Incentive structures for widespread adoption of long-term carbon sequestration in biochar

Abstract

Drawdown of atmospheric CO_2 is an urgent requirement if we are to mitigate our emissions in order to stabilise the climate and avert at least some of the catastrophic impacts of warming. There are ways to use growing plants and to remove a portion of the carbon captured in their biomass from the natural cycle. Perhaps the simplest and most compelling one is to encourage the widespread manufacture of biochar. A combination of three main actions from central government and primary industry groups will speed this process:

1. A statutory recognition of biochar's value as a safe, long-term carbon sequestration vehicle;
2. The formation and oversight of a marketplace for first- and second-order sequestration credits; and
3. Strategic funding of pilot projects.

By doing these things, we will not only hasten the arrival of New Zealand's net zero emissions status, but we will gain a range of corollary benefits to soil fertility, waterway cleanliness, animal health and land management.

Background

New Zealand intends to improve its efforts to reduce greenhouse gas emissions, and a stated target of net zero CO_2e by 2050 is currently our official goal. However, we are nowhere near the trajectory required to reach this at either the global or the national level (IPCC SR15)[i]. Even if we were able to achieve this on a global basis, a feat vanishingly unlikely under present policy scenarios, we are still left with a dangerously high atmospheric concentration that will have effects on climate and ocean acidification on an millenial time scale. We need to actively draw down the excess CO_2 on a steadily increasing long-term basis, both as a mitigation of the likely overshoot in emissions reduction targets, and as a multigenerational strategy to repair and rehabilitate the planetary system back to safe and stable levels.

Given the general resource constraints that we already face, and which will become far more limiting in the face of declining fossil fuel production, any proposed solution of carbon capture that relies on high energy or capital inputs will not be viable for the long haul. We need to focus our attention on sequestration in biomass, leveraging the energetic bonanza of photosynthesis and then carefully removing as large a fraction as possible of captured carbon from the biological cycle. Commercial forestry, with its short time cycles and low durability of end products[ii], is definitively not an answer. At present, we do know of a handful of methods that are regarded as providing reliable storage of biomass carbon in excess of 50 years. The most relevant ones for the New Zealand context are permanent forestry (native and exotic), wetlands creation and restoration, usage of biomass in durable construction materials, and pyrolysis of biomass to yield biochar. The last method will be the focus of this discussion.

Biochar history and properties

Biochar is a product that results from pyrolysis (heating in the absence of oxygen) of biomass – e.g. wood, bark, stalks, chaff and crop residue, nut shells, or virtually any organic material – leaving behind a durable carbon matrix with a porous structure[iii]. This substance has a range of physical, chemical and biological properties that can provide multiple, cascading ecological services. The first, and most compelling, application of biochar comes from the nature of the carbon it comprises. If the feedstock is processed at the correct temperature range, the resulting char is a highly stable and long-lived form of carbon, and as such represents a low-tech means of sequestering atmospheric CO_2 captured by photosynthesis of the plants that provide the feedstock. If we embarked upon a programme to pyrolise large quantities of biomass and then simply stored the end result in landfill, we would have an effective tactic for global CO_2 drawdown over time. The fifteenth special report of the IPCC includes biochar as a promising mitigation technology and this development has acted as a catalyst for expanded funding of trials in the EU.

However, there are so many other worthwhile uses of biochar aside from its value as a carbon sink that this direct storage route, although worthwhile, would represent a host of missed opportunities. The physical structure of biochar is a massively porous matrix, averaging over a hectare of surface area per 25 g of material. This property means that it can retain moisture and provide habitat for diverse and flourising microbial populations. This carbon matrix also provides an array of chemical bonding sites where ions dissolved in solution can attach and be held where they later become available for uptake by microbes or plants. The combination of these factors mean that biochar can effectively take out dissolved contaminants from water, for example. It also makes biochar an effective soil amendment for a range of settings, from arable, pastoral, and forestry lands to rehabilitated wetlands and marginal habitats.

The effects of biochar incorporation into soils over the long term can be seen in many settings, but the most striking examples would be the *terra preta* (black earth) of the Amazon, the famed black soils of Iowa and Ukraine, and, closer to home, in pā gardens where burnt matter was deliberately added to the plots. In the Amazon, a flourishing and settled farming civilisation was reported by the first Europeans to explore the interior in the 16th and 17th centuries. As the profoundly infertile nature of tropical rainforest soils was better understood, the presence of this culture (subsequently exterminated by introduced diseases) stood as a conundrum that was not solved until the last 100 years, when chemical analysis revealed high fractions of stable carbon in the farmed soils, and more recently when the carbon was reliably dated, its effects understood, and a mechanism for its presence was formally described. For a period of at least 1,500 years, and likely up to twice as long, the settled farming culture of the Amazon basin was routinely and purposefully incorporating charred organic matter into their severely depleted and leached rainforest soils and reaping the rewards of the increased fertility[iv].

