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

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Based on talks at AGU, EGU and several seminars since 2008
and papers of Zeng (2008, CBM), Zeng et al., (2013, Clim. Change)
In near final form in 2016 seminar at FEEM/Eni Foundation
Minor update in 2021

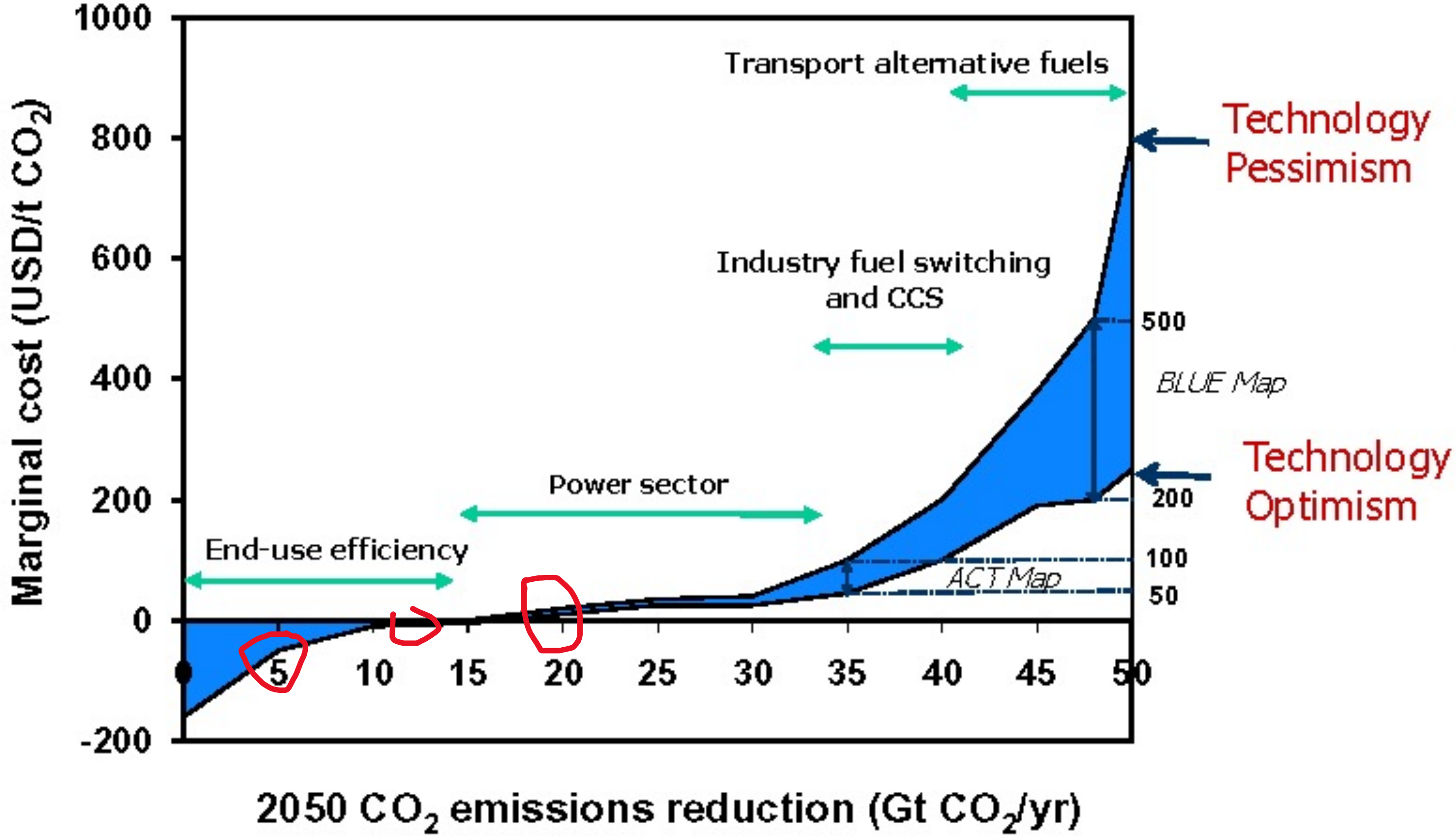
What can we do about the climate problem?

- 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 CO_2

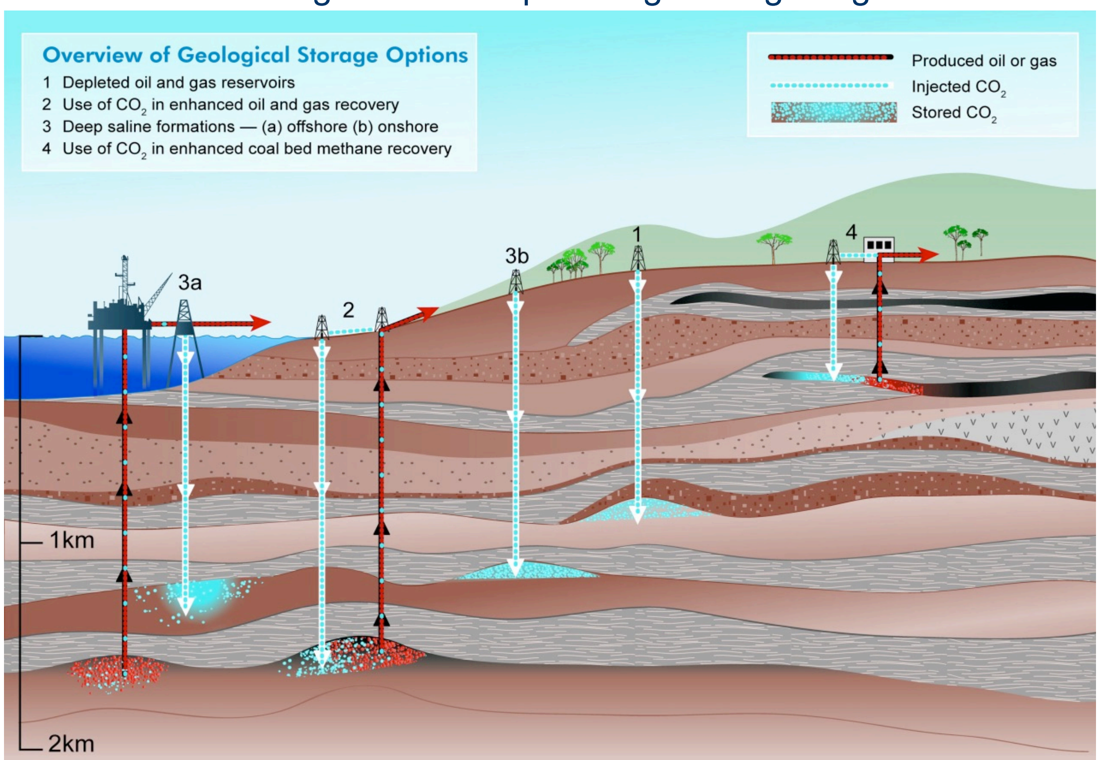
Carbon sequestration methods -- by stage

- 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 aquaifers
  - 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

Methods for storing CO2 in deep underground geological formations



SRCCS Figure TS-7

IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

May capture 80-90% of CO2 emission

Needs 10-40% more energy

30-60% more expensive

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

Storage capacity: 1000 GtC? Potential leakage?

