Sequestering of Atmospheric Carbon through Permanent Disposal of Crop Residue

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Abstract

We propose the sequestering of crop residues to capture a significant fraction (26%) of the present US atmospheric carbon emission. With adequate fractions of farm waste left in and on the soil to supply nutrients and retard erosion, the bulk of the waste could be shipped at low cost, using the existing crop transport network, at a cost of $22.5 billion per year. Disposal in river deltas may ensure carbon capture for years at best. Deep ocean disposal would probably sequester carbon for millennia. Globally, roughly 20% capture of currently emitted carbon seems possible by this method. Costs are lowest for those nations already exporting grains, which have transport systems in place. The leverage of this approach comes from an acre of corn's ability to hold 400 times the carbon that human emissions deposit annually in the air above it. All such methods for pulling CO2 from the air enjoy a leverage of 2.2 over sequestering before emission, since the biosphere absorbs over half of all gross human emissions. Implementation of this proposal would not only allow the US to meet the emissions levels stipulated under the Kyoto Accord, but would permit the US to continue its current carbon emission increase of 1.5% per year for the next 9 years.

Seen in the largest perspective, our current atmospheric buildup of CO2 stems from our first great invention, the discovery of fire. Given that, our eventual discovery of fossil fuel and our political short time horizons made a greenhouse problem inevitable. Perhaps we can offset our species' greenhouse effects by using our second great invention, agriculture, with some help from the wheel.

Farming is the largest scale human activity, covering about 10% of the globe. Perturbing this large effect seems a wise way to affect our atmosphere, based on a simple fact: a field of corn

captures about 400 times as much carbon as there is in man made atmospheric carbon in the entire column of air above the field, from ground to space (1). Harnessing this prodigious method of arresting carbon could give us great leverage over the global CO_2 imbalance.

Worldwide human activities result in estimated annual carbon emissions of 7.1 Gigatonne of carbon (GtC), composed of industrial emissions of 5.5 GtC, with an added 1.6 GtC from biospheric burning (2). These emissions produce an increase in global atmospheric CO_2 of 1.6 ppm/year, representing 3.2 GtC/year. The difference between the carbon emitted and that which remains in the atmosphere is due to the biosphere's ability to sequester 55% these emissions. In 1990 the United States, with only 4% of the world's population, emitted approximately 19% of this CO_2, some 1340 GtC, of which 740 GtC was sequestered in the biosphere, with 600 GtC remaining in the atmosphere (3).

There are two ways to cut this CO_2 rise: reducing emissions, and sequestering of atmospheric carbon. Sequestering offers many possibilities: tree growth, CO_2 disposal in oceans (gaseous, liquid and solid), trapping CO_2 in exhausted oil fields and beneath salt domes, and fertilizing plankton production in the oceans by using iron.(4)

Sequestering of CO_2 after it has been emitted into the atmosphere offers a distinct advantage over emission reductions, by taking advantage of the biosphere's ability to sequester 55% of those emissions, which gives a leverage factor of 2.2 times over emission reductions approaches (5). This factor is shared by any process that removes carbon from the air. We propose a new sequestering approach, utilizing post-emission sequestering in order to take advantage of the high leverage factor, through the permanent storage of unwanted farm waste (crop residue) in river deltas or the deep oceans.

The great advantages of sequestering carbon in farm waste are that this approach

(a) uses biomass that is now mostly left to rot in the fields
(b) demands no new land
(c) uses residue that can be gathered and shipped with the same equipment used to bring in the crop, and
(d) requires no new technologies or transport systems

In the global carbon budget, as illustrated in Table 1, the deep oceans sequester in the form of sediments, the vast bulk of the world's carbon. The oceans are not CO2 saturated, and the deep ocean circulates carbon back to the surface in times measured in many centuries or even millennia (4,6).

Table 1

Atmospheric:	720 Gt
Biosphere:	550-830 Gt
Soils	1500 Gt
Fossil Fuel Reserves	6000 Gt
Deep Oceans	38,000 Gt
Marine Sediments	20,000,000 Gt

We focus upon using farm waste in the US, for which data is extensive (6-9). Generally, most crop residues have 40% by weight of carbon (10). We analyze primarily corn production because it is the single largest US crop in both acreage planted and crops produced. It is extremely efficient at fixing carbon, using a unique C4 photosynthesis process (11), yielding about three times more grain per acre harvested than wheat, which grows under more common C3 photosynthesis processes (7). In 1996, according to US Department of Agriculture statistics, 79 million planted acres produced 236 million tonnes of corn, or 3.00 tonnes/acre. Crops typically

generate 1.5 pounds of residue for each pound of harvested material, so in the case of corn, residues of 4.5 tonne/acre can be expected (8)

Most crop waste can be removed without nutrient penalty. Historically, farmers tilled residue back into the soil, believing that it would increase the soil organic matter (SOM) content. However, research shows that in fact this practice leads to long term reduction of organic matter in the soil, due to disruption of soil microfauna (12-16). As a specific example, it was found that under no-till methods (in which crop residue was left on the soil surface), when compared to conventional tillage, that the carbon content in the soil was 35, 39 and 53% greater for wheat, sorghum, and soybean crops, respectively (15).

