TERRESTIAL GEO-ENGINEERING SCHEMES

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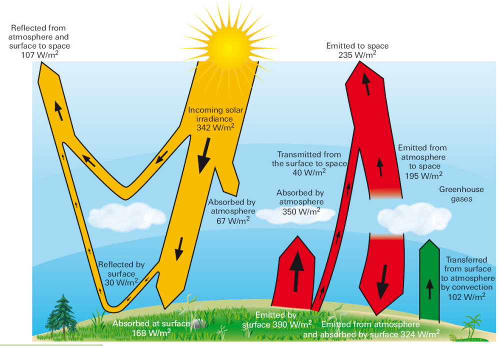
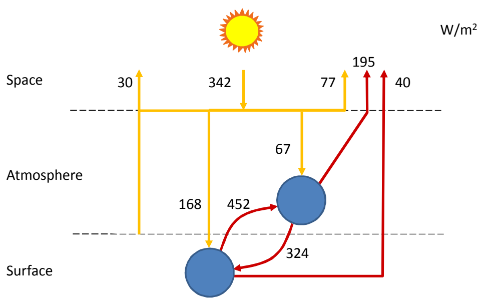
ENERGY BALANCE



Short-wave
Long-wave

[Fig 1.1 Royal Society Report, UK. Geoengineering the Climate, Sept 2009]

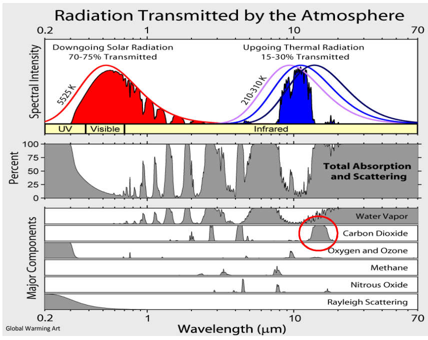
ENERGY FLUXES



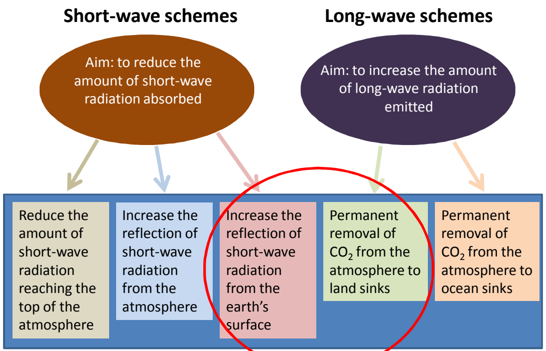
A huge cycling of heat...

Short-wave
Long-wave

RADIATION TRANSMISSION AND ABSORPTION



GEOENGINEERING

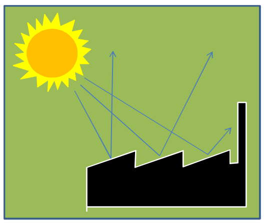


[Adapted from Lenton and Vaughan, 2009]

SURFACE ALBEDO

Make the surface of the earth more reflective:

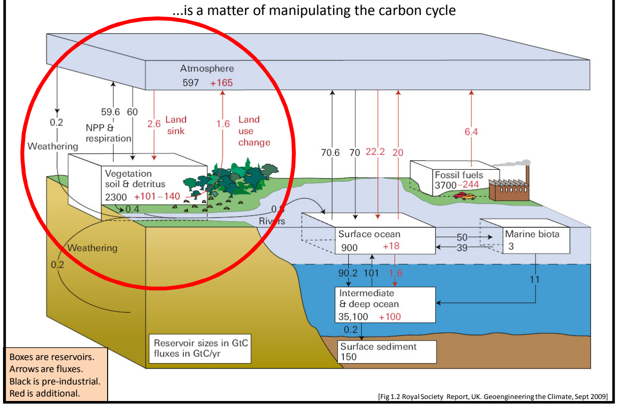
- deserts
- grasslands
- croplands
- human settlements
- cities



