]… with modelling, long-term LCA and project support via Mangrove" See https://www.mangrove.systems/#Our-Platform-Section

[10] https://canadianwollastonite.com/applications/soil-amendment/carboncaptureproject-2/

[11] https://www.sciencedirect.com/science/article/abs/pii/S0961953410000991 Pratt & Moran 2010. *Evaluating the cost-effectiveness of global biochar mitigation potential.* A useful article, but complete text is behind a paywall.

[12] "recalcitrant" is a term often used in soil biochemistry to describe material that is "intrinsically resistant to decomposition". This is probably a simplistic explanation. See https://www.publish.csiro.au/en/pdf/EN10006

[13] https://biochar.co.uk/55-uses-of-biochar/ An update of an earlier paper by Schmidt and Wilson (2014) available at https://www.biochar-journal.org/en/ct/2

[14] https://link.springer.com/article/10.1007/s42773-023-00258-2 Lefebvre et al. 2023. *Biomass residue to carbon dioxide removal: quantifying the global impact of biochar*. From the abstract "…a generalized framework for quantifying the potential contribution biochar can make toward achieving national carbon emissions reduction goals, assuming use of only sustainably supplied biomass, i.e., residues from existing agricultural, livestock, forestry and wastewater treatment operations. Our results

illustrate … CDR potential of 6.23 ± 0.24% of total GHG emissions in the 155 countries covered based on 2020 data over a 100-year timeframe, and more than 10% of national emissions in 28 countries."

[15] https://www.nature.com/articles/s41598-019-53044-1 Huang et al. 2019. *Methane and Nitrous Oxide Flux after Biochar Application in Subtropical Acidic Paddy Soils under Tobacco-Rice Rotation*

[16] https://www.sciencedirect.com/science/article/abs/pii/S1385894720308330 Chen et al. 2020. *Biochar reduces nitrous oxide but increases methane emissions in batch wetland mesocosms.*

[17] https://onlinelibrary.wiley.com/doi/10.1111/gcbb.12553 Schmidt et al. 2018. *Pyrogenic carbon capture and storage*. PyCCS offers distinct opportunities for CO_2 sequestration above those attributable to biochar alone. Schmidt et al. estimate total potential removals of ~6 Gt CO_2 per year.

[18] The justification for claiming that CO_2 released from biochar products (and from firewood, or other "fresh" biomass) is carbon-neutral occurs because the CO_2 was fixed by living plants, typically within the previous few years, whereas burning fossil fuels releases CO_2 that was fixed by plants millions of years ago.

[19] https://www.mdpi.com/1996-1073/14/20/6529 Arous et al. 2021. *Effect of Pyrolysis Temperature and Wood Species on the Properties of Biochar Pellets* (This paper in *Energies* journal is from a Canadian research group. It does not address the value of biochar for CO_2 sequestration benefits, but would be a good start for investigation.)

[20] https://www.suez.com/en/news/canada-zero-carbon-future# Suez 2024. *In Canada, we're turning up the heat for a zero carbon future.*

[21] https://portal.nifa.usda.gov/web/crisprojectpages/1001665-sustainable-biofuel-feedstocks-from-beetle-kill-wood-bioenergy-alliance-network-of-the-rockies-banr.html Colorado State U Report 2020. *Sustainable Biofuel Feedstocks from Beetle-Kill Wood: Bioenergy Alliance Network of the Rockies (BANR)*

[22] https://storymaps.arcgis.com/stories/195bf70601c244f7bd2bf3ae0524069b McFarland et al. 2024. *Forest Biochar Potential for Gunison County*. This item explains (inadequately) how trees killed by mountain pine beetle are being used to create biochar which can then be applied to the forest floor to improve its condition.

[23] https://www.sciencedirect.com/science/article/abs/pii/S0038071711000769 Zimmerman et al. 2011. *Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils.*

[24] https://can-bv.ca/wp-content/uploads/2020/04/2020-03-23-Carbonator-1.pdf

[25] https://www.biochar-journal.org/itjo/media/doc/1437139451142.pdf Schmidt et al. 2014. *Kon-Tiki flame curtain pyrolysis for the democratization of biochar production*.

[26] https://www.tandfonline.com/doi/pdf/10.3846/16486897.2016.1254089 Hilber et al. 2017. *The different faces of biochar: contamination risk versus remediation tool.*

[27] https://www.sciencedirect.com/science/article/abs/pii/S1385894721038663 Han et al. 2022. *Contaminants in biochar and suggested mitigation measures – a review*.

