Ecological carbon sequestration via wood harvest and storage (WHS): Can it be a viable climate mitigation and adaptation strategy?

Ning Zeng
Department of Atmospheric and Oceanic Science and Earth System Science Interdisciplinary Center
University of Maryland, USA

Collaborators: Tony King, Ben Zaichik, Stan Wullshleger
Jay Gregg, S. Wang, Daniel Kirk-Davidoff

Thanks to: AOSC658 students, the Gemstone CarbonSinks team,
A. Cowie, D. Nepstad, G. J. Collatz, L. Heath, E. Matthews, F. Norbury,
H. Sloan, D. Abbas, B. Bond-Lamberty, T. West, S. Smith,
R. Salawitch, J. Carton, G. Marland, M. Post, W. Kurz, L. Gu,
P. Read, R. Birdsey, A. Janetos, G. Poisson,
The Heinz Center

Based on talks at AGU, EGU and several seminars since 2008
In near final form in 2016 seminar at FEEM/Eni Foundation
Minor update in 2021

© Copyright Ning Zeng 2008-present
Permission for non-commercial use is granted, provided explicit acknowledgement of this source
What can we do about the climate problem?

- Nothing: suffering
- Adaptation
- Mitigation: reduce emissions
- Geoengineering with solar radiation management (SRM)
- (Semi-)permanent carbon sequestration
Cost of Emissions Reductions

To bring emissions back to current levels by 2050 options with a cost up to USD 50/t are needed. Reducing emissions by 50% would require options with a cost up to USD 200/t, possibly even up to USD 500/t CO₂.

In support of the G8 Plan of Action
Carbon sequestration methods -- by stage

- **CO2 capture and removal from the atmosphere**
  - From flu gas at point sources (power plants, etc)
  - Free air capture
    - Chemical processes: ‘Artificial trees’ and other CO2 scrubbers
    - Geological: weathering
    - Biological: photosynthesis (planktons, trees, grasses)
    - Engineered/accelerated versions of the above

- **CO2 storage in semi-permanent reservoirs**
  - Geological: sedimentary rocks, saline aquifers
  - Oceanic: deep ocean, sediment
  - Terrestrial: live or dead biomass (plants and soil)
Carbon capture and storage (CCS) in geological formations

Capturing carbon dioxide (CO2) from large point sources such as power plants and subsequently storing it away safely may capture 80-90% of CO2 emission. Needs 10-40% more energy and 30-60% more expensive.

Cost: $20-270 per tCO2 (mostly capture)

Storage capacity: 1000 GtC? Potential leakage?
CAN WE CONTROL THE CARBON DIOXIDE IN THE ATMOSPHERE?

FREEMAN J. DYSON†
Institute for Energy Analysis, Oak Ridge, TN 37830, U.S.A.

(Received 26 July 1976)

Abstract—The carbon dioxide generated by burning fossil fuels can theoretically be controlled by growing trees. Quantitative estimates are made of the size and cost of a plant-growing program designed to halt the increase of carbon dioxide in the atmosphere.

STATEMENT OF THE PROBLEM
At present (1976) the CO₂ in the atmosphere contains $7 \times 10^{11}$ tons of carbon.¹ The burning of fossil fuels is adding to the atmosphere $5 \times 10^9$ tons of carbon per yr.² Of this amount, only $2.5 \times 10^9$ tons per yr is appearing as net increase of atmospheric CO₂. The remaining $2.5 \times 10^9$ tons per yr is absorbed by the ocean and the biosphere. How much goes into the ocean and how much into the biosphere is still a matter of conjecture.³ The present carbon content of the biosphere is
Enhancement of terrestrial carbon storage

Reforestation

- Low cost and environmentally appealing (popular option for carbon offset)

- Capacity (limited by available land): 40-600 MtC/y for US for few decades (Richards and Stokes 2004) less than 100 GtC total Global (IPCC2000)

- Cost: low ($0-400/tCO2)

- Limitations: limited by available land saturates cost rises sharply at high capacity
Cost rises at larger sequestration rate

Physical potential

Social potential

Van Minnen et al. 2008

Stavins 1999
Terrestrial bio-sequestration

- Restore land to pre-human condition
  - Reforestation
  - Land management: No-till agriculture, etc.
  - Peatland restoration

- Continuous use of biomass
  - Biochar
  - Biomass energy with carbon capture (BECCS)
  - Long-term wood use: construction, furniture, etc.
  - ‘Pickled trees’
  - Wood harvest and storage (WHS)

One thing in common: photosynthesis is “free”
A new twist: avoided deforestation
Reduced Emissions from Deforestation and Degradation (REDD)

Major progress in Copenhagen
Natural forests are full of dead wood. We collect deadwood or selectively cut un-productive live trees, then bury them in trenches, submerged under anaerobic water store in above-ground shelters so as to prevent decomposition.

