Energy 36 (2011) 2011–2016

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Biochar as a viable carbon sequestration option: Global and Canadian perspective

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ARTICLE INFO

Article history:
Received 11 January 2010
Received in revised form
19 August 2010
Accepted 18 September 2010
Available online 25 October 2010

Keywords:
Biochar
Carbon sequestration
Global warming
Forestry
Forest fire
Biomass

ABSTRACT

Biochar production and mixing in soil are seen as the best options for atmospheric carbon sequestration, providing simultaneous benefits to soil and opportunities for distributed energy generation. The proximity of biomass source and biochar dispersal greatly reduces the energy and emissions footprint of the whole process. The viability of the whole biochar process is examined from two boundary points: is there enough biomass around to have significant impact on the atmospheric CO_2 levels and is there enough soil area for biochar dispersal. The answers are soundly positive, both for the world as a whole and for Canada, for which a more detailed analysis was done. However, the massive adoption of biochar solution is critically dependent on proper recognition of its carbon sequestration impact its soil improvement potentials. To that extent the International Biochar Initiative, together with national chapters, including recently formed Canadian Biochar Initiative, are actively promoting biochar related research and policy framework. This paper addresses the questions of availability of sources and sites that would benefit from its dispersal.

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1. Introduction

Current trend in atmospheric CO_2 concentration calls for dramatic reduction in anthropogenic CO_2 emissions in order to avoid runaway scenario of potentially catastrophic temperature and sea level rise. The annual mean CO_2 growth rate was significantly higher for the period from 2000 to 2005 (4.1 ± 0.1 Pg/yr), compared with the flux in the 1990s (3.2 ± 0.1 Pg/yr), even though only 45% of combined anthropogenic emissions have remained in the atmosphere, the rest being naturally sequestered by terrestrial and oceanic systems ([1], p. 515). In addition to curbing the fossil fuel and cement industry CO_2 emissions, several strategies for CO_2 sequestration are being proposed. A special IPCC report on carbon capture and storage (CCS) [2] lists seven climate change mitigation options: carbon capture and storage, energy efficiency, switch to low-carbon fuels, nuclear power, renewable energy, enhancement of biological sinks and reduction of non-CO_2 greenhouse gas emissions. Of these options, only enhancement of biological sinks and CCS from biomass combustion products can remove CO_2 already in the atmosphere. Other mitigation options only reduce or prevent further emissions. CCS is energy intensive option requiring additional emissions associated with carbon capture. A natural gas power plant (even when in combined cycle) emits equal or less amount of CO_2 than the one run on coal, with CCS [3]. It is estimated that CCS in Europe in 2020 will result in an increase in the production cost of electricity by coal and natural gas technologies of 30–55% [4]. Little is known about the long-term storage issues [5], from slow seepage into the atmosphere or sea water to the catastrophic release as in the case of LakeNyos disaster [6]. Overall, CCS has many obstacles to overcome, if it was to become a viable carbon emissions reduction strategy, and even then, the expected time frame for full implementation may be around 2050 [2]. Other proposed methods include injecting CO_2 into chemically reactive rock, even dead wood burial [7].

Production and deposition of biochar (or black carbon, as it is sometimes called [8]) into the soil are rapidly gaining recognition as a viable option in permanent carbon storage, while its benefits to soil fertility continue to emerge.

A number of methods can be used for producing biochar. Modern biochar is a product that can be manufactured from almost any uncontaminated organic matter, such as crop residues, bark, stem timber (logs), non-stem logging residues (bark, branches, tree-tops), various grasses and agricultural plant residues. The main processes for modern char production are fast or slow pyrolysis (biomass heating without air or oxygen) or gasification (run in the regime that leaves charcoal residue). Biochar production is typically self sufficient in energy requirements and can produce surplus energy as heat or biofuel for use in various energy conversion processes, including transportation and electricity production.

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doi:10.1016/j.energy.2010.09.031

This paper is focused on three aspects of biochar production and dispersion:

1. Can we offset the full annual CO_2 level increase by using biochar?
2. How much carbon can be sequestered worldwide and in Canada?
3. Is there enough soil area for its dispersal?

The anthropogenic impact on carbon dioxide atmospheric levels can principally be attacked in three ways: (a) CO_2 production reduction via phasing out fossil fuel use; (b) CO_2 capturing and storage from the source and (c) CO_2 capturing and storage from the air. Of course, the overall strategy that is pursued now and will be pursued in the near future is a mix of all three. For completeness, we should add the fourth mechanism for the atmospheric CO_2 reduction, namely, natural capture via terrestrial carbon cycle. In fact, it is this last mechanism that is mostly counted on for climate change mediation, combined with emission reductions. Direct capture from the source (e.g. power plant flue gases) seems to be favoured among all the capturing options by the policy makers today, although it is limited to large scale plants situated in good location. Currently, most economically viable projects are those that combine CCS with oil/gas extraction, already practiced in US, Canada, Brazil, Turkey, Hungary, Croatia, Norway and few other countries [9,10].