Energy, Vol. 2. pp. 287–291. Pergamon Press 1977. Printed in Great Britain

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 CO_2 in the atmosphere contains 7×10^{11} tons of carbon.[1] The burning of fossil fuels is adding to the atmosphere 5×10^9 tons of carbon per yr.[2] Of this amount, only 2.5×10^9 tons per yr is appearing as net increase of atmospheric CO_2. The remaining 2.5×10^9 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

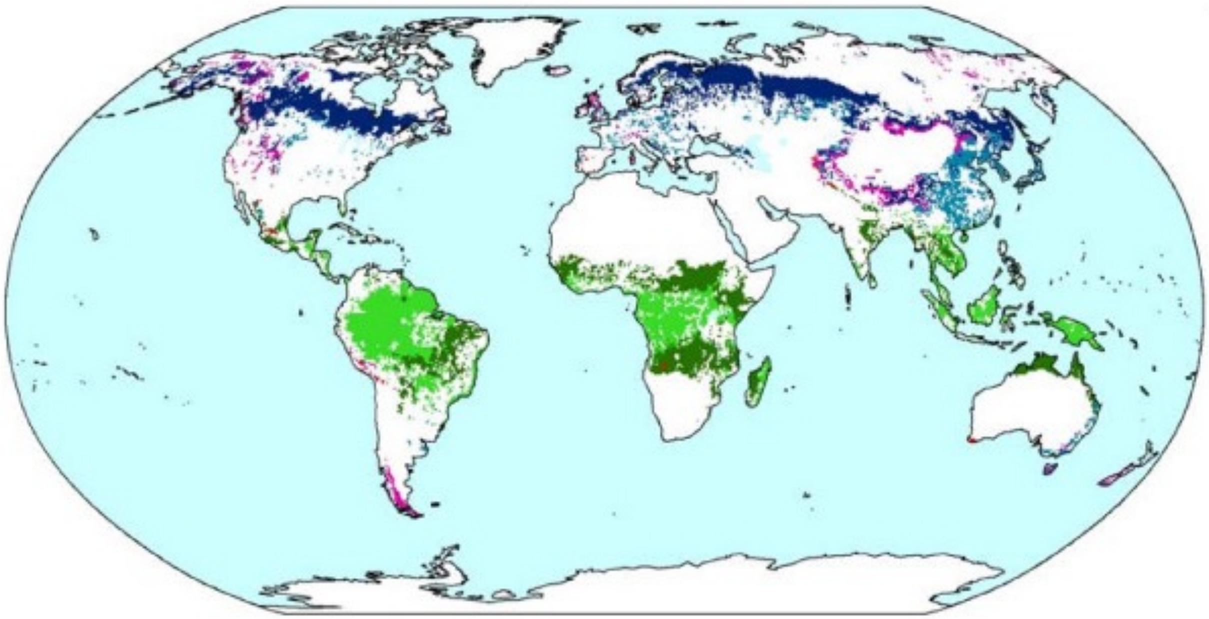
Enhancement of terrestrial carbon storage
Reforestation

•Low cost and environmentally appealin
(popular option for carbon offset)

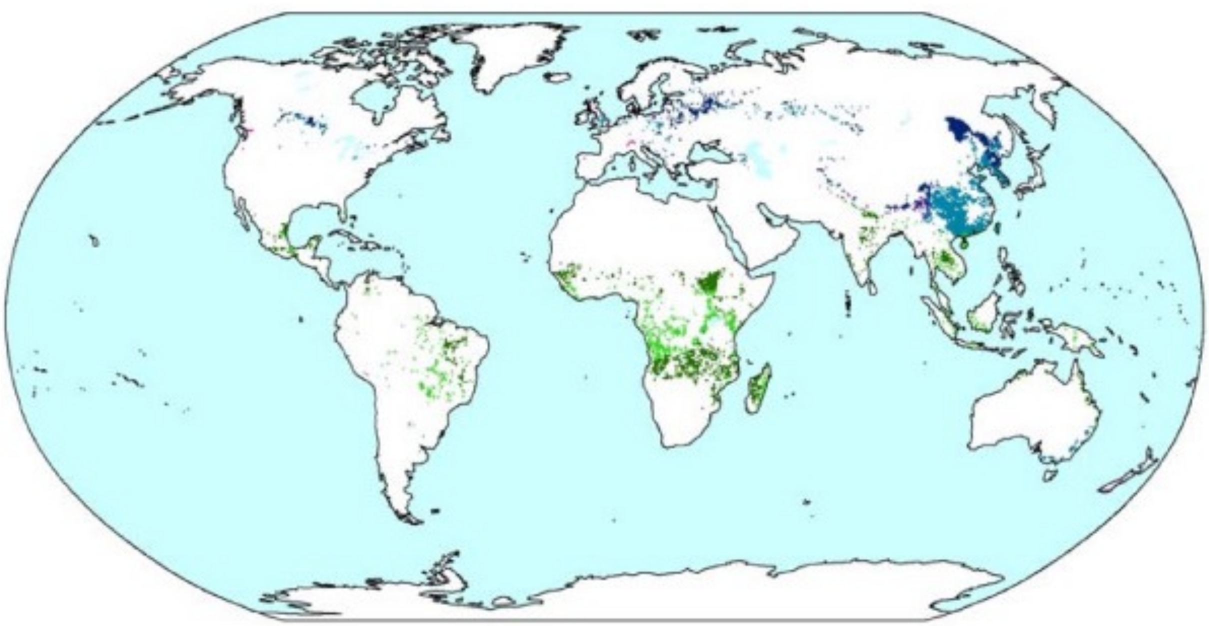
•Capacity (limited by available land):
40-600 MtC/y for US for few decades
(Richards and Stokes 2004)
less than 100 GtC total Global (IPCC200

•Cost: low ($0-400/tCO2)

•limitations:
limited by available land
saturates
cost rises sharply at high capacity



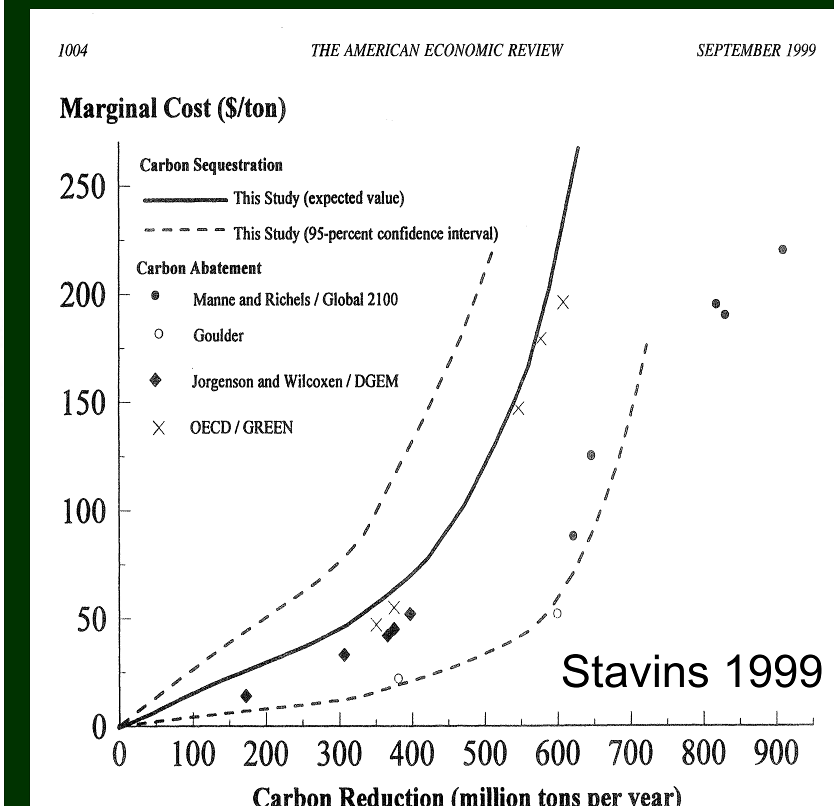
Physical potential



Social potential

Van Minnen et al. 2008

Cost rises at larger sequestration rate



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

Carbon sequestration via wood harvest and storage (WHS)

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"

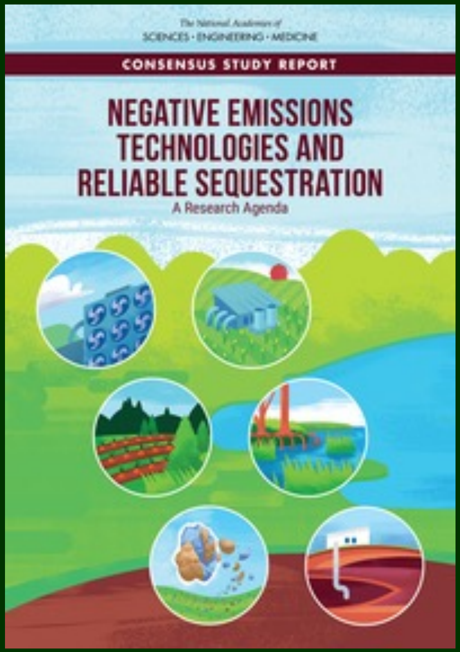
  R. Lovett, *New Scientist*
- "Your suggestion for sequestering carbon is a good one…The big question is how much would it really cost"

  Freeman Dyson, Inst. Advanced Studies, Princeton
- "I read your paper on burying trees with great interest"

  Thomas Schelling, Nobel economist
- "It might work"

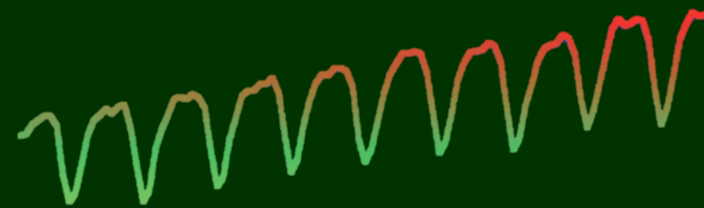
  Paul Crutzen, Nobel laureate
- "… could be viable approaches to increasing carbon removal… To date, this proposed approach has not been tested though the technology is simple and easily applied."