In temperate regions, the most productive agricultural areas are atop the deep soils formed by humid grasslands – places like the US midwest, southern Russia and Ukraine, and the Argentine pampas. Soils with high amounts of durable carbon have formed in these locations by repeated low-intensity fires that charred the abundant aboveground vegetation and surface litter. The fire regime had natural antecedents but would have been enhanced in frequency by the presence of humans, who deliberately set them in order to drive game and modify the landscape. Radiocarbon dating of these soils has yielded carbon fraction ages of over 12,000 years in Ukraine and 7,000 years in Iowa[v]. This is our evidence that incorporation of biochar in soil is one of the surest and safest methods of long-term sequestration available. Its corollary benefits to primary productivity are just the icing on the proverbial cake, but these can be regarded as additional motivators to bring biochar to the forefront of our carbon management strategy.

Jump starting an industry with a credit marketplace

Field trials and commercialisation of biochar in New Zealand are presently hampered by a classic chicken/egg problem: Insufficient supply exists to serve potential trial applications at scale, and demand is low due to the novelty, which makes capital investment required for higher volumes of production unattractive. Compounding the niche status of biochar in the marketplace are its absence of recognition in the emissions trading scheme, a lack of awareness in policy circles, and a deficit of information at the official level – exemplified by the Parliamentary Commisioner for the Environment's March 2019 report that contained in its nearly 200 pages a solitary reference followed by a dismissal that appears grounded in partial evidence at best[vi]. Contrary to what the report infers, biochar's residence time in soils is proven through reliable and accurate dating, and its superb resistance to chemical and biological breakdown means that the only way to negate its value as a carbon sink is to burn it. The economic viability remark in the same paragraph, however, is an accurate criticism and sums up the difficulty faced by biochar advocates and practitioners.

In order for biochar manufacture and deployment to scale up to useful levels, incentives must be provided that soften some of the risk taken on by producers in the vanguard. Fortunately, the intrinsic value of biochar as a carbon capture vehicle and the numerous applications that remove it from the atmospheric cycle for suitably long time scales mean that a market in verified carbon credits would be an obvious and transparent means of valuing the process. Early formation of such a market might require a government subsidy to provide better signals until the price of carbon reaches a threshold that supports investment.

The preferred mechanism for such a carbon marketplace would involve oversight by an independent public agency or by a consortium with a mix of public and private sector representation. The scheme's accountability will be paramount: a verification framework will be required to maintain confidence in the integrity and efficacy of the system, and in particular to deter diversion of biochar into fuel for generation or industrial process heat. Producers would be eligible for credits upon certification of a quantity of material based on published durable carbon yields per volume of input feedstock and process utilised. These credits would only be issued upon affirmation of application of the full quantity of material to soil, water, or other ecological service where it is rendered unable to be used for fuel, as well as deemed safe from inadvertent burning. An authentication mechanism for this use case could be implemented atop a blockchain ledger and thereby make attempts at fraud unrewarding from a cost and complexity perspective.

Feedstocks and applications

The most obvious source of biomass for treatment by pyrolysis is the enormous amount of debris and slash remaining after commercial forestry blocks are harvested. The incentive for operators to reduce this volume of material is increasing in the face of events such as the storms of June 2018 in

East Cape, that sent millions of tonnes of logs and debris from the steep slopes down the rivers and out to sea, causing massive damage and disruption along the way. Given the present maturity of forests planted in the 1990s, we can expect to see continued high levels of harvest for at least another decade, as evidenced by the record 35 million m^3 recorded by the industry in 2018[vii]. At least ten percent of the volume of commodity products (logs and chips) arising from harvest activities typically remains on site as slash and debris. A requirement for source reduction of this material would be a powerful driver of increased biochar production, since *in situ* pyrolysis achieves an average 75% volume and mass reduction and the end product is then much more transportable. It could also be applied directly where it was made, to enhance future productivity of the forest soils.

Municipal solid waste is another high carbon feedstock whose emplacement in landfill contributes to high methane emissions. Pyrolysis of this material would be an obvious gain for city and district councils in terms of their greenhouse gas budgets, not to mention the costs and logistics of disposal. Sewage solids are also a candidate for treatment, and in an example of cascading services, biochar could be used to adsorb excess nitrate and phosphorus from the effluent before it is discharged, providing a lower cost avenue for mitigation and compliance with consents. And because pyrolysis is an exothermic process, the energy released is available for cogeneration or process heat, with the most obvious application being drying the feedstock prior to introduction to the kiln or retort.

Biomass stocks on farms represent an opportunity for the agricultural sector to approach carbon neutral – or even negative – status by way of holistic management. Examples of on-farm carbon sources include maize or other grain stalks, animal bedding, solids from sheds, standoff pads and raceways, low-quality standing pasture, and outputs from farm forestry, shelterbelt trimming, and bespoke carbon crops such as willow, hemp, or miscanthus. Utilisation of these materials at or near their source reduces or eliminates transportation, storage, and handling required by centralised treatment methods, and cuts the emissions associated with these activities.

