What Can Ecosystem Models Tell Us About Carbon-Negative Bioenergy?

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Beyond Carbon Neutral seminar series
University of Michigan
Thursday, February 9, 2017
Overview

1. Intro to CSU & carbon-negative bioenergy
2. Case study 1- Optimal landscape design for carbon-sequestering perennial bioenergy grasses in SW Kansas
3. Case study 2- Biofuel and biochar production from beetle-killed pine trees in the Rockies (BANR project)

Still working towards synthesis!
1. Intro to CSU & carbon-negative bioenergy

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My institution, background
Carbon-Sequestering Bioenergy

- Terrestrial bioenergy crops fix atmospheric CO2
- Globally, we appropriate ~25% of net primary production
BECCS- Plan B... or To-Do List Item Z?

COMMENTARY:
Betting on negative emissions

Sabine Fuss, Josep G. Canadell, Glen P. Peters, Massimo Tavoni, Robbie M. Andrew, Philippe Ciais, Robert B. Jackson, Chris D. Jones, Florian Kraxner, Nebojsa Nakicenovic, Corinne Le Quéré, Michael R. Raupach, Ayyoob Sharifi, Pete Smith and Yoshiki Yamagata

**Figure 1** | Carbon dioxide emission pathways until 2100 and the extent of net negative emissions and bioenergy with carbon capture and storage (BECCS)
Sustainability challenges—past & present

• Supply chain fossil energy use?
  – Probably not a deal-breaker, especially for cellulosic feedstocks

• Fertilizer nitrous oxide (N₂O) emissions?
  – Perennial crops have high nitrogen use efficiency

• Changes in ecosystem C storage, a.k.a. LUC emissions
  – No free lunch, always direct or indirect impacts
  – Harvested C doesn’t contribute to photosynthesis, ecosystem C storage
  – It’s a dynamic question, not a binary one!
Working through the Land Use challenge

• System design- targeting ‘safer’ feedstocks
  – Dedicated crops grown on ‘marginal’ lands
  – Crop & forestry residues
  – Companion policy to discourage loss of high-C ecosystems

• Assessment- moving beyond C-neutral assumption
  – Ecosystem modeling- both *productivity* and *carbon storage dynamics*
  – Accounting for what’s being displaced
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Landscape case study- Hugoton KS

- Biochemical conversion of residues, dedicated energy crops
- BCAP program site, ~4000 acres switchgrass
- 7-county area modeled
Relevant biogeochemistry

- High spatial, temporal
  - Environmental factors
  - Management factors - ‘Management swing p

http://pnwmg.org/mgsoils.html
Landscape design tradeoffs

A biorefinery contracting feedstock producers might consider:

<table>
<thead>
<tr>
<th>High production intensity</th>
<th>Low production intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>to minimize transport distances</td>
<td>to minimize soil N2O emissions</td>
</tr>
<tr>
<td>Targeting <strong>prime</strong> lands to maximize yields</td>
<td>Targeting <strong>marginal</strong> lands to minimize opportunity costs</td>
</tr>
<tr>
<td>Avoiding <strong>coarse soils</strong> to encourage SOC accumulation</td>
<td>Avoiding <strong>fine soils</strong> to minimize N2O emissions...</td>
</tr>
</tbody>
</table>

**How to navigate these contradictions?**

**Research question:** Can bioenergy feedstock cultivation be sited and managed to increase SOC levels-

- Without sacrificing other lifecycle impacts (N2O emissions, farm energy & inputs, iLUC, etc.)?
- With reasonable additional cultivation & transport costs?
DayCent biogeochemistry model
Switchgrass crop parameterization

Goal:
- Adjust crop parameters (phenology, partitioning, tissue C:N ratio limits) for a general model with good growth, SOC, N2O performance
- Independently validate performance where possible

Approach:
- Reproduce US switchgrass field trials from literature in DayCent
  - Yield:
    - 25 studies, 152 site-treatment combos
      - Enough for formal holdout validation
    - 18 SOC site-treatment combos, 10 N2O
  - Required some dataset filtering
Parameterization results

- Strong yield/GHG interaction, potential for systematic bias
- Good intensification response; ambiguous on land quality (not shown)
Landscape scale assessment

- Nationwide intersect of GIS coverages representing environmental, management variables
- Processed at native resolution

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td>NARR</td>
<td>32 km</td>
</tr>
<tr>
<td>Soil</td>
<td>SSURGO</td>
<td>~10 m</td>
</tr>
<tr>
<td>Land use</td>
<td>NLCD</td>
<td>30 m</td>
</tr>
<tr>
<td>Irrigation</td>
<td>MIrAD-US</td>
<td>250 m</td>
</tr>
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</table>

~3,800 unique DayCent run scenarios

- Parallel simulation execution, analysis & figure-making automated in Python, SQLite & matplotlib
Land characterization

Area-weighted soil surface texture distribution by land use class

<table>
<thead>
<tr>
<th>Land use category</th>
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</thead>
<tbody>
<tr>
<td>Cropland</td>
</tr>
<tr>
<td>Cropland, LCC=4</td>
</tr>
<tr>
<td>CRP</td>
</tr>
<tr>
<td>Rangeland</td>
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<tr>
<td>BCAP</td>
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</table>
Integrated assessment
Landscape optimization

