Wedges from the Biosphere:
Land-based options for climate mitigation

David Hawkins and Steve Pacala
Fate of anthropogenic CO₂ emissions (2008–2017)

Sources = Sinks

<table>
<thead>
<tr>
<th>Sources</th>
<th></th>
<th>Sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.4 GtCO₂/yr</td>
<td>87%</td>
<td>17.3 GtCO₂/yr</td>
</tr>
<tr>
<td>5.3 GtCO₂/yr</td>
<td>13%</td>
<td>11.6 GtCO₂/yr</td>
</tr>
</tbody>
</table>

Budget Imbalance:
(the difference between estimated sources & sinks)

5% 1.9 GtCO₂/yr

A Wedge every nine years that is taken for granted.

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018
Wedges from the Biosphere

BECCS and Biofuels

Agricultural Soils

Avoided Deforestation

Re/Afforestation Forest Management
Are these options comparable to fossil emissions reductions? Four issues for each.

• Co-benefits and additional costs
• Permanence
• Additionality
• Leakage
Questions for David

Is there any set of policies that can effectively manage permanence and additionality?

Is there any way to stop a gold rush if the price is large enough to support a major change in land use that could cause more problems than benefits (the leakage issue)?

Do we know enough about these far-field effects to design effective policies?

Is governance strong enough in developing nations?

Do you support immediate use of these measures? If so, what are the needed restrictions before we begin?
Land-based options for climate mitigation

• Reduced deforestation
• Afforestation, deforestation, changes in forest management
• Agricultural soils
• BECCS and biofuels
### Fate of anthropogenic CO$_2$ emissions (2008–2017)

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<thead>
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<tbody>
<tr>
<td>34.4 GtCO$_2$/yr</td>
<td>17.3 GtCO$_2$/yr</td>
</tr>
<tr>
<td>87%</td>
<td>44%</td>
</tr>
<tr>
<td>13%</td>
<td>29%</td>
</tr>
<tr>
<td>5.3 GtCO$_2$/yr</td>
<td>11.6 GtCO$_2$/yr</td>
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<tr>
<td>22%</td>
<td>22%</td>
</tr>
<tr>
<td>5%</td>
<td>5%</td>
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</tbody>
</table>

Budget Imbalance: (the difference between estimated sources & sinks)

1.9 GtCO$_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018
Magnitude of benefit from avoided deforestation.

Dark Grey = ≤$10/tCO_2$
Light Grey = ≤$100/tCO_2$
Co-benefits and additional costs:

Avoided deforestation.
  a. Co-benefits: **Biodiversity preservation**; maintenance of ecosystem services.
  b. Additional costs: Reduced expansion of agricultural land to supply additional food demand and support economic development.

Fossil emissions reductions.
• Permanence (land based problem > fossil)
  Deforested later and the cumulative emission is the same.
  CCS later turned off to save money.
• Additionality (similar)
  Why so cheap if land is really in danger?
  Wind and solar cheaper in many locations.
• Leakage (land-based problem > fossil)
  Demand for agricultural land increases deforestation elsewhere.
  Reduced fossil use decreases price and increases use elsewhere.
Questions for David

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Do you support immediate use of these measures?
Land-based options for climate mitigation

- Reduced deforestation
- **Afforestation, deforestation, changes in forest management**
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- BECCS and biofuels
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<th>Negative Emissions Technology</th>
<th>Estimated Cost ($/tCO₂)</th>
<th>Upper Bound* for Safe* Potential Rate of CO₂ Removal Possible Given Current Technology and Understanding and at ≤$100/tCO₂ (GtCO₂/y)</th>
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<tr>
<td>Coastal blue carbon</td>
<td>L</td>
<td>US</td>
</tr>
<tr>
<td>Afforestation/Reforestation</td>
<td>L</td>
<td>US</td>
</tr>
<tr>
<td>Forest management</td>
<td>L</td>
<td>US</td>
</tr>
<tr>
<td>Agricultural soils</td>
<td>L to M</td>
<td>US</td>
</tr>
<tr>
<td>BECCS</td>
<td>M</td>
<td>US</td>
</tr>
<tr>
<td>Direct air capture</td>
<td>H</td>
<td>US</td>
</tr>
<tr>
<td>Carbon mineralization</td>
<td>M to H</td>
<td>US</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>US</td>
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</table>

* Upper bound assumes full adoption of agricultural soil conservation practices, forestry management practices, and waste biomass capture.

*Safe means without large-scale land-use change that could adversely affect food availability and biodiversity.
A recent TNC-study concludes that more than 1 GtCO$_2$/y of low-cost afforestation, reforestation and forest management negative emissions are achievable. This is qualitatively consistent with other analyses (i.e. McKinsey).
Afforestation, reforestation, changed forest management. Similar to avoided deforestation

• Co-benefits and additional costs (biophysical impacts, biodiversity benefits much less than for reduced deforestation)

• **Permanence** (land based problem > fossil)
• **Additionality** (land based problem < fossil)
• **Leakage** (land-based problem > fossil)
Questions for David

Is there any set of policies that can effectively manage permanence and additionality?

Is there any way to stop a gold rush if the price is large enough to support a major change in land use that could cause more problems than benefits (the leakage issue)?

Do we know enough about these far-field effects to design effective policies?

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Soil C & biochar mitigation potentials

• Biochar (Woolf et al., 2010)
  • Technical potential = 6.6 GtCO2/y
  • Potential accounting for competition for non-waste biomass = 2.6 GtCO2/y

• Soil C sequestration (Smith et al., 2008; Smith, 2012)
  • Technical potential = 4.8 GtCO2/y
  • Economic potential at 20-100 US$/tCO₂ = 1.5-2.6 GtCO2/y
  • Most of the economic potential has negative cost.

Smith (2016)

Courtesy of Dr. Pete Smith
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<tr>
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<td>H $&gt;100$</td>
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<td></td>
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<td>Agricultural soils</td>
<td>L to M</td>
<td>0.25</td>
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<tr>
<td>BECCS</td>
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<td></td>
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Agricultural soil carbon enhancement

• **Co-benefits** (land based benefits: increased fertility, water holding capacity, nitrogen retention) and additional costs (N2O emissions in some soils)

• **Permanence** (land based problem > fossil) Stop new agricultural practices and carbon gains are completely lost.

• **Additionality** (no-till already practiced and increasing)

• **Leakage** (none)
Questions for David

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Land-based options for climate mitigation

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• **BECCS and biofuels**
Existing land options for negative emissions with the high capacities are land hungry: afforestation, reforestation and BECCS. 600 million hectares of land is devoted to bioenergy – 40% of today’s cropland - in RCP 2.6 (IPCC AR5 WG III, Chapter 6).

10 -20 GtCO2/y of negative emissions plus avoided fossil emissions in some studies.

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*Safe means without large-scale land-use change that could adversely affect food availability and biodiversity.
• **Co-benefits** (electricity and fuels production) and additional costs (**Carbon Debt** and the set of problems that come with with intensive agriculture).

• Permanence (not an issue)

• Additionality (not an issue)

• **Leakage** (land-based problem > fossil). Demand for agricultural land causes deforestation elsewhere.
Questions for David

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