Zeng, 2008
Carbon Balance and Management
Some reactions to the idea

- “Brilliant or crazy?”
  S. Plummer, *the New Republic*

- “The idea of burying carbon in biomass makes sense”
  R. Lovett, *New Scientist*

- “Your suggestion for sequestering carbon is a good one...The big question is how much would it really cost”
  Freeman Dyson, Inst. Advanced Studies, Princeton

- “I read your paper on burying trees with great interest”
  Thomas Schelling, Nobel economist

- “It might work”
  Paul Crutzen, Nobel laureate

- “…could be viable approaches to increasing carbon removal... To date, this proposed approach has not been tested though the technology is simple and easily applied.”
  National Academy of Science Report on NETs, 2019
How does it work?

A carbon cycle perspective

Atmospheric CO₂

NPP
Photosynthesis
60

Decomposition
57

Fossil fuel

Biomass Bioenergy Carbon Reserve

Future Alternative use

Wood harvest and storage

Low cost carbon sequestration

3

60

2

57

3

9
Issues I will address

- WHS sequestration potential: From theoretical to ‘practical’
- Implementation and scale of operation
- Cost
- Potential issues
- Co-benefits (low-hanging fruits)
Theoretical Potential

Theoretical potential rate: 10 GtC/y
-- based on coarse wood production rate

Tropical forests: 5.6 GtC/y
Temperate forests: 3.3
Boreal forests: 1.1

One-time pool: 65 GtC
-- coarse dead wood on forest floor

Zeng (2008), Carbon Balance and Management
"Practical" Potential

Constraints considered:
- Land use
- Conservation (50%)
- Accessibility
- Other wood use

Final global potential 3 GtC/y
Sequestration potential by continent

Global total: 3 GtC

Percent of fossil fuel emissions

GIS by Ben Zaitchik (Johns Hopkins U) using updated data of Zeng et al. (2013)
Comparison of carbon sequestration potential by 2050

1. Higher values (Biochar/BECCS) assume highly productive energy crops
2. Restoration methods (Reforestation/SoilC) approach steady state after some years
“Practical” Potential v2

**Bottom up Assessment**

- Current global wood harvest is on the order of 1 Gt C per year.

- Accounting for burning, post-harvest decay, and other loss, ~0.1-0.2 Gt C per year is sequestered.

- Consider land use and implementation constraints.

- Appears that with a doubling of wood harvest + reduced post-harvest loss, a potential of 1-2 Gt C per year may be possible.
Implementation Strategy

- Access
- Trench digging or shelter building
- Collection or tree cutting, deliming, bucking for burial or storage

Dead trees collect and bury
Old trees cut and bury
Regrowth
Old trees storage in shelter
Old trees cut and bury

Dead trees collect and bury

Regrowth

Old trees storage in shelter
Cut-to-length logging
Felling, delimming, bucking
Operation -- A vision

In-situ
1. Harvesting
   Hauling/skidding (short distance)
2. Excavation and burial

Large facility (woodfill)
1. Harvesting/collection
   Hauling/skidding
2. Transportation (long-distance)
3. Excavation and burial
Scale of Operation

- Over an area of 1km x 1km (100 hectares), 500 tC coarse wood can be collected and buried in a trench/mound 40m x 10m x 7m. The trench surface area is 0.04% of wood collection area.
- To sequester carbon at 1 GtC/y, 2 million trenches per year, or 1 trench every 15 seconds need to be dug! Double the present harvesting rate!
- If a crew of 10 people (with the machinery) needs 1 week to dig such a trench and collect/bury the wood over 100 hectare, 40,000 crews/machineries (0.4 million workers) will be needed continuously!
- Cost: at $50/tC, $100 billion will be needed for 1 GtC sequestration, 0.1% of world GDP of $48 trillion, compared to 5-20% of projected economic damage from climate change (Stern2006).