Carbon capture from air is being contemplated on an industrial scale by the closed-cycle sodium hydroxide absorption at a cost of $500/tC (USD), or by a combination of biomass with carbon capture and sequestering at roughly half the cost [11]. Significant cost, both in energy and finance, is associated with compressing carbon dioxide and pumping it into the ground. Biochar production and distribution do not incur that cost at all, and offer additional agricultural and ecological benefits. This triple benefit puts is in a unique position among various sequestration options: it can be produced by relatively simple processes (that need to be non-polluting, nevertheless), it can be produced wherever there is biomass and soil (i.e. practically everywhere) and it improves soil quality. The role of biochar as a viable sequestration vehicle has recently been recognized formally, in the draft negotiating text for the upcoming Copenhagen round of Climate Change talks: "Consideration should be given to the role of soils in carbon sequestration, including through the use of *biochar* and enhancing carbon sinks in drylands" [12].

What is the optimal amount of biochar addition to soil? Kurth et al. [13] investigated different soils that have undergone 1–3 forest fires in the last 100 years and found that they contain between 0.3% and 0.9% of charcoal. Estimates of the optimum in agricultural soil range between 1% and 5%. For purposes of this study, it is assumed that the charcoal is added to the soil at the 3% level to the top 30 cm, i.e. 13.5 t/ha.

The question of biochar interaction with soils, while important and even critical to the policy of biochar incorporation into arable soils, is beyond the scope of this paper. A recent comprehensive review done by the EU commission [14] found "… a small overall, but statistically significant, positive effect of biochar application to soils on plant productivity in the majority of cases. The greatest positive effects were seen on acidic free-draining soils". M work needs to be done in this area, leading to more specific knowledge about optimal conditions and concentrations in various agricultural scenarios. Black carbon is also seen as beneficial in binding anthropogenic hydrophobic organic compounds (e.g. persistent aromatic hydrocarbons, polychlorinated biphenyl, pesticide and herbicides) in soil, responsible for 80–90% of total uptake of trace HOC in soils [15]. The negative effects of biochar on soil are mainly avoidable (e.g. dust exposure during application, soil compaction and risk of passing the contaminants to the soil if biochar is produced from contaminated source material, esp. if it contains heavy metals). Other potential pitfalls, such as the loss of minerals if the crop residues are removed for char production to be dispersed elsewhere, can easily be avoided by the appropriate policies in biochar production and use.

2. Potentials for carbon removal: world

Storing biochar rather than burning it forfeits 32 MJ/kg °C of heat energy. This is certainly more than CCS penalty, estimated at 10–30% for large power plants [2]. However, CCS can only be applied in the very specific cases of large-scale power plants close to suitable storage reservoirs. Optimal siting for CO_2 storage usually invokes efficiency penalty, since combined heat and power (CHP) utilization opportunities are lost. It is often quoted that the large-scale power plans have higher efficiency, and this is certainly true if measured by the ratio of fuel caloric value to electricity produced (up to 40%). In reality, smaller, community-based CHP plants achieve much higher overall efficiencies, around 75%. In addition, charcoal production can be done in a much more distributed way, e.g. on farms and forest grounds, drastically reducing transportation costs and energy use both for biomass supply and for charcoal dispersal. An additional efficiency penalty, when biomass is used in large energy plants is in transportation. Lower caloric value of biomass (per weight and especially per volume) means that substantial amount of energy is lost in transportation.

If we focus now on biochar production and distribution/storage, we first ask if there is enough raw material available to have a meaningful impact on the atmospheric carbon dioxide. Fig. 1 illustrates overall carbon budget for all planetary ecosystems (atmospheric, terrestrial and aquatic) ([1], p. 515). The arrows with numbers represent annual fluxes in GtC/yr, while the numbers in the boxes represent the totals contained in each reservoir (atmosphere, vegetation, soil & detritus, fossil fuel reservoirs, surface, intermediate and deep ocean, marine biota and ocean bottom surface sediments). The reservoir figures do not include the lithographic storage, estimated at 20 PtC, i.e. 99.8% of the total terrestrial carbon [16], since it can be considered inert on a millennial and shorter time scales. Anthropogenic annual emissions of carbon due to fossil fuel use and cement production are 7.2 ± 0.3 GtC/yr in 2000–2005 period, as indicated in ref. [1], Table 7.1, page. 516. Of this total, 4.1 GtC/yr remains in the atmosphere, increasing the CO_2 concentration, while 3.1 GtC/yr is being absorbed by terrestrial and oceanic systems (1 GtC/yr and 2.1 GtC/yr, respectively), as indicated in Fig. 1.

To examine the potential for carbon sequestration via terrestrial biomass conversion to biochar we will assume that the biomass available for conversion is 10% of the net primary production (NPP), currently estimated at 60.6 Gt/yr [17]. This estimate fits well within the range of 15 models reviewed in [18], placing NPP in the 44.4–66.3 GtC/yr range. Further calculations are summarized in Table 1.

As seen in the table, 10% of NPP of biomass would be more than sufficient to offset the entire annual CO_2 increase in the atmosphere (4.8 vs. 4.1 GtC/yr). The next question is where this amount of biochar would be dispersed. As will be discussed later, the most beneficial use of biochar is in mixing it with soil. As a soil constituent it is both chemically stable and biologically beneficial. If we assume adding 3% of biochar (by mass) into the top 30 cm of the total agricultural land area (standing at ~45 mil. km^2 worldwide [19]), the capacity worldwide would be 600 GtC of biochar. The average soil density for this calculation was assumed to be 1.5 t/m^3 (Loam with 40% sand, 22% clay and 38% silt [20]), amounting to 13.5

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