Changing the reflectance of deserts is most effective

REMOVING CO_2 TO LAND SINKS

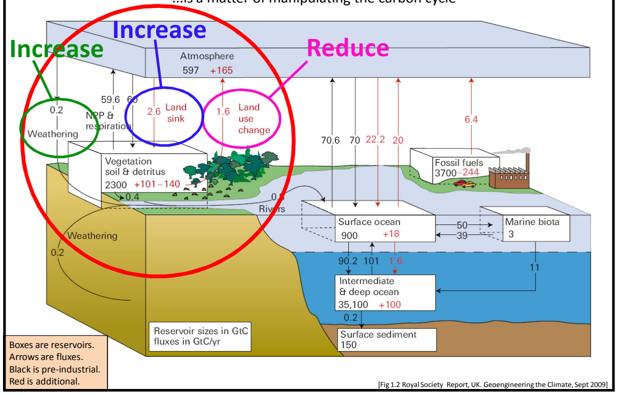
...is a matter of manipulating the carbon cycle



[Fig 1.2 Royal Society Report, UK. Geoengineering the Climate, Sept 2009]

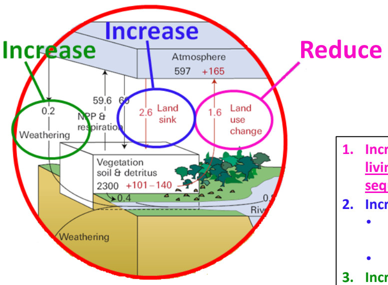
REMOVING CO_2 TO LAND

...is a matter of manipulating the carbon cycle



[Fig 1.2 Royal Society Report, UK. Geoengineering the Climate, Sept 2009]

REMOVING CO_2 TO LAND



1. Increase carbon storage in living biomass and sequestration of living biomass.
2. Increase soil carbon levels by
   - stabilising soil organic carbon
   - biochar amendment
3. Increase the CO_2 capture by weathering minerals

1. CARBON STORAGE IN LIVING BIOMASS

Land use change accounts for ~20% of anthropogenic GHG emissions. These arise principally from:

- deforestation
- burning
- depletion of soil carbon levels.

Eco-system storage is temporary and so is not regarded as geoengineering. However, it is easy to understand. Over a timeframe of ~50 years, a positive storage flux can offset some emissions.

The **most promising approaches** are avoided deforestation and forest degradation, afforestation, and reforestation.

BUT, achieving greater eco-system storage is complex, balanced by competing land uses for food production and biodiversity.

Policy frameworks and markets are essential.

1. SEQUESTRATION OF LIVING BIOMASS

Biomass can be directly sequestered in deep oceans or underground where decay rates are low.

The **most promising feedstocks** are agri-forestry residues...

BECAUSE, long term sequestration of biomass carbon must not adversely affect land use for food production and biodiversity.

Policy framework and markets are essential.

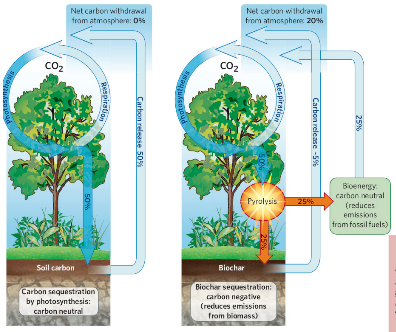
2. INCREASE SOIL CARBON BY STABILISATION

1/3 of terrestial organic carbon is in biomass, 2/3 exists as soil organic carbon

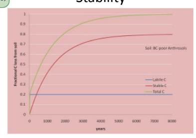
Soil organic carbon decays aerobically to CO_2. It may be stabilised in the soil by aggregating the soil carbon with minerals such as:

- organo aluminium complexes
- alumina silicate minerals

2. INCREASE SOIL CARBON WITH BIOCHAR



Stability



[Lehmann, 2007] [Adapted from: B. Liang et al., Geochimica et Cosmochimica Acta 72 (2008) 6069–6078]

2. INCREASE SOIL CARBON BY BIOCHAR AMENDMENT

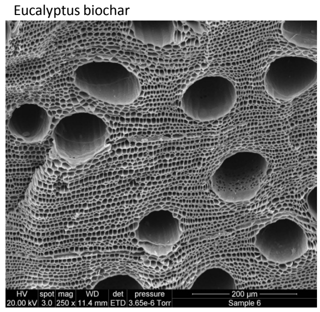
Agricultural benefits that occur in some systems

- Improved crop yields
- Improved water retention of soil
- Less fertiliser requirement
- Less energy to harvest

Through

- Improved soil aeration
- Lowered soil bulk density
- Lowered soil strength
- Reduces soil acidity
- Alters the supply of electron acceptors and redox potential in soil
- Reduced NO_2 emission from soil
- Reduced CH_4 emission from soil
- Increased P uptake by plants
- Reduced leaching of nitrate
- Reduced leaching of phosphorus