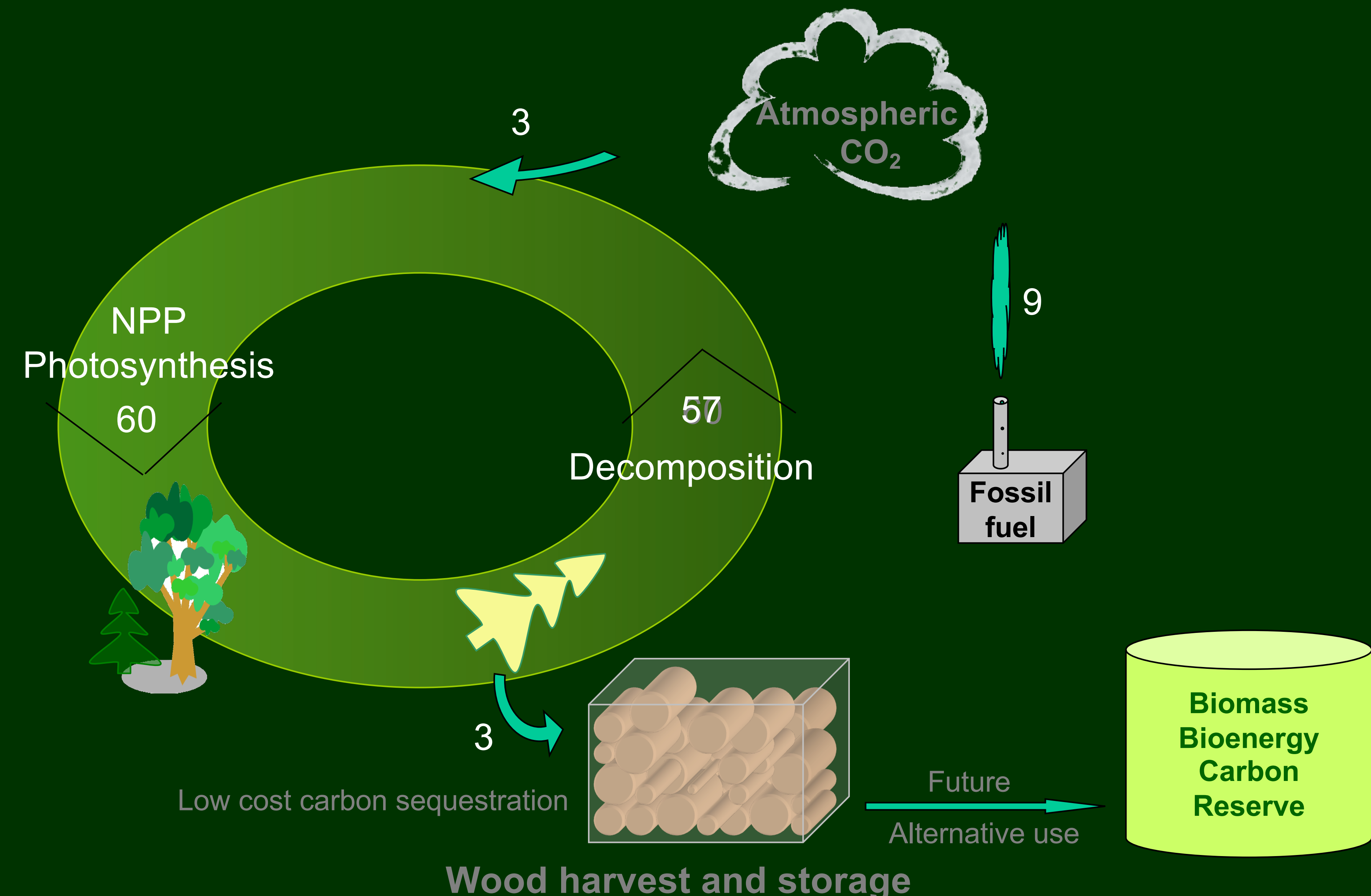
  National Academy of Science Report on NETs, 2019



How does it work?