The scale reflects the enormous scale of the climate change problem. Is it manageable?
## Cost

<table>
<thead>
<tr>
<th></th>
<th>Power plant CO₂ capture with geological storage (CCS)</th>
<th>Price on Chicago Climate Exchange (CCX) 2006</th>
<th>European carbon trading market price during 2005-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Burial</td>
<td>$20-270/tCO₂ (IPCC, 2005)</td>
<td>$3-4/tCO₂</td>
<td>€1-33/tCO₂</td>
</tr>
<tr>
<td>€14/tCO₂ ($7-27)</td>
<td>$73-990/tC</td>
<td>$12-16/tC</td>
<td>€4-120/tC</td>
</tr>
<tr>
<td>$50/tC ($25-100)</td>
<td>Possibility of leakage; lower cost storage capacity small</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage safe; semi-permanent, reversible; some environmental concern</td>
<td>Potential rate is limited by scale of operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential: 10 (5-15) GtC/y</td>
<td>Longterm: &gt; 500 GtC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term: thousands of GtC or no practical limit</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Why is wood burial relatively cheap: photosynthesis is ‘free’ (but with a finite rate); main cost: logging/collection and burial

1. Wood burial cost based on US logging industry data
2. The markets use tCO₂ as carbon unit which has been converted into tC with the conversion factor CO₂:C=44:12.
From forest to lumber:
Cost, CO$_2$ emissions, and the fate of wood

- Harvesting (Stump to Landing):
  - Cost: $12/m^3$ log
  - CO$_2$ emissions: 0.01 tCO$_2$/m$^3$log
  - Wood in product: 60% (% of live biomass)

- Transportation (Landing to Mill):
  - Cost: +$12 = $24
  - CO$_2$ emissions: +0.01 = 0.02

- Processing to Lumber:
  - Cost: $100/m^3$Lumber
  - CO$_2$ emissions: +0.04 = 0.06
  - Wood in product: 23%

- Transportation Handling:
  - Cost: $200/m^3$Lumber
  - CO$_2$ emissions: +0.22 = 0.28

- End use:
  - Wood in product: 18%

Source: CORRIM Consortium; Ingerson (Wilderness Society)

- Furniture is expensive, but raw wood is Not
- 5 times more carbon in raw wood than in lumber
Comparison of negative emissions technologies (NETs)

McLaren (2011) Provisional global assessment of NETs: scale, cost and readiness

Biomass burial

- Low cost ($10-50/tCO₂)
- Potential
  - 2-10 GtCO₂/y

Demo projects show that WHS technology is now commercially ready (2021)
Potential Issues

1. How permanent is the buried carbon: can be very long, depending on how it’s buried
2. Nutrient lock-up
   - Fertilization may be needed in some areas, or don’t do it?
   - C:N ratio is 200:1 for wood (20:1 for leaves); 10 GtC/y locks away 50TgN/y, only a fraction of the fixation (110 TgN/y) or anthropogenic deposition (140) rate (Galloway et al., 1995).
3. Competition with other wood use (furniture, paper, biofuel, etc.): current wood use 0.9 GtC/y (Hurtt 2006)
4. Habitat loss
5. Disturbance to forest floor and soil
6. Other unintended consequences: deforestation follows roads!
Buried wood can decompose extremely slowly

Wooden coffin 1.5 m below ground after 2500 years

Feilong, Heshan, Pujiang, Sichuan, China

http://www.china.org.cn/english/MATERIAL/192520.htm
Ancient Kauri trees >50,000 years old

New Zealand

Source: the internet

Buried wood can decompose extremely slowly
Buried wood can decompose extremely slowly

Wood in a landfill after 46 years, Australia

Wood in landfills in US: 0-3% decomposed after 30 years (Micales and Skog, 1996)
Lifetime of buried wood can be long compared to the residence time of fossil fuel CO$_2$ in the atmosphere.

CO$_2$ based on a scenario in which 1000 GtC fossil fuel is burned in few hundred years.
Other storage methods

Cold

Snow covering Quebec, Canada
The goal is to prevent decomposition.

Other storage methods

- Wet
  - Sweden

- Dry
  - Southwestern US?
2. Nutrient lock-up

Fortunately for our purpose, wood is nutrient-poor

- C:N ratio is 200:1 for wood (20:1 for leaves); 10 GtC/y locks away 50TgN/y, only a fraction of the global N fixation (110 TgN/y) or anthropogenic deposition (140) rate (Galloway et al., 1995).

- Fertilization may be needed in some areas, or intensity of wood harvest reduced, or don’t do it at all

Bottomline: bury wood, especially coarse wood, certainly not leaves

More research is needed!
3. Competition with other wood usage
(what a waste to bury that wonderful tree?)