[28] https://biochar-us.org/usbi-nabc24-californapyrolysisplasticcontamorgwastevhernandez See also PowerPoint presentation at https://biochar-us.org/sites/default/files/presentations/USBI-NABC24-Californa_PyrolysisPlasticContamOrgWastev_Hernandez.pdf Hernandez-Charpak et al. 2024. *Pyrolysis as a valorization strategy for plastic-contaminated organic waste streams*. This work suggests that pyrolyzed material contaminated with common plastic waste produces biochar that is as safe to use as that produced from non-plastic contaminated feedstock.

[29] https://www.frontiersin.org/journals/environmental-science/articles/10.3389/fenvs.2024.1388606/full Olubusoye et al. 2024 *Removal of microplastics from agricultural runoff using biochar: a column feasibility study*. Lab studies find that biochar removes about 90% of microplastics from runoff. "Overall, this proof-of-concept work suggests biochar may serve as a cost-effective approach to remove MPs from runoff, and that subsequent field studies are warranted."

[30] https://www.researchgate.net/publication/263736042 Zhao et al. 2014. *Laboratory Investigation of Bio-Char Modified Asphalt Mixtures*

[31] https://www.youtube.com/watch?v=erUE769v4zU Commercial video from Verde on their product *BioAsphalt* being developed and tested in Alabama.

[32] https://www.biochar-journal.org/en/ct/77 Embrén 2016 *Planting Urban Trees with Biochar* "To improve tree health and survivability … Stockholm has been testing and refining the use of structured soils and biochar for nearly 10 years. … structured soils consist of gravel mixed with smaller soil amendments such as peat, sand, clay, lava and more with great success: biochar. In some cases 6 year old trees planted in structured soils with biochar were five times larger than 30 year old trees planted using more traditional urban tree planting techniques."

[33] https://doraagri.com/seaweed-fertilizer-development-history-and-market/

[34] https://fppn.biomedcentral.com/articles/10.1186/s43014-022-00103-2 Zhang et al. 2022. *Global seaweed farming and processing in the past 20 years.*

[35] https://openknowledge.fao.org/server/api/core/bitstreams/a2090042-8cda-4f35-9881-16f6302ce757/content DORA 2022. *The State of World Fisheries and Aquaculture – Towards Blue Transformation.*

[36] https://www.sciencedirect.com/science/article/pii/S0048969724006624 Pessarrodona et al. 2024. *Carbon removal and climate change mitigation by seaweed farming: A state of knowledge review*. "A first-order estimate …suggests that, at present … any carbon removal capacity provided by seaweed farms globally is likely to be offset by their emissions (median global balance net emitter: -0.11 Tg C yr^{-1}; range -2.07–1.95 Tg C yr^{-1}), as most of a seaweed farms' energy and materials currently depend on fossil fuels."

[37] https://www.nature.com/articles/srep09665 Roberts et al. 2015. *Biochar from commercially cultivated seaweed for soil amelioration* "We find that seaweed biochar is a unique material for soil amelioration that is consistently different to biochar derived from ligno-cellulosic feedstock. Blending of seaweed and ligno-cellulosic biochar could provide a soil ameliorant that combines a high fixed C content with a mineral-rich substrate to enhance crop productivity."

[38] https://www.sciencedirect.com/science/article/abs/pii/S2213343721002578 Ranguin et al. 2021. *Biochar and activated carbons preparation from invasive algae Sargassum spp. for Chlordecone availability reduction in contaminated soils*. This paper refers to human health threats posed by *Sargassum* blooms in the Caribbean—which could be mitigated by converting the algal material to biochar for treating contaminated soils and other possible uses--- but does not address GHG mitigation.

[39] https://www.iea.org/reports/co2-emissions-in-2022 Report.

[40] https://pubmed.ncbi.nlm.nih.gov/34068692/ Videgain-Marco et al. 2021 *The Effects of Biochar on Indigenous Arbuscular Mycorrhizae Fungi from Agroenvironments* In three different greenhouse experiments, addition of biochar increased arbuscular mycorrhizal fungi (AMF) activity, root colonization, spore production and biomass production of lettuce.

[41] https://gust.com/companies/biochar_g_n_ration Lambert. 2022. *Biochar Génération* A start-up company headed by Benoit Lambert which is "A global leader aiming to assist organizations in regenerative agriculture, desertification reversal, water retention, carbon sequestration and credit".