A carbon cycle perspective

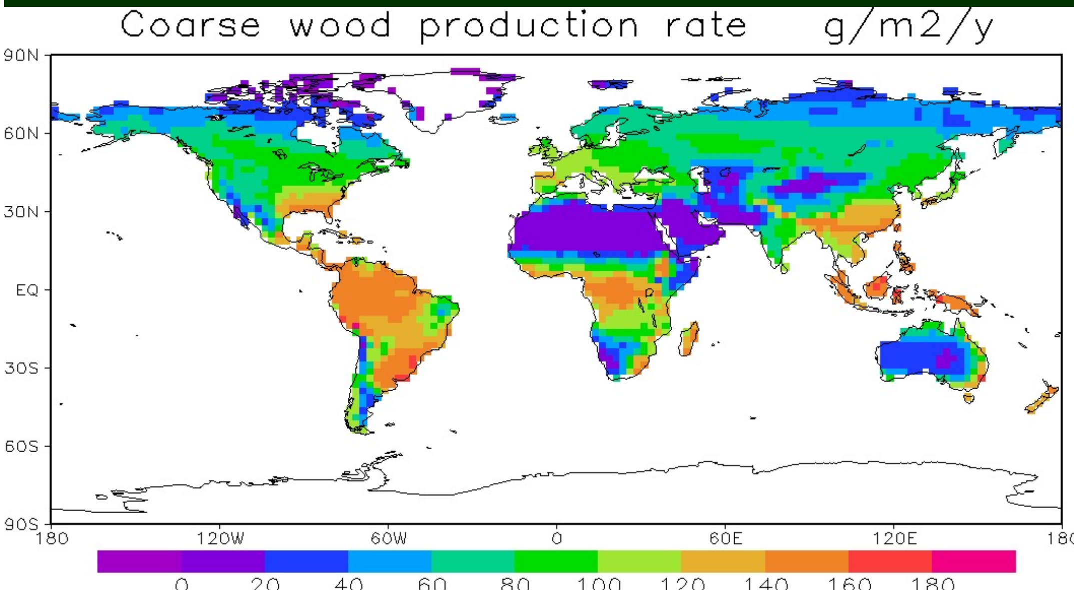




Issues I will address

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

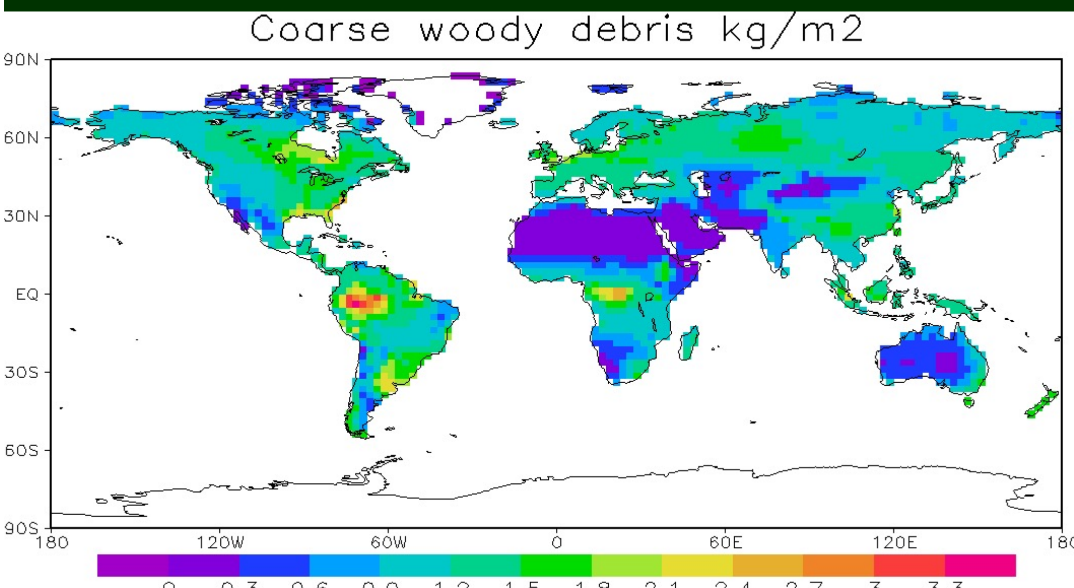
Theoretical Potential



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

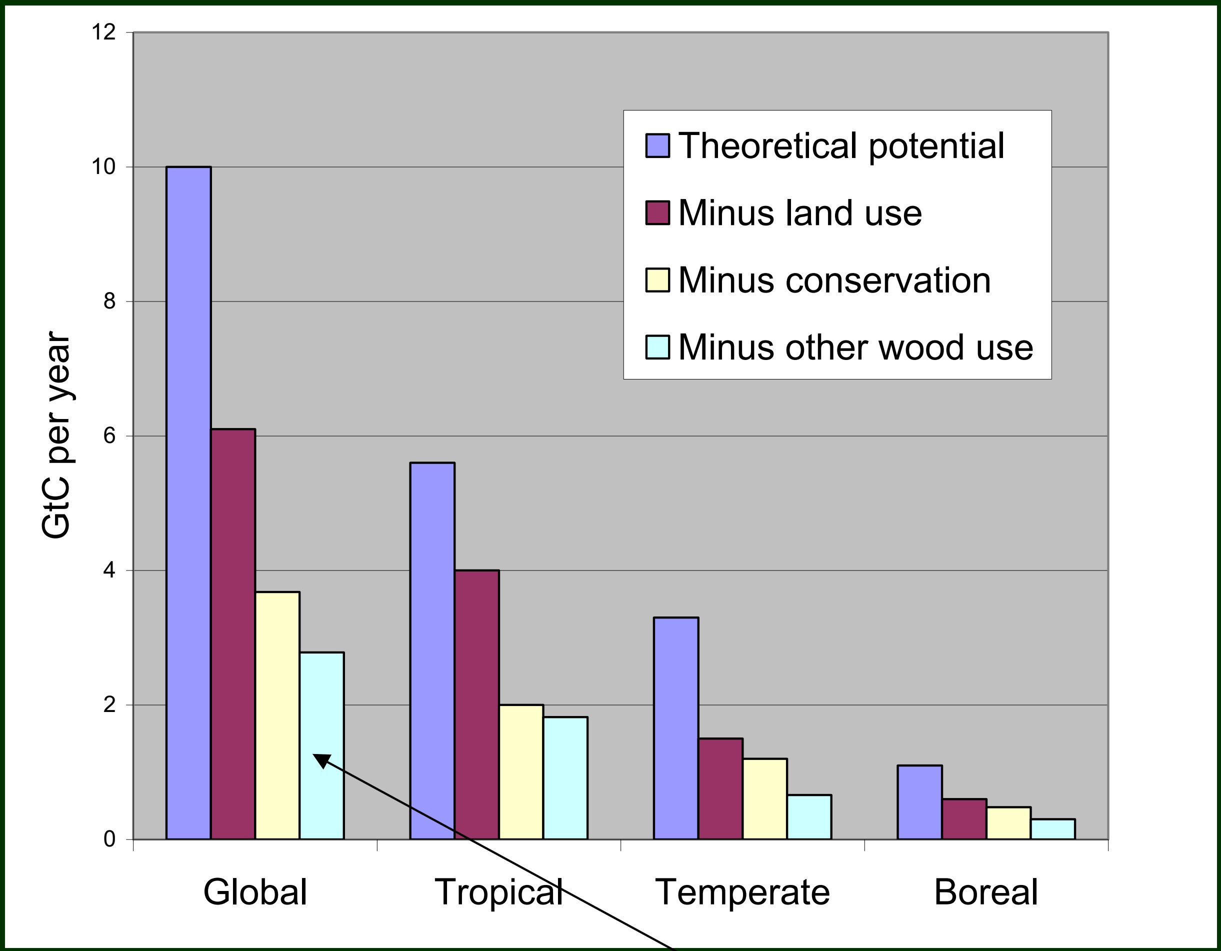
-- coarse dead wood on forest floor

Zeng (2008), Carbon Balance and Managemen

"Practical" Potential

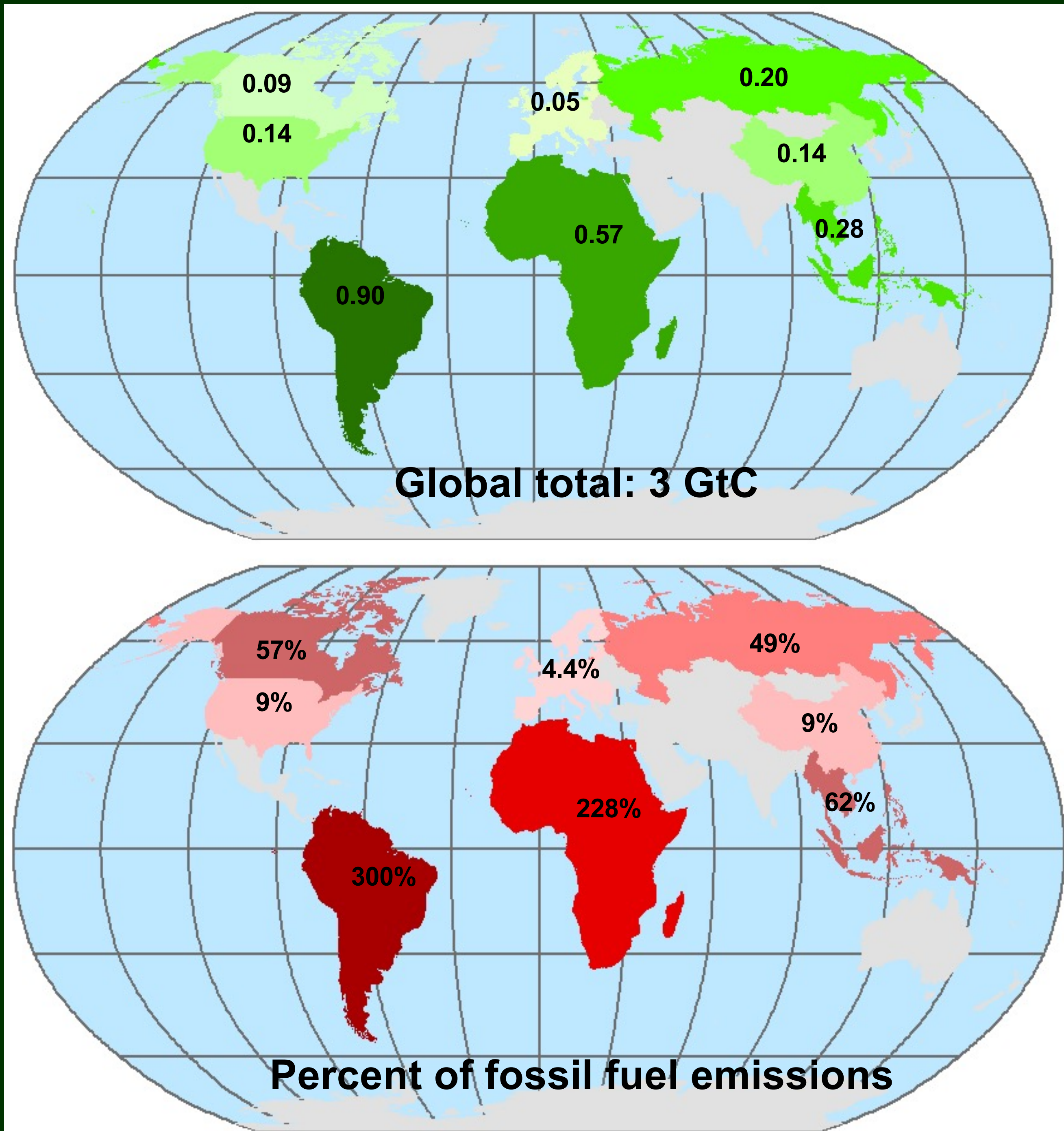
Constraints considered

- Land use
- Conservation (50%)
- Accessibility
- Other wood use



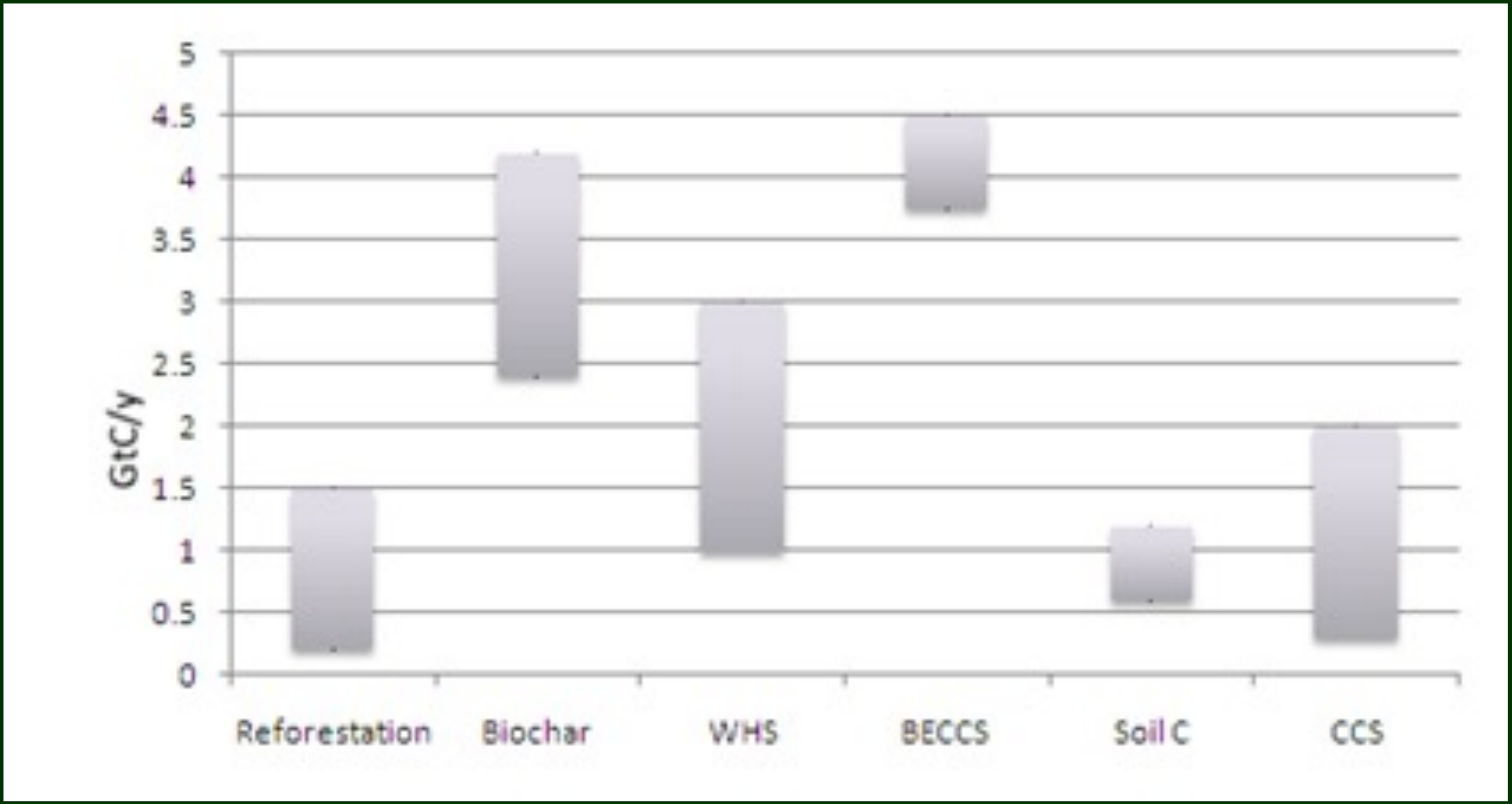
Final global potential 3 GtC/y

Sequestration potential by continent



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