- Current world wood use is 0.9 GtC/y (Hurtt et al., 2006), compared to the 10GtC/y potential. The rest decomposes.
- Post-consumer wood could also be buried: no additional ecological impact, but may be costly and difficult to find enough space (?)
- Why not use it for biofuel?
  - Burial is more efficient for C sequestration; cellulosic ethanol and wood chip burning are not currently cost efficient and environmental issues need to be addressed when implemented at large scale. Likely both will find their own niches.
  - Wood burial or above-ground storage essentially puts the terrestrial biosphere’s ‘excess’ wood production in a ‘carbon bank’ that could be used as lumber, biofuel and other purposes in the future.
- Even if we can quickly reduce CO2 emissions, the climate change resulting from what’s already in the atmosphere may still be undesirable, so some CO2 already emitted needs to be removed, i.e., some substantial carbon sinks will be needed. Wood burial and storage appears competitive relative to other carbon sequestration method such as CCS or OIF.

Bottomline: a major part of the world wood production is not utilized, so why not use it to help solving the climate problem and reducing its negative consequences to the trees and ecosystems?
Potential Issues

1. How permanent is the buried carbon: can be very long, depending on how it’s buried
2. Nutrient lock-up
   - Fertilization may be needed in some areas, or don’t do it?
   - C:N ratio is 200:1 for wood (20:1 for leaves); 10 GtC/y locks away 50TgN/y, only a fraction of the fixation (110 TgN/y) or anthropogenic deposition (140) rate (Galloway et al., 1995).
3. Competition with other wood use (furniture, paper, biofuel, etc.): current wood use 0.9 GtC/y (Hurtt 2006)
4. Habitat loss
5. Disturbance to forest floor and soil
6. Other unintended consequences: deforestation follows roads!

Do not seem to hold back the proposal, but more research and thinking are needed!
Co-benefits with other activities (low hanging fruits?)

- **Reforestation and afforestation**
  Making the carbon sink permanent

- **Deforestation**
  Cutting off the carbon source by burying/storage, not burning

- **Post-consumer wood**
  Making waste a carbon sink

- **Fire suppression**
  Bury the fuel

- **Disturbance: storm blowdown, insect outbreak**
  Burial/storage instead of rotting
Avoided deforestation does not really reduce emissions, but just ‘avoid’ emissions from a baseline deforestation scenario.

The stored carbon is never really safe, and always subject to the risk of going back into the atmosphere.

The relatively ‘cheap’ price of REDD discussed, e.g., in Copenhagen, pays only for keeping the forest for 10-20 years: not long enough for climate!

So let’s do REDD+WHS by managing the forest as a carbon scrubber, not a carbon storage.

Keeping the chicken not for the chicken, but for the eggs.
Amazonia: Replace deforestation and ‘no-touch’ with forest management

- 50% (3 million km²) of the original Amazon forest is projected to be lost by 2050 if business-as-usual
- Continued deforestation is bad
- Pay-not-to-touch is not a long-term solution: too costly

How about:

Restore deforested land from the past, managed in mixed use for carbon sequestration, biomass and bioenergy, sustainable timber production, conservation and biodiversity, as well as cropping and livestock
On 2 Mkm², 0.3 GtC/y (=1GtCO₂/y)

Carbon market can make it work!

Soares et al., 2006
Reforestation followed by carbon management with WHS and other use

Change in forest coverage, FAO (2010)
America West: Biomass from bark beetle and fire suppression
Partial harvesting to prevent fire and store carbon

• Forests dying from infestation by beetles whose larvae survive through warm winters
• Decades of fire suppression left forests choked with fuel
• Effort at utilizing the wood for biomass or energy is hampered by the cost: Most trees are expected to be unutilized and release CO2

How about
Thin the forest for fire prevention and store the wood at low cost for carbon sequestration, with options of utilizing it when infrastructure is ready and deemed more desirable
Concluding Remarks

- Wood burial is a first step of a fossilization process, thus a ‘natural’ way to undo fossil fuel burning.
- WHS is a ‘no-regret’ strategy: distributed, low tech, low cost, safe, easy to monitor, can be stopped or reversed at any time.
- Synergy with other activities such as reforestation, deforestation control, waste wood management, fire suppression, disturbance wood, avoided deforestation.
- Provides green jobs.
- The carbon sequestration potential may rival current fossil fuel emission rate, but only part of it can be realized.
- Economically viable for large-scale implementation soon in a serious world-wide carbon market.
- Research needed to address practical issues.
Thank You