Varying degrees of conservation tillage methods (of which zero tillage represents the extreme) -- those in which at a minimum, at least 30% of the soil surface is covered by residue after planting - are available. Conservation tillage is used primarily on corn, soybeans and small grains (9) - those crops which we are proposing to use as our primary sources of crop residue. By 1994, more than 45% of corn and soybean acreage was conservation-tilled. Zero till methods for corn production more than tripled from 1989 to 1994, increasing from 5 to 17%. Such statistics clearly show trends toward less and less tilling, coupled with reduced erosion benefits. (9) This suggests that as conservation and zero tillage methods are more widely used, greater amounts of crop residue will be available for harvesting.

After corn, the three next largest US crops by acreage are wheat (76 million acres), soybeans (63 million acres), and hay (61 million acres). For this analysis we assume that hay generates no collectable residues, since the crop is usually taken down to the roots. We also neglect rice, though in the US, much of its residue rots in moist fields, releasing methane, a much more powerful greenhouse gas. Crop residues of those we are interested in for this study typically yield 1.5 times the harvested crop mass (8), and we shall consider this also the case for soybeans for this analysis. (Often, though, soybean residues are plowed under to replace nitrogen in the soil. Whether this practice would survive a carbon credit pricing is unclear.)

Table 2 illustrates the amounts of residues available from these major crops as well as the equivalent carbon, based on an average carbon content in these crops of 40% (10).

Table 2

Crop	**Acres Planted**	**Residue/Acre**	**Total Residue** (million tonne)	**Total Carbon** (million tonne)
Corn	79 million	4.5 tonne	356	142
Soybeans	63 million	2.0 tonne	126	50
Wheat	76 million	1.5 tonne	114	46
Total			595	238

If we assume a typical erosion abatement policy that leaves 25% of the residue on the field, this yields a total potential carbon reserve in these crop residues of 180 mtC (million tonne of carbon). Using the 1990 estimate of 600 mtC as the amount of net carbon which US activities permanently place in the atmosphere, and using the estimated annual increase of US carbon production of 1.5% (3), results in a 1998 US atmospheric carbon placement of 676 mtC into the atmosphere. Permanently sequestering this 180 mtC would represent 26.6% of the current US carbon emission.

The Kyoto Accord calls for a 7% reduction in CO2 emissions below the 1990 level, 1250 mtC (3). The 180 mtC trapped in this approach is a post-emission reduction, and therefore equivalent to 396 mtC if removed in the form of emissions reductions. If this crop residue were sequestered in 1998, the net carbon placed in the atmosphere by the US would be 496 mtC [676 - 180 mtC]. This is equivalent to 1091 mtC of emissions, well below the Kyoto requirement of 1250 mtC. If the US continues to increase carbon emissions at a rate of 1.5% per year, and the sequestering of these crop residues were performed, US emissions would stay below the levels stipulated by the Kyoto Accord through 2007. Thereafter, the 1250 GtC level agreed upon at Kyoto for the 2012

emission levels could be maintained by reducing the annual increase of the US emission rate from 1.5% to zero. At no time under this approach are any actual reductions in carbon emissions required in order to meet the Kyoto targets.

Because other nations, particularly those just developing, make more extensive use of their crop residue for animal fodder, fuel and manufacture, estimating waste in these locations is difficult. China appears to use about 40%, whereas Bangladesh is nearer 90% (4). Availability will depend on any carbon credit which enters as another "market" to compete for these uses.

However, the potential can be estimated. Considering only grains (wheat, milled rice, and corn), the total combined world production in 1996 was 536 million tonnes of wheat, 372 million tonnes of milled rice, 810 million tonnes of corn and other coarse grains, for a total of 1718 million tonnes (7). Assuming an average crop residue of 1.5 times the crop yield implies 2.58 Gt total available world crop residue, or 1.0 Gt of carbon. This represents 32% of that permanently placed in the atmosphere due to man's activities. Were only half of this available globally, CO2 emission could still effectively be reduced by 16% -- surely significant.

Having established the availability of vast carbon sources In crop residues, how can one permanently sequester the carbon? Three possible methods appear practical: sequestering in exhausted oil/gas fields or beneath salt domes (4); sinking in oceans (both shallow and deep beneath the thermocline); or burning in power plants to replace oil and coal (4).