Eucalyptus biochar



[image supplied by Marta Camps]

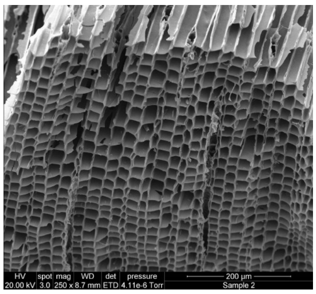
2. INCREASE SOIL CARBON WITH BIOCHAR

Downsides

- Dust
- Spontaneous combustion
- Altering local ecosystem
- Runoff
- Competition between biochar/biofuels and food production
- Land use change

Full Life Cycle Analyses (LCA) are required to avoid any unintended negative consequences.

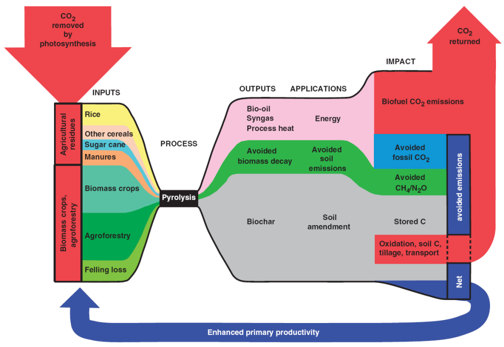
Pine biochar



[image supplied by Marta Camps]

2. INCREASE SOIL CARBON WITH BIOCHAR

The Sustainable Biochar Concept

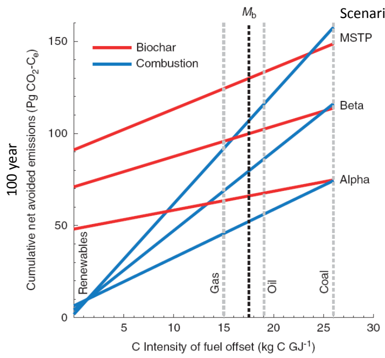


[Woolf et al, 2010]

2. INCREASE SOIL CARBON WITH BIOCHAR

Potential of biochar

Scenario: feedstock availability



1 Pg = 1 Gt

MSTP = maximum sustainable technical potential, M_b = baseline energy intensity 17.5 kgC GJ^{-1} [Woolf et al, 2010]

3. WEATHERING

In Practise

ex situ

Mining silicates → Grinding → Transport → Integration into soil

Requires huge volumes ~ 7 km^3/yr

A 1GW coal-fired power station requires 55,000 tonnes/yr to capture the CO2

in situ

CO_2 capture from air/flue gas → Injection into basalt bedrock

Geological storage

CCS research is driven coal-fired power producers

3. WEATHERING

Silicate Minerals

Serpentine

$$\frac{1}{3}\, Mg_3Si_2O_5(OH)_4 + CO_2 \rightarrow MgCO_3 + \frac{2}{3}\, SiO_2 + \frac{2}{3}\, H_2O + 64\ \text{kJ/mole.}$$

magnesite

Olivine (fosterite)

$$\frac{1}{2}\, Mg_2SiO_4 + CO_2 \rightarrow MgCO_3 + \frac{1}{2}\, SiO_2 \qquad + 90\ \text{KJ/mole}$$

magnesite

Anorthite

$$CaAl_2Si_2O_8 + CO_2 + 2H_2O \rightarrow CaCO_3 + Al_2Si_2O_5(OH)_4$$

calcite

In wet pedoclimatic conditions the carbonate exists as a bicarbonate ion in solution and makes its way into the oceans.

[Goldberg et al. http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/6c1.pdf]

3. WEATHERING

Basalts

Basalts contain 7-10% wt Calcium, 5-6% wt Magnesium and 7-10% wt Iron.
These metals are readily liberated by reaction with CO_2-rich water

CO_2 solubility in water is a function of pressure

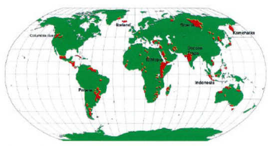


FIGURE 2 Locations of continental basalts that could serve as in situ mineral carbonation sites

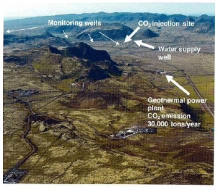


FIGURE 4 The field-scale, in situ basalt-carbonation pilot plant in Hellisheidi, Iceland. PHOTO BY MATS WIBERLUND

