Biofuels
in Polysys
Model design, simulation and expansion

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I will present...

- A Brief Introduction to POLYSYS
- Biofuel model design and modifications
- Our recent results of 25 x 25’ simulation
- Undergoing expansion for energy and net carbon flux estimation
POLYSYS Introduction

ERS Livestock Model
- Beef
- Pork
- Turkeys
- Broilers

Grains and Crops:
- Corn
- Sorghum
- Barley
- Oats
- Rice
- Cotton
- Wheat
- Soybeans

+ Hay
USDA Baseline (10 year)

### Corn

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Planted acres (Mil)</td>
<td>80.90</td>
<td>81.60</td>
<td>80.50</td>
<td>82.00</td>
<td>84.00</td>
<td>84.50</td>
<td>85.00</td>
<td>85.00</td>
<td>85.00</td>
<td>85.00</td>
<td>84.50</td>
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<tr>
<td>Harvested acres</td>
<td>73.60</td>
<td>74.30</td>
<td>73.20</td>
<td>74.70</td>
<td>76.70</td>
<td>77.20</td>
<td>77.70</td>
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<td>77.70</td>
<td>77.70</td>
<td>77.20</td>
<td>77.20</td>
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<tr>
<td>Yield/harvested acre</td>
<td>160.40</td>
<td>148.40</td>
<td>147.70</td>
<td>149.50</td>
<td>151.30</td>
<td>153.10</td>
<td>154.90</td>
<td>156.70</td>
<td>158.50</td>
<td>162.10</td>
<td>163.90</td>
<td></td>
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<tr>
<td>Exports</td>
<td>1,814</td>
<td>2,000</td>
<td>2,100</td>
<td>2,025</td>
<td>2,075</td>
<td>2,100</td>
<td>2,125</td>
<td>2,175</td>
<td>2,225</td>
<td>2,275</td>
<td>2,325</td>
<td>2,375</td>
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<tr>
<td>Farm price</td>
<td>2.06</td>
<td>1.80</td>
<td>2.00</td>
<td>2.20</td>
<td>2.45</td>
<td>2.55</td>
<td>2.60</td>
<td>2.60</td>
<td>2.60</td>
<td>2.55</td>
<td>2.60</td>
<td>2.60</td>
</tr>
<tr>
<td>Net returns (per ac)</td>
<td>197.05</td>
<td>135.40</td>
<td>124.44</td>
<td>125.37</td>
<td>164.79</td>
<td>182.16</td>
<td>192.15</td>
<td>194.51</td>
<td>197.01</td>
<td>202.15</td>
<td>204.73</td>
<td></td>
</tr>
</tbody>
</table>

### Regional Acreage and Production

Regional Acreage and Production

(305 Linear Programming Models)

Simulate Change
Demand, Exports, Land Availability, etc.

### National Demands, Prices, Exports and Government Payments

National Demands, Prices, Exports and Government Payments

(Elasticities for price and export response)

### POLYSYS Regional Output

Annual acreage, production, government payments, income

### POLYSYS National Output

Annual Prices, production, government payments, exports, income.
POLYSYS Simulation
Structure and Flow (Annual)

Expected Prices

Shock

Exports

Regional Production / Allocation

National Prices And Demand

Livestock Production
Additions for Biofuels Model

• Add Feedstocks
  – Energy Dedicated Crop – switchgrass.
  – Crop Residues – corn and wheat.
  – Wood Residues – forest trimmings, and wood and mill wastes.

• Potential conversion of pasture.

• Make corn grain and biomass ethanol compete.
Pasture Conversion

1) Only pasture classified as historical cropland is available.

2) Pasture can only come in at the rate at which hay acreage can grow.

3) Hay lands must replace lost forage production at regional hay yield levels.

4) There must be a crop with positive net expected income to absorb the new land available.

Out of 60 million acres available, 33 million come in.
Corresponding Price

• If we are producing corn grain ethanol, what feedstock price could we offer to biomass to produce ethanol at the same price?

\[
\text{Corn Grain Ethanol Cost} = \text{Biomass Ethanol Cost}
\]

\[
\frac{\text{CONV}_{\text{corn}} + P_{\text{corn}}}{\text{TECH}_{\text{corn}}} = \frac{\text{CONV}_{\text{biomass}} + P_{\text{biomass}}}{\text{TECH}_{\text{biomass}}}
\]

\[
P_{\text{biomass}} = \left(\frac{P_{\text{corn}}}{\text{TECH}_{\text{corn}}} + \text{CONV}_{\text{corn}} - \text{CONV}_{\text{biomass}}\right) \times \text{TECH}_{\text{biomass}}
\]

• Where:
  – \text{CONV}_{\text{corn}} is the conversion cost of corn grain to ethanol per gallon*,
  – \text{P}_{\text{corn}} is the price of corn grain,
  – \text{TECH}_{\text{corn}} is gallons of ethanol per bushel of corn grain,
  
  – \text{CONV}_{\text{biomass}} is the conversion cost of biomass to ethanol per gallon,
  – \text{P}_{\text{biomass}} is the corresponding price of biomass,
  – \text{TECH}_{\text{biomass}} is the gallons of ethanol per dry ton of biomass.

*transportation costs of biomass are included (average of $8.85 per ton)
Finding Optimal Feedstock Mix

New Biomass Price

Crop Demand
New Corn Price Determined

Figure Corresponding Biomass Price

Compare