GCAM Biomass

Summary of Progress, New Modeling Capability, Early Results

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Outline

- Recap of findings from modeling efforts of last couple of years published last Fall.
- Capability building in GCAM biomass modeling
  - In parallel with new detailed GCAM agriculture
  - Multiple bioenergy crops and energy conversion technologies
  - Helped greatly by funding from EERE Office of Biomass Programs
- Early results exploring international land use policy and agricultural trade assumptions on US biomass and agricultural.
- Discussion of next steps for agriculture, land use, and biomass
Published Study on Global Biomass Use in the Energy System in a CO₂ Mitigation Scenario

- Study included split between biomass into fuels and electric power under tight global climate policies.

- Explored potential role and impact of CO₂ capture and storage (CCS) combined with biopower and biofuels.
Where is the Biomass Used?

**450ppm CO₂ Scenario when CCS *is not* available**

Global Electricity

Global Transportation Fuels

GCAM Results: when CCS is not available, biomass is more valuable for reducing emissions in transportation fuels than electric power, which has other low or no-carbon technology options in this scenario.
Where is the Biomass Used?

450ppm CO₂ Scenario when CCS is available

With CCS, biomass is concentrated in electric power, with bio+CCS contributing net negative emissions. This allows headroom for continued use of some fossil fuels in transportation. Biomass still has a large role there, with CCS in the fuel processing.
Economics of Large Plantation Scale Biomass Energy Production and Trade are very Different in a Greenhouse Gas Constrained World

The fraction of the bioenergy price that accounts for the cost of collecting, transporting and delivering a uniform bioenergy commodity energy feedstock drops precipitously as the price of carbon permit rises.

GCAM explicitly accounts for the cost of biomass collection/preparation (including dehydration, densification and pelletization) and long distance transportation.


GCAM Biomass Modeling Update
GCAM Global Biomass Modeling Upgrades

- Several AEZ and regionally-specific biomass crops (a significant upgrade from our previous generic ligno-cellulosic crop assumption in each of 14 large regions)
  - Capture differences in which crops grow better in which AEZ and regions
  - Considers difference in which crops are more suited for making fuels versus electricity given technology options.

- Researched and revised our modeling of cellulosic biomass from crop and forest residues
  - These supplies are built from bottom up directly resulting from modeled crop and forest production in GCAM

- Added model links and processing technologies to create liquid fuels from corn, oil, and sugar crops
Some New GCAM Biomass Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Region</th>
<th>Yield (tonne/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgrass</td>
<td>Most regions</td>
<td>EPIC Yields</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>Western Europe</td>
<td>10</td>
</tr>
<tr>
<td>Willow</td>
<td>Eastern Europe</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Western Europe</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>China</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>15</td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>Africa</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Latin America</td>
<td>12</td>
</tr>
<tr>
<td>Jatropha (oil)</td>
<td>Africa</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>1.4</td>
</tr>
</tbody>
</table>

All yields are on an annual basis
* Jatropha also outputs 2.2GJ of cellulosic biomass for every GJ of oil (from husks and seedcake)

- Willow is commonly suited to cold, wet climates, with high yields, but has a harvest period of 3-4 years
- Eucalyptus in tropical climates, currently used for charcoal
- Miscanthus may have higher yields than Switchgrass but may be more costly to grow
- Jatropha is costly to grow, but is readily converted to fuel
- Note that other crops can be modeled, but we chose these as representative. Point here is to demonstrate capability.
- Future yields around the world are a very important, but uncertain, data set for us to research and to explore implications with GCAM

Sources: (Faaij 2006; de Wit and Faaij 2010) for Willow & Miscanthus, (Hamelinck et al. 2005) for Eucalyptus, (Openshaw 2000) for Jatropha
Introducing New Biomass Crops into GCAM

- It is a general challenge to model new crops and technologies on a level playing field with existing crops and technologies that are part of the calibration set.

- We have attempted to model biomass crops to be consistent with practices, technologies, and yields of existing food crops in each subregional AEZ.
  - Otherwise, in developing regions we would be competing a modern biomass crop with food crops with lower yields – this creating the appearance in the model of a super biomass crop.
  - On the other hand, the new biomass crops’ profitability is measured relative to competing crops within a subregional AEZ, which may also have low yields. (Comparative advantage is the relevant metric.)

- Potential future yields for biomass crops in developing regions is a key area for future research.
New GCAM links from Food Crops to Liquid Fuel (main point is capability, not data)

- **Corn to ethanol**
  - Costs about the same as 2020 cellulosic ethanol cost

- **Sugar to ethanol**
  - 580 kg of sugarcane per GJ of fuel. Cane is crushed to extract the juice and remainder (bagasse) used to fuel plant
  - Increased volumes lead to slightly higher cost than corn to ethanol
  - Same process for sugarbeet-to-ethanol

- **Oil Crops**
  - Palm oil or Soybean oil can be used for biodiesel after a transesterification process
  - We model a continuous reaction with methanol catalyzed by sodium hydroxide (at ~60° C)
  - Low cost (about 33% of corn ethanol cost), but crop price is generally higher