[Oelkers et al., 2008]

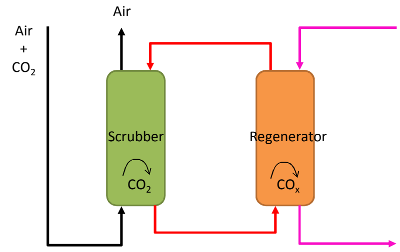
LAND-BASED CO_2 REMOVAL

Table 2.1. Carbon dioxide removal methods

	Land	Ocean
Biological	Afforestation and land use Biomass/fuels with carbon sequestration	Iron fertilisation Phosphorus/nitrogen Fertilisation Enhanced upwelling
Physical	Atmospheric CO_2 scrubbers ('air capture')	Changing overturning circulation
Chemical ('enhanced weathering' techniques)	*In-situ* carbonation of silicates Basic minerals (incl. olivine) on soil	Alkalinity enhancement (grinding, dispersing and dissolving limestone, silicates, or calcium hydroxide).

[Table 2.1. Royal Society Report, UK. Geoengineering the Climate, Sept 2009]

PHYSICAL REMOVAL - SCRUBBERS



Large scale scrubbing will be developed first for industrial flue gases where the CO_2 concentrations are elevated.

PHYSICAL REMOVAL - SCRUBBERS

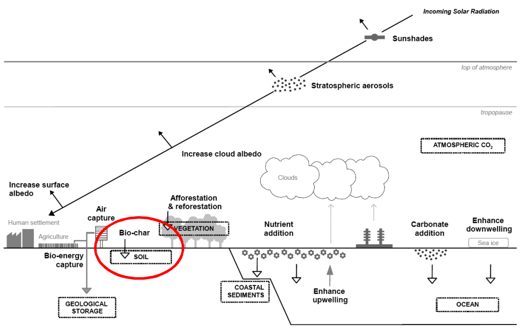
Methods of carbon dioxide scrubbing include :

Absorption (into solution)
Takes advantage of solubility and reaction chemistry. E.g.,
- Regenerative CO_2 removal using strong bases (e.g. LiOH, NaOH) The $LiCO_3$ or $NaCO_3$ are then regenerated.
- Amine absorption: monoethanolamine solution absorbs CO_2 when cold and release it when warmed.

Adsorption (onto surfaces)
Takes advantage of the surface affinity as a function of humidity, temperature and pressure. E.g.,
- Molecular sieve s (e.g. activated carbon)
- Polymer membrane gas separators

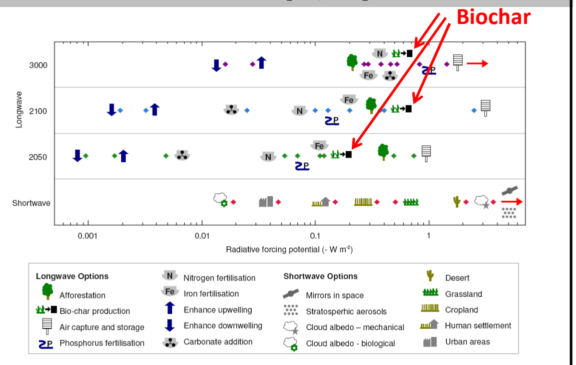
FORCINGS [W/m²]

How effective is **biochar** compared to other geoengineering schemes?



[Lenton and Vaughan, 2009]

FORCINGS [W/m²]



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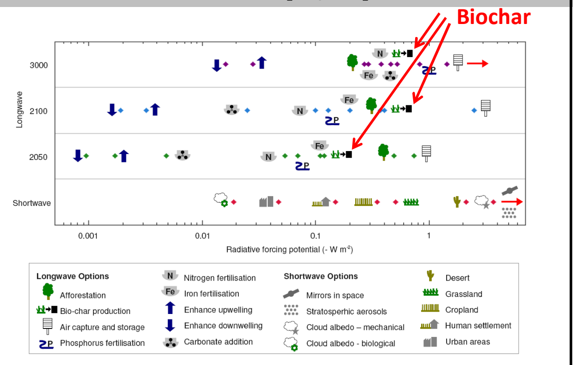
FORCINGS [W/m²]



[Lenton and Vaughan, 2009]

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