Cost/mitigation tradeoff defined by Pareto frontier
Landscape optimization

![Graph showing landscape optimization with various lines and markers representing different scenarios. The x-axis represents ethanol production cost for 94 ML facility [USD L⁻¹], and the y-axis represents Ethanol GHG footprint [g CO₂eq MJ⁻¹]. Key markers and line types include:

- Cropland conversion
- Interagency SCC range ($13-64/MgCO₂)
- LCFS credit price ($102/MgCO₂)
- RFS2 cellulosic waiver equiv. ($205/MgCO₂)
- RFS2 'cellulosic' limit
- Cropland, 50-km collection radius limit
- Biophysically marginal cropland (LCC>=4)
- Economically marginal (BCAP plantings)
- Ecologically marginal (CRP conversion)
- Rangeland conversion
- Any land conversion
- Random solutions

Legend areas are marked as 'Sub-optimal solutions' and 'Infeasible region' on the graph.]


Some lessons learned...

- Lots of data $\neq$ great parameterization
  - More landscape position field trials needed
- Significant opportunities to improve biofuel GHG footprint
- Conventional wisdom on minimizing collection radius, targeting most marginal lands is likely misleading
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Mountain pine beetle: little bug, big problem

• Native, but infestation driven by:
  – Management: Harvest history, fire exclusion
  – Climate: Summer drought stress, milder winter minimum temps

http://earthobservatory.nasa.gov/IOTD/view.php?id=78677
Useable as bioenergy feedstock?

• >42 million acres of forest impacted
  – Remote sensing instead of breeding/agronomy

• Often a byproduct of current mgmt. practices
  – Timber salvage – Fire risk mitigation – Ecological restoration – Safety & recreation

• Can bioenergy complement & incentivize management goals?

<table>
<thead>
<tr>
<th>Pros:</th>
<th>Cons:</th>
</tr>
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<tbody>
<tr>
<td>• Large biomass per area</td>
<td>• Spotty and episodic</td>
</tr>
<tr>
<td>• Avoids food-v-fuel issues</td>
<td>• Challenging access</td>
</tr>
<tr>
<td>• Low stumpage costs</td>
<td>• Expensive logistics</td>
</tr>
<tr>
<td>Infrastructure availability?</td>
<td></td>
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<tr>
<td>Environmental impacts?</td>
<td></td>
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<td>Public perceptions?</td>
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Objective: To provide the **science-based underpinnings** – through targeted research, education, training and extension – to support the development of sustainable biofuel/bio-products from beetle-killed and residual wood feedstocks.
Cool Planet Energy systems

Thermochemical technology
• Multi-stage pyrolysis process
• Catalytic conversion to liquid fuel
  – High-octane gasoline blend stock
  – Fuel fleet tested with Google and Ventura County
• Biochar co-product
  – Upgraded to a high-performance soil amendment
• Plans for commercial-scale production in Louisiana
Climate impact modeling overview

Supply chain modeling (GREET)

- Harvest equip. fuel use
- Biomass transport fuel use
- Final feedstock pre-processing
- Conversion process energy use
- Yields

System configuration

- Untreated
  - 2016
- Harvested: Biomass Removal
  - 2066

Wildfire risk?
Supply Chain Detail

- **1st-order LCA**: GREET defaults
- **Full LCA**: Integration of BANR logistics work
  - Partners from OSU, USFS
  - Field work in CO, MT, ID

![Residue-to-chip diesel use graph](image-url)
- Developed and commonly used by US Forest Service
- FORTRAN language
- Empirically based growth/mortality
- Individual trees modeled
- Tree interactions affect growth and mortality
Some representative FVS output

Using BANR-collected stand data from CSF
gasoline it displaces. To track how much of the released CO₂ remains in the atmosphere we use the revised version of the Bern Carbon cycle model, assuming a background CO₂ concentration of 378 ppm [13, 15]. Specifically, the decay of a pulse of CO₂ at time $t$ is given by

$$a_0 + \sum_{k=1}^{3} a_k e^{\left(-\frac{t}{\tau_k}\right)}$$

(10)

where $a_0 = 0.217$, $a_1 = 0.259$, $a_3 = 0.338$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years$^9$. From O’Hare et al. 2009
Time-dependent climate forcings
Initial Sensitivity Results

- biorefinery process energy
- harvest & transp. energy
- char recalcitrant fraction
- char half-life
- wildfire risk multiplier
- peak stand maturity age
- site productivity

Decrease in forcing break-even time
Some lessons learned…

- Overall climate impacts equally or more sensitive to ecosystem factors as to traditional ‘supply chain’ factors
  - Including factors that are very difficult to estimate
- More field work needed to understand the potential for shifts in stand species composition
To learn more:

- Website: http://banr.colostate.edu
- Twitter: @BANR_Bioenergy
- YouTube: https://www.youtube.com/user/banrbioenergy

Or contact me directly: John.L.Field@gmail.com