<table>
<thead>
<tr>
<th>Crop Input (kg)</th>
<th>Dedicated Bioenergy Input (GJ)</th>
<th>Natural Gas (GJ)</th>
<th>Electricity (GJ)</th>
<th>Cost (2008$/GJ)(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Ethanol</td>
<td>112</td>
<td>-</td>
<td>0.32</td>
<td>0.03</td>
</tr>
<tr>
<td>Sugar Ethanol</td>
<td>582</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soybean Biodiesel</td>
<td>146</td>
<td>-</td>
<td>0.03</td>
<td>-</td>
</tr>
<tr>
<td>Palm Biodiesel</td>
<td>128</td>
<td>-</td>
<td>0.03</td>
<td>-</td>
</tr>
<tr>
<td>Fischer-Tropsch</td>
<td>-</td>
<td>1.96</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cellulosic</td>
<td>-</td>
<td>-</td>
<td>2.06</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\): Costs do not include feedstock cost. An additional cost markup of $3.50/GJ is added between the refining sector and the transportation sector

GCAM New Ag/Land Use and Biomass: Some Early Results

- GCAM can run several types of policies that impact biomass
  - Carbon Policies
  - RES
  - Biofuels Standards (new capability)

- Here, we will show GCAM model results for two scenarios
  - 1. A Reference Scenario (no new policy)
    - Starting low and rising to about $150/mtCO2 by end of century
Global Biomass Primary Energy by type

Reference

Policy

EJ/yr

2005 2020 2035 2050 2065 2080 2095

MSW
Conventional Crops
Residue
Jatropha
Eucalyptus
Willow
Miscanthus
Switchgrass

EJ/yr

2005 2020 2035 2050 2065 2080 2095

MSW
Conventional Crops
Residue
Jatropha
Eucalyptus
Willow
Miscanthus
Switchgrass

Pacific Northwest
NATIONAL LABORATORY
Land Allocation by AEZ (Policy)

Africa AEZ1

US AEZ10

Southeast Asia AEZ6

China AEZ14

Desert

Pasture

Biomass

Tundra

Pasture
Early Results: Impact of International Climate Policy and Agricultural Trade Assumptions on US Biomass and Agriculture
GCAM Scenarios on Biomass Import Considerations/International Policy

Motivation from a joint modeling study (EMF) where one of the required assumptions was that we restrict US biomass use to domestic supplies. (as a way to address land use emissions leakage)

We ran a spectrum of cases to span some of the possibility space with US policy of reducing emissions to 80% below 2005 by 2050 (a big reduction).

- No Biomass Import Restriction / international muddling through carbon policy (not all regions participate) including land use
- No Biomass Import Restriction / global carbon value equal to US, including land use
- No US Biomass Imports / muddling through carbon policy (not all regions participate), no reduction in US corn exports from current levels
- No US Biomass Imports / no carbon policy outside US, no reduction in US corn exports from current levels
Results, US Biomass Imports (80% Case)

- The Muddling Through is not much different than No Global Carbon Tax in terms of biomass imports to the US
  - Land use and emissions leakage still a problem as long as some of the world is not covered under policy.

- Equal Global Carbon Tax Case is very similar to the US-Only Case in terms of biomass imports.
  - In fact there is a slight export in the equal tax case
  - But these exact results are of course also a reflection of model data assumptions around the globe.
The international context has a large influence on domestic effects.

Muddling Through: Assuming roughly 50% reductions by 2050 in the developed countries, and less aggressive or no action elsewhere.
Both national and international policy will effect the agricultural sector.

The increased price reflects both the demand for bioenergy and the value of carbon in land.

Somebody will grow the corn.
Now Consider the Scenarios where U.S. constrains biomass and corn production and trade?

- Assume U.S. consumes only U.S. grown corn and biomass.
- Assume that the U.S. maintains corn exports.
Trade policy will interact with climate policy.

The U.S. Corn Price is Decoupled from the Global Price
US Food Production in 2050 under 80% US Reduction Cases

- Valuing Land Carbon in US but not in all other regions would tend to drive food production outside US (along with land use emissions)
  - As would restricting US Biomass imports.
- To have no leakage of land use emissions, would have to fix US production of all crops to avoid imports and maintain exports.
- Many other scenarios are worth exploring.
Discussion: Current and Future Directions for GCAM Agriculture, Land Use, and Biomass
Directions for GCAM and Biomass Modeling

The model is now capable of modeling multiple crop management practices or technologies, considering costs, yields, and soil carbon implications.

- Tillage and other management practices
- Crop Rotations
- Irrigation and fertilizer (though not in integrated with supply models yet)

**DATA** - Next effort is to research and populate model with data on practices and technologies where impactful

- Near-term – US subregional projects
- Longer-term – International, modeling the potential for modern practices in developing nations for both food and biomass crops

Continued study of land policies, including.

- REDD
- Carbon Parks
- Protected land categories (internationally)
Directions for GCAM and Biomass Modeling (2)

- **Fertilizer -** Integrate closed model of demand and supply of fertilizer with crop technologies.
  - We have an initial, internal version that incorporates the energy requirements for producing fertilizer.

- **Integrate with Water Modeling**
  - Water is a Major Initiative at JGCRI!
  - Currently adding modeling of water demands from agriculture
  - Developing water supply model in parallel
  - Eventually, integrate water and the cost (or value) of water into economic decisions about technology and management practice choice