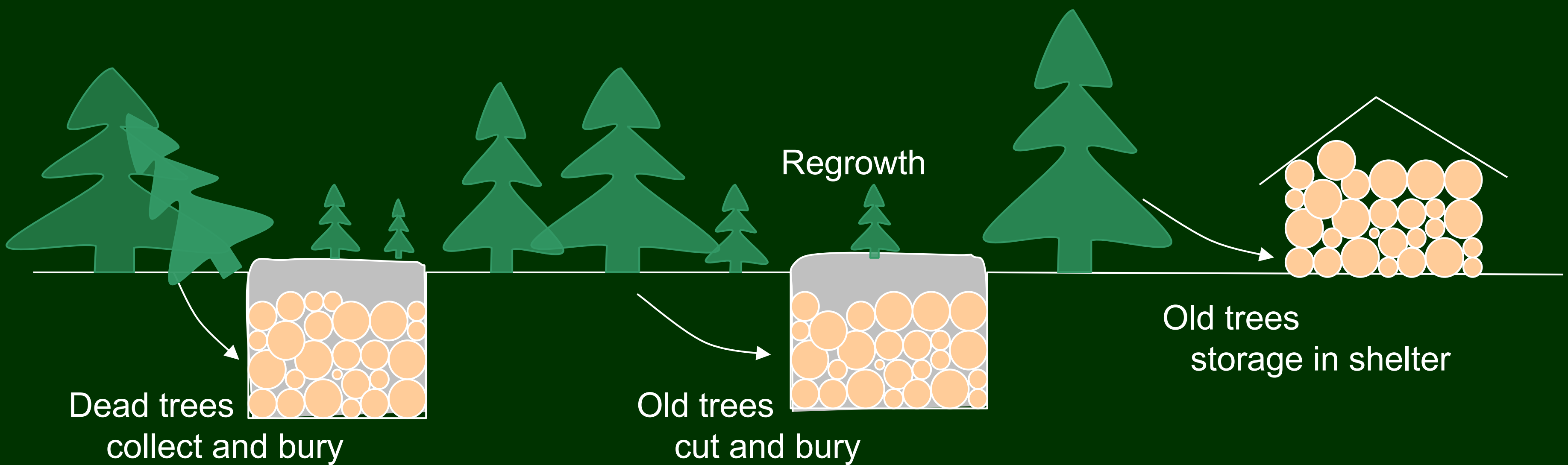
"Practical" Potential v2

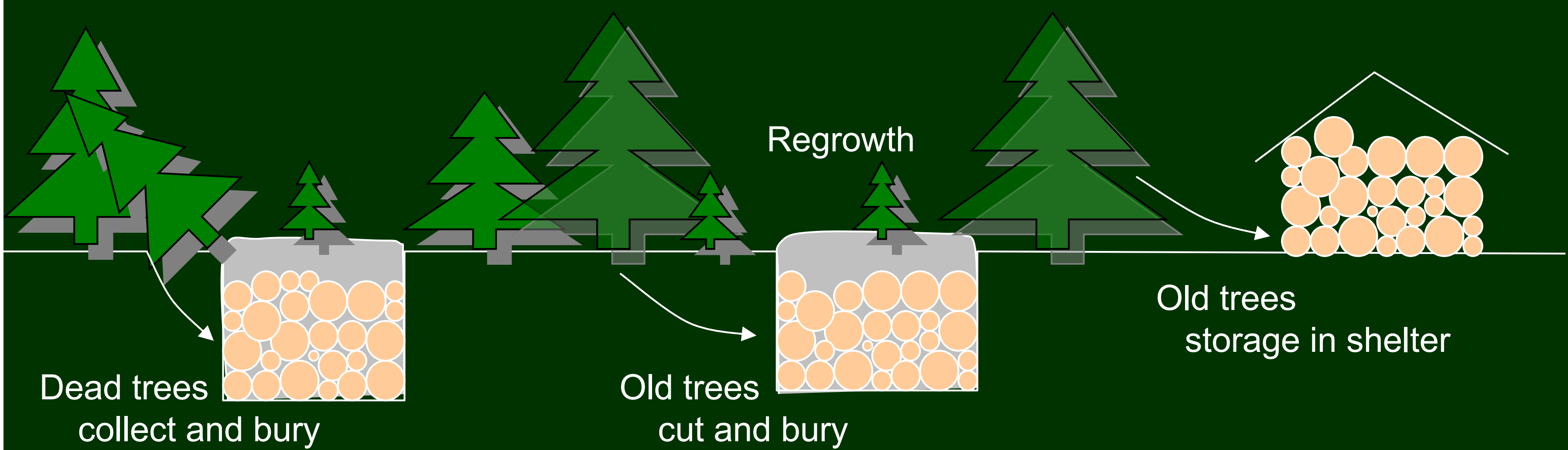
Bottom up Assessment

- 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

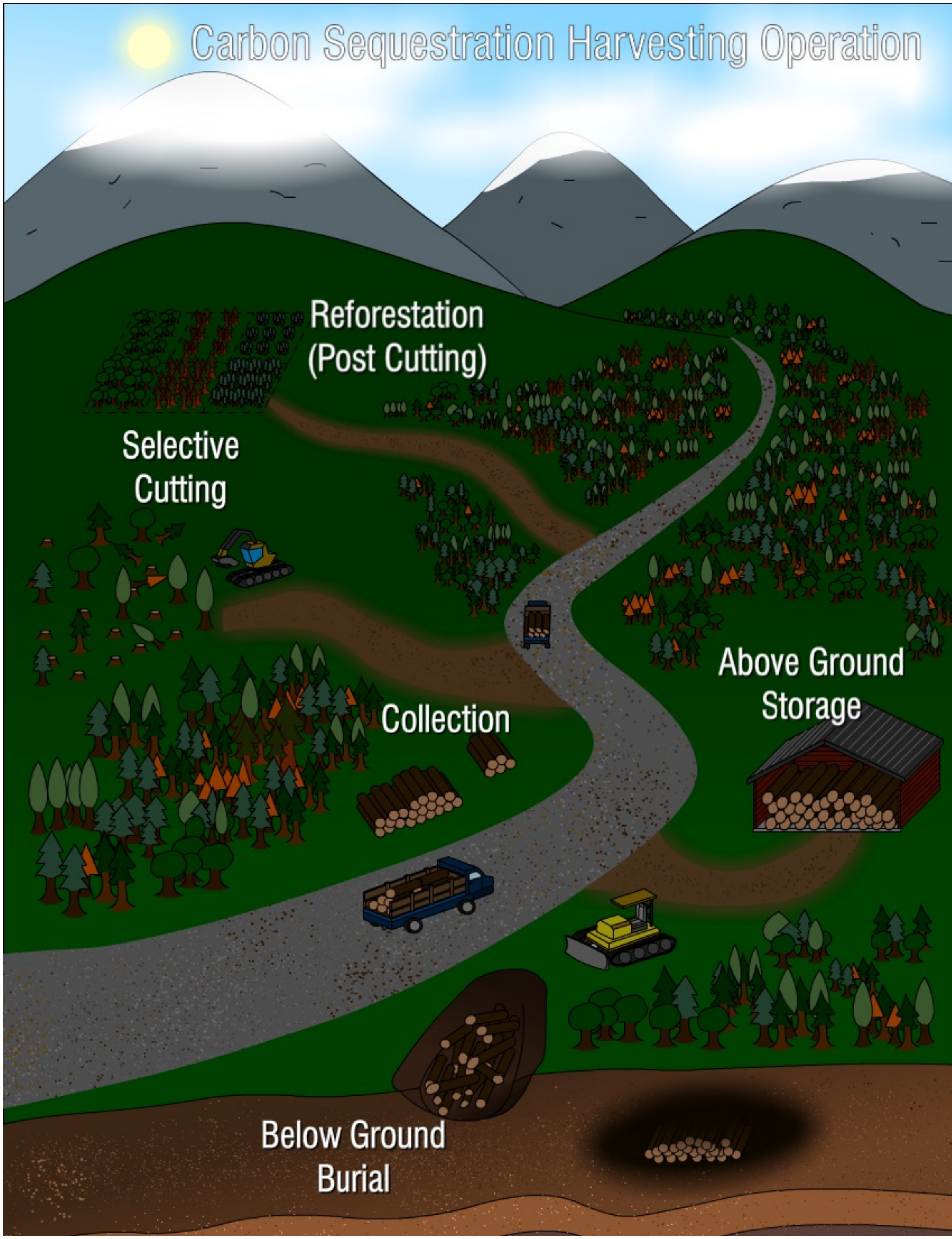
- Access
- Trench digging or shelter building
- Collection or tree cutting, delimbing, bucking for burial or storage




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

Cut-to-length logging

Felling, delimbing, bucking



Operation
-- A vision

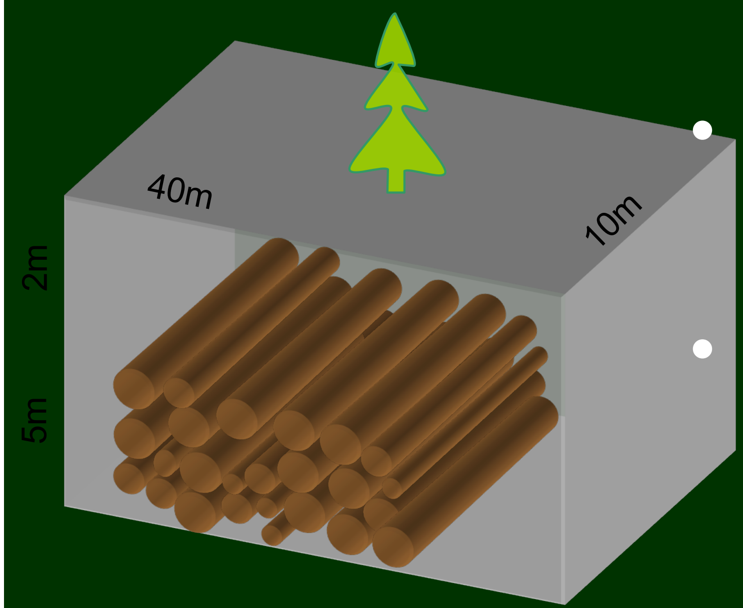
In-situ

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

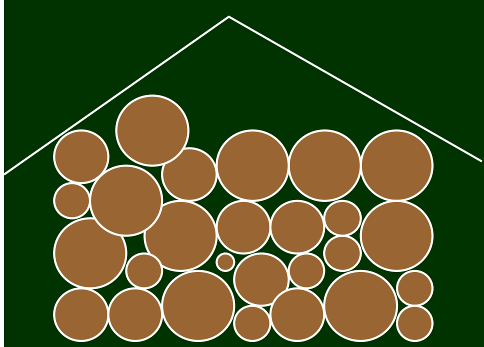
Large facility (woodfill)

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

Wood Burial	Power plant CO_2 capture with geological storage (CCS)	Price on Chicago Climate Exchange (CCX) 2006	European carbon trading market price during 2005-2011
\$14/tCO_2 (\$7-27)	\$20-270/tCO_2 (IPCC, 2005)	\$3-4/tCO2	€1-33/tCO_2
\$50/tC (\$25-100)	\$73-990/tC	\$12-16/tC	€4-120/tC
Storage safe; semi-permanent, reversible; some environmental concern	Possibility of leakage; lower cost storage capacity small		
Potential: 10 (5-15) GtC/y Long-term: thousands of GtC or no practical limit	Potential rate is limited by scale of operation Longterm: > 500 GtC		

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 tCO_2 as carbon unit which has been converted into tC with the conversion factor CO_2:C=44:12.