In each case the crop waste must first be harvested, bailed, and readied for transport. Estimated costs for this range from $8 to $26 per ton for various studies and different crops, with a mean cost of about $20 per ton for biomass uses. (Currently, only 3% of US biomass power production comes from farm waste (4). Crop residue for energy production is generally undesirable, burning at low temperatures and depositing unwanted minerals on heat exchange surfaces.) (17).

Sequestering in depleted gas/oil fields and beneath salt domes would require grinding up the waste, and transforming it into a slurry to be pumped down. This is a distinct cost disadvantage, although there may be some advantages to this approach if one could use existing pipelines to

transport it, and transportation distances might not be far. Both salt domes and depleted gas/oil fields are plentiful in the USA midwest, the region producing much corn waste. These methods should be explored, but face questions about how long carbon can be so trapped.

Here we propose two sequestering sites -- near the coast in shallow waters above the thermocline, and further out, beneath the thermocline. Simply offloading corn waste into an actively depositing river delta like the Mississippi's can bury it within days as later river silt falls upon it. We know of no study measuring how long deposited organic matter takes to decay into gas which reaches the surface (CO_2 or methane), though short times ~ years seem probable. Gulf deposits near the coast save on transport at sea, deposition times of only years may preclude their use.(18)

In the Gulf of Mexico, excursions ~100 km. from the delta reach deep ocean waters. Below ocean depths of about 1 km lies the thermocline, where there is little oxygen and temperatures are only a few degrees above 0 ∞C. This anaerobic environment mixes with surface waters very slowly, requiring centuries to millennia (4). Simply dropping baled waste, with weights attached to ensure that trapped air does not make the bales float, should then sequester the waste. (The weights could be made of carbon-rich solid wastes which, left on land, would normally decay into CO_2; this sequesters more carbon.)

To make doubly sure, and extend the sequestering time, one might shape the waste into cylinders with conical weight heads. These "carbon torpedoes" would penetrate the bottom sediments to several meters, sealing in decay products. This may prove particularly useful, since then trapped methane or CO_2 can attain the concentration where stable hydrates of methane or CO_2 form, securing the carbon for very long times (18).

Depositing the entire disposable US waste tonnage, 450 mt, would cost about $22.5 billion if total collection and transport costs were $ 50/ton (19). Still, $22.5 billion seems a small cost to hide 26% of all US emitted carbon; satisfying Kyoto levels in 1998 would range around $10 billion/yr.

Scaling this result to other nations makes sense only for those nations already producing substantial crops that may be easily moved to ocean dumping sites. This probably includes some European states, the Ukraine and a few developing nations such as South Africa.

This proposal is qualitative, outlining areas that should be explored: the fate of wastes in deltas, shipping costs for farm residue, and other economic factors. Intended as stimulating, not definitive, we conclude with a few thoughts on tradeoffs and political realities.

Hiding waste carbon is a general strategy suggesting other approaches. There can be many local adaptations, large and small. For example, many cities separate organic waste during their trash collections and dump it in landfills or nearby ocean beds, where it quickly generates both CO2 and methane (a far worse greenhouse offender than CO2). New York City dumps most of its general wastes off the aptly named Fresh Kill point, creating a large, lifeless, anoxic zone. Far better to send barges of organic waste 200 miles offshore, where it would fall to the deep ocean bed beneath the thermocline.

The US confronts an embarrassing mismatch between its high emissions and a general unwillingness to incur high costs to offset these. Estimates of $100 billion to comply with the Kyoto Accords are common and the need for 15 TWatt of power by the year 2050, with no net carbon emission has been argued (20). Much political opposition also arises from the perception that Kyoto means sending tax dollars to distant lands, through a system of carbon credits, for which there is little domestic support.

Farm waste disposal promises to lower such costs, with political bonuses. The $10-20 billion per year spent to sequester farm residue will go to the American heartland, into the hands of ordinary laboring people such as farmers and truck drivers. It demands no new infrastructure and is easily stopped if unwanted effects occur.

A program of domestic carbon credits exchanged in a market could drive efficiencies in disposal. After all, waste need not be cleanly handled, as are edible crops; coal barges will serve nicely. Such bulk disposal is the simplest, lowest tech way to hide carbon from our atmospheric cycle.

As a bonus, it will give ordinary working people a feeling that they, too, can do something active about climate change. And because farm waste plausibly rises with population, as does energy use, this sequestering method will then keep pace with the predicted rise of our numbers to ten billions within a half century.

2700 words

Notes and References

1. This calculation assumes that an average acre of corn has a dry mass of 10 tonnes (grain, stalks, leaves and roots); 40% consists of carbon. In the air above the corn field, the additional CO_2 placed in the atmosphere due to human activities is 1.6 ppm per year, a total of 10 kg in the column of air above the cornfield to the reaches of space. Therefore, one acre of corn incorporates an equivalent amount of excess atmospheric carbon in the air column above 400 acres.

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