The most advantageous example in a typical pastoral setting would be to establish short rotation coppice plantings using fast-growing species, such as hybrid willow or poplar, that are easy to manage, can be harvested mechanically, and can yield 11-24 T/ha of dry matter pa within two to three years of planting[viii]. Each tonne of woody biomass would yield 300-600 kg of biochar under different process conditions, with the higher end more likely in small scale batch methods appropriate to farm scale production. If an average 150 ha dairy farm were to devote five percent of its area to short rotation coppice planting in marginal strips along paddock boundaries, drains and raceways, it could be storing 50 tonnes of carbon annually using midpoint figures from the yields described above. Scaling this approach up to the roughly 15,000 dairy farms nationwide, this would conservatively total 2.5 MT pa of CO_2 removed from the atmosphere with a relatively minor alteration to land use and practices. This is equal to 3% of our combined gross CO_2e emissions, or 4.5% of our net when current forestry is accounted for.

The horticulture sector, especially fruit growers, has a ready source of biomass ideally suited to pyrolysis. Prunings turned to biochar and incorporated into the soil under growing trees and vines will bring positive outcomes from the aeration, water retention, nutrient binding and microbial activity created. Air quality in these districts would also be improved if the feedstock were pyrolised via recommended methods that emit low levels of smoke and particulates, as opposed to the traditional open burn piles that force residents indoors with their windows shut to avoid the health-damaging effects of particulate emissions. Regional councils could create incentives for this avenue as a condition of the consenting process.

Cascading services and secondary credits

As greater quantities of biochar are produced under a favourable carbon credit regime and available for applications in the primary sector, data can be gathered that show the levels of emissions reduction achievable under real farming conditions. Multiple studies, including research performed in New Zealand, have shown that biochar in pasture soils reduces the release of N_2O, a potent greenhouse gas with 298 times as much warming potential as CO_2 and an atmospheric persistence of centuries. Any reduction in N_2O efflux from pastoral farming is a win for the sector and having more precise values with regard to soil types, pasture composition, seasonality and stocking rates will mean that the carbon credit market can account for these as well. Additionally, the adsorption of nitrate ions onto biochar not only limits their leaching into groundwater, providing an advantage to farmers in relation to regional councils and consent compliance, but the bioavailablity of the retained nitrate to pasture plants would then decrease the amount of synthetic nitrogen fertilisers applied to the farm – yet another feedback loop that will lower the farmer's exposure to carbon liabilities in the form of fertiliser levies.

Biochar in the form of activated charcoal has long been used in veterinary medicine as a means of promoting animal health and treating toxicant ingestion, and has shown considerable promise as a feed additive that inhibits methanogenesis in ruminants. It is now in widespread use in the EU in this form, and also commonly employed in bedding for wintering barns and poultry operations, where its denitrification attributes are improving stock health and reducing farm costs by inhibiting the formation of ammonia.

In New Zealand forestry settings, successive rotations of *Pinus radiata* tend to reduce the fertility of soils where they are grown. By pyrolysing the residues from harvest and incorporating the biochar we could slow or reverse the trends of soil carbon losses and demineralisation in soils under commercial management. This would also aid the conversion to native or exotic hardwood forestry to alleviate the "pine desert" effect and move to a more sustainable and high value mix of timber species for the long term. On the conservation estate, biochar production could partner with removal of wilding pines and other invasive plants as a means of helping to underwrite the costs of mounting this effort.

Decentralised and low-tech production methods

One of the most pervasive critiques of biomass pyrolysis on a large scale questions the level of investment required to build large industrial plants, and the inputs of expertise and energy to run them and to transport and handle the feedstocks required. Due to the exothermic nature of the process of pyrolysis, the first energy question could be dismissed as a red herring, but the other issues are legitimate. Fortunately, there are several methods for biochar production that are simple enough to be carried out in a home garden setting, all the way down to small-scale batches in a residential log fire. For farms, burning biomass in a pit is a viable proposition and can yield a high quality product with minimal capital investment. Mobile flame cap kilns, in the form of troughs or cones, are a step up the ladder of intensity but still provide a means of taking the process to the feedstock and thereby avoiding the logistics, associated emissions and expense of gathering bulky materials and hauling them to a stationary plant.

This is not to say that there is no place for centralised industrial production when envisioning widespread biochar use. Larger pyrolysis facilities are appropriate wherever the volumes of biomass and opportunities for exploiting the process heat exist, and economies of scale coupled with market signals from rising carbon prices and sequestration credit regimes can drive investment in this sector. But we need to remain mindful of the fact that our debt to future generations is to set up a system that can continue to draw down the overhang resulting from the carbon profligacy of the past century, and to do it in a way that can persist through the looming decline in fossil fuel use. Embedding a pattern of land and resource management habits that can be implemented on a distributed basis, with no specialist expertise, and has proven outcomes in the areas of safe sequestration and primary productivity, is an obligation we now have to carry out with as much urgency as we can muster.

From the standpoint of central government and the leading groups representative of the primary sector, three actions are required:

1. A statutory recognition of biochar's value as a safe, long-term carbon sequestration vehicle;
2. The formation and oversight of a marketplace for first- and second-order sequestration credits; and
3. Strategic funding of pilot projects.

Together, these steps will enable critical development of this humble, yet powerful, solution to several grave problems we face, both as New Zealanders and as citizens of a finite planet.

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