- Furniture is expensive, but raw wood is Not
- 5 times more carbon in raw wood than in lumber

From forest to lumber:

Cost, CO_2 emissions, and the fate of wood

Pulpwood

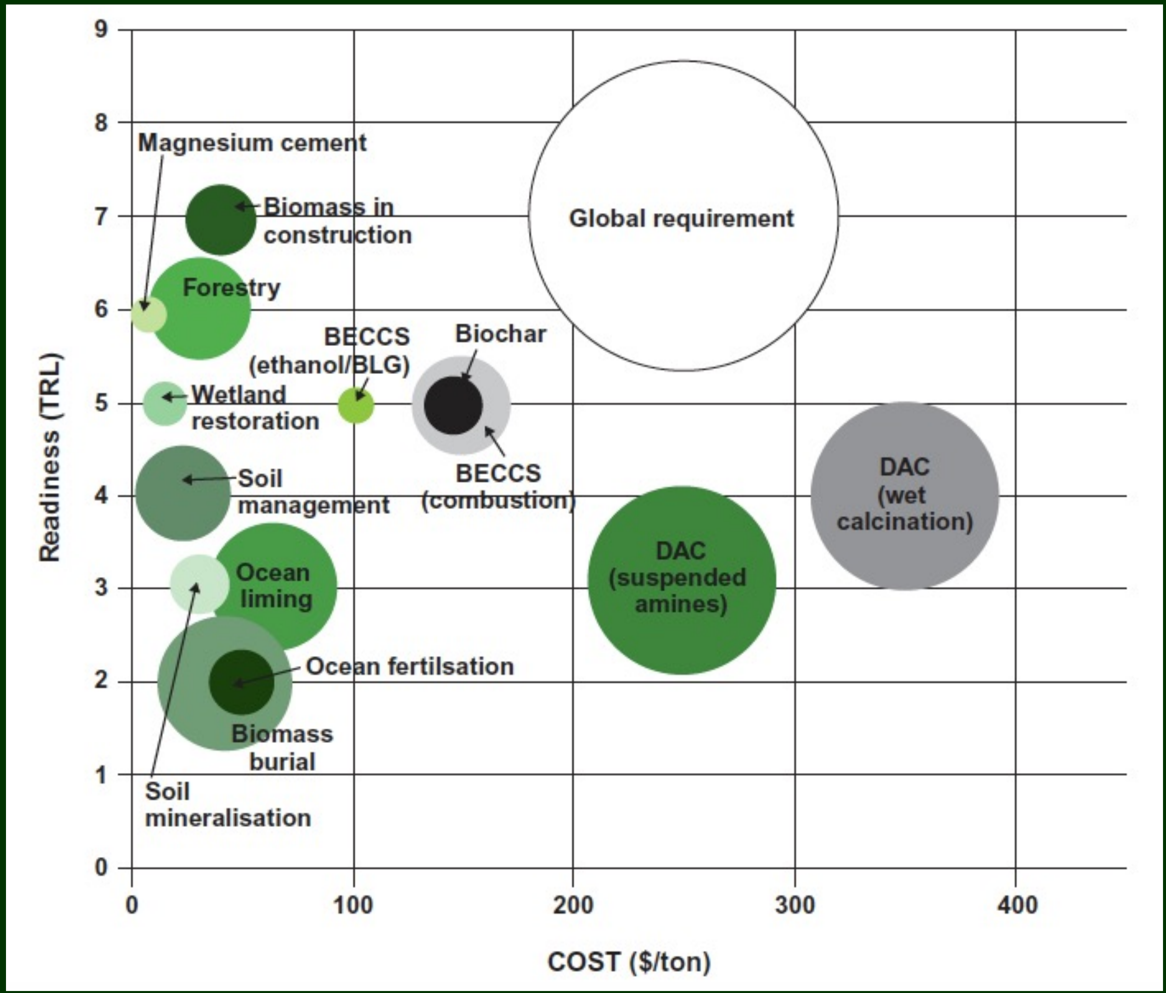
fue

	Harvesting (Stump to Landing)	Transportation (Landing to Mill)	Processing to Lumber	Transportation Handling
Cost	$12/m³log	+$12=$24	$100/m³Lumber ($50/m³log?)	$200/m³Lumber
CO_2 emissions ($tCO2/m^3log$)	0.01	+0.01=0.02	+0.04=0.06	+0.22=0.28
Wood in product (% of live biomass)	60%		23%	End use 18%

Source: CORRIM Consortium; Ingerson (Wilderness Society)

Comparison of negative emissions technologies (NETs)

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



Biomass burial

Low cost ($10-50/t$CO_2$)

Potential

2-10 GtCO_2/y

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

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

uried wood can decompose extremely slowly

Ancient Kauri trees >50,000 years old

New Zealand
Source: the internet

Buried wood can decompose extremely slowly

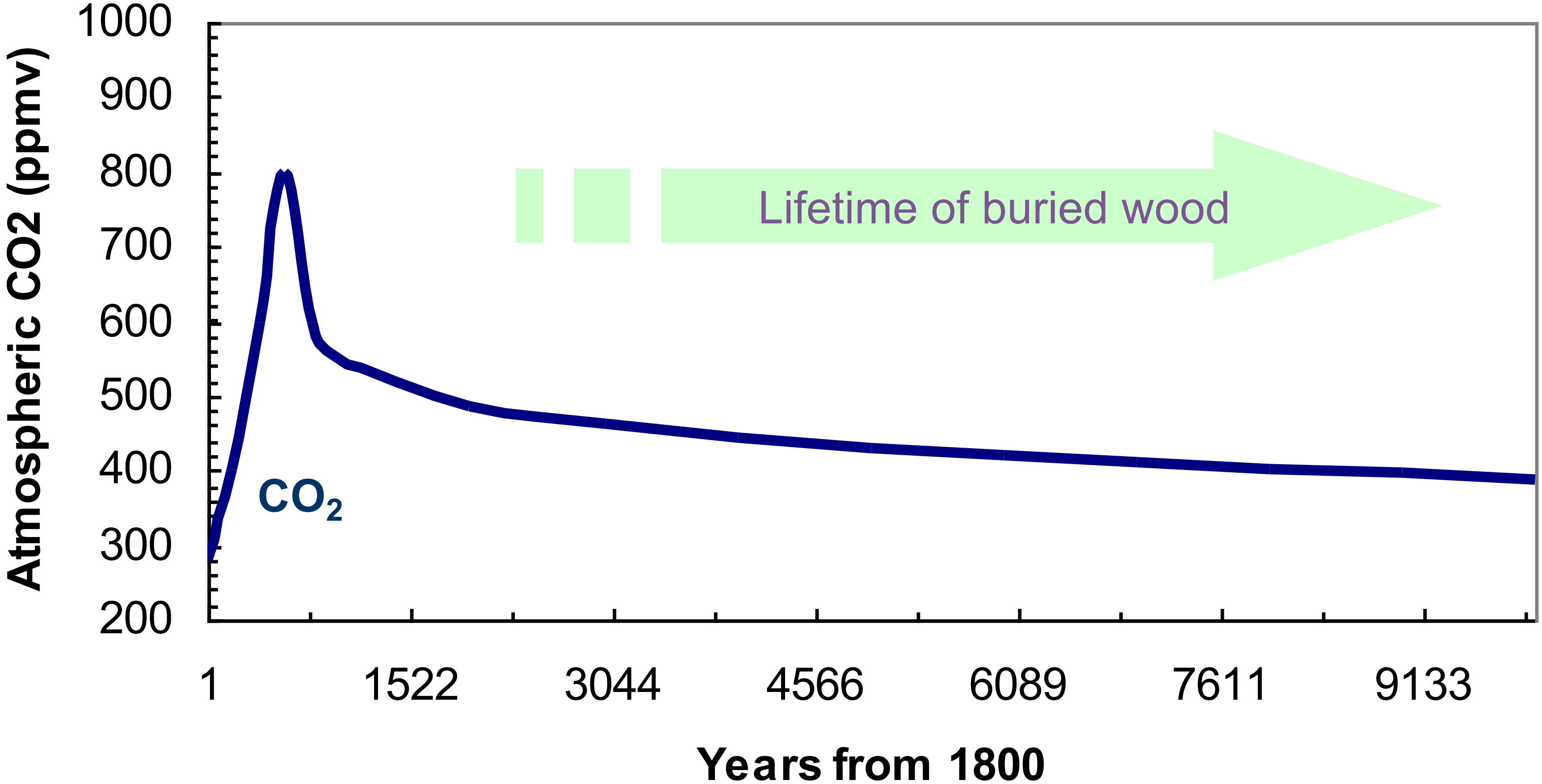
Paper

Wood in a landfill after 46 years, Australia

Ximenes et al., 2008

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

Other storage methods

Wet

Sweden

Dry

Southwestern US?

The goal is to prevent decomposition

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
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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

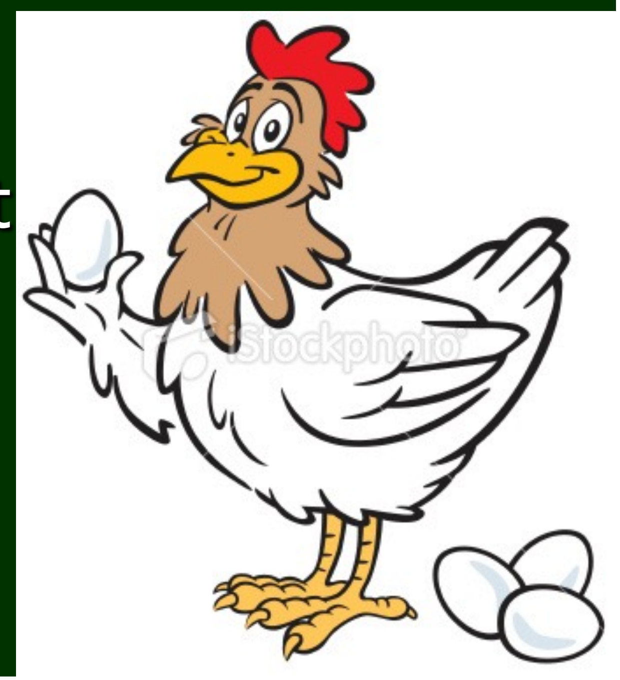
- Post-consumer wood
  - Making waste a carbon sink
- Fire suppression
  - Bury the fuel
- Disturbance: storm blowndow, insect outbreak
  - burial/storage instead of rotting

REDD + WHS ?

- 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



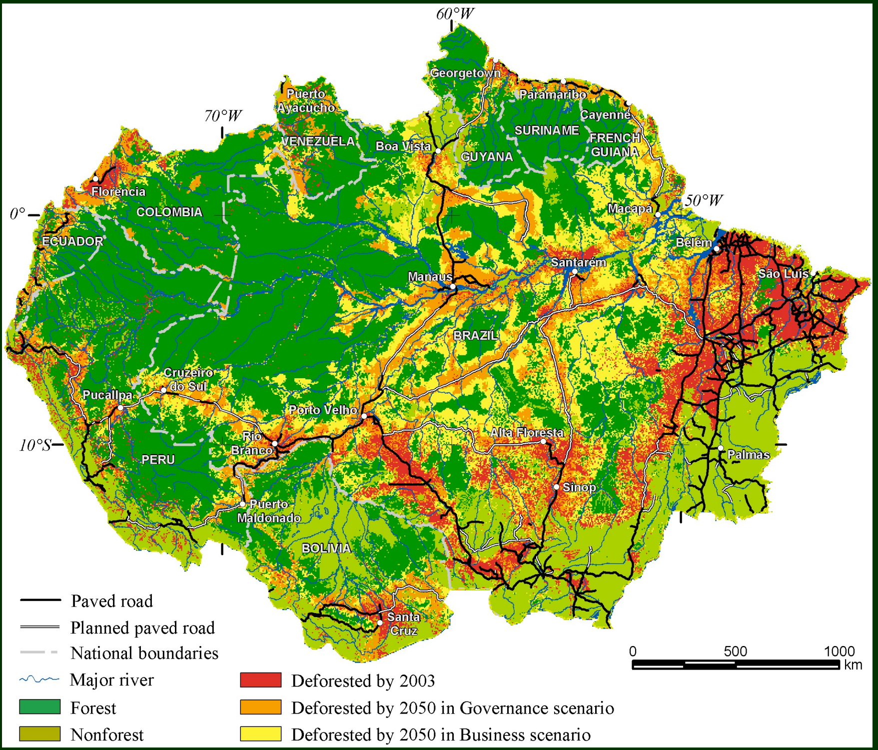
Amazonia: Replace deforestation and 'no-touch' with forest management

- 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 Mkm^2, 0.3 GtC/y (=1$GtCO_2$/y)

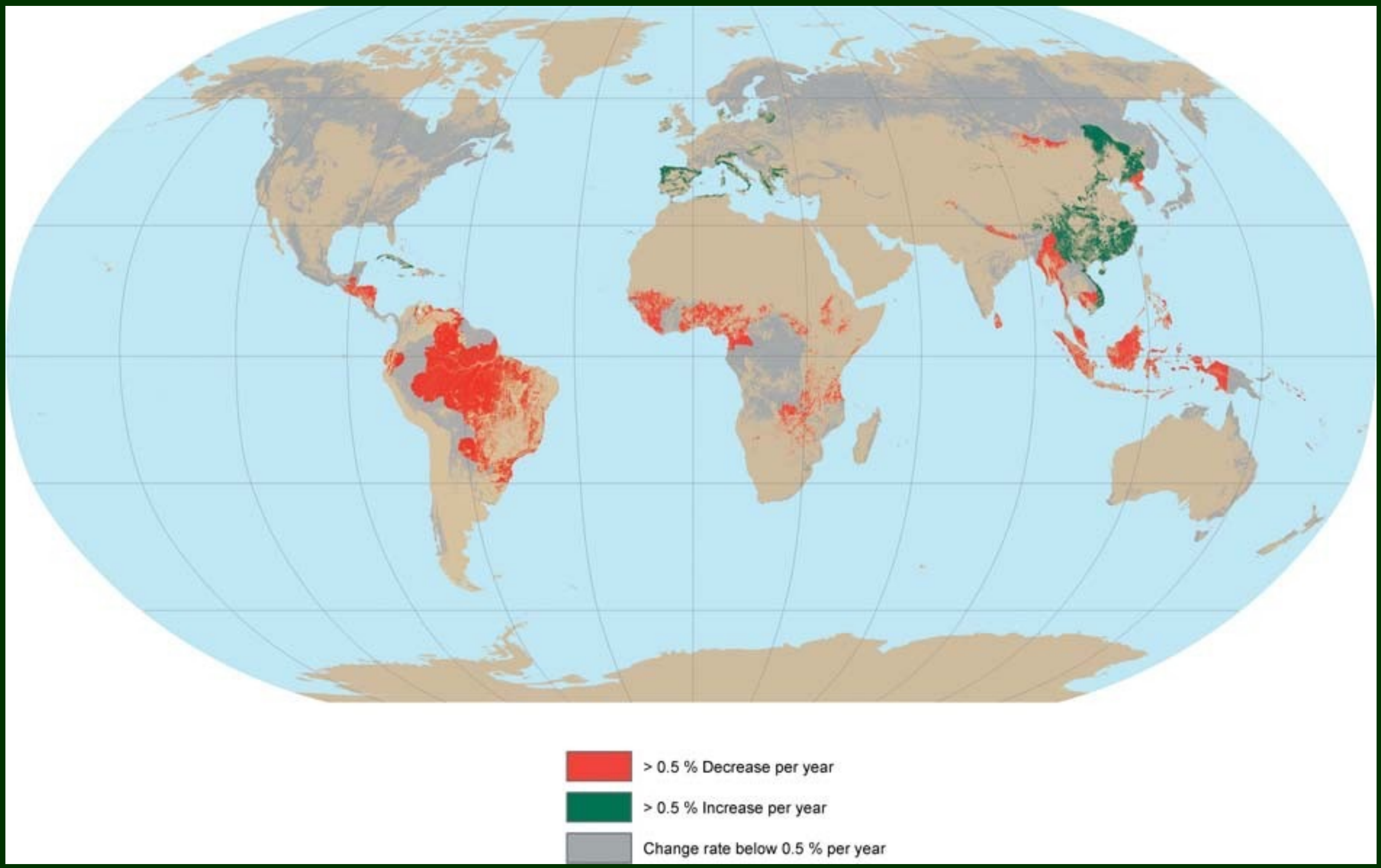
Carbon market can make it work!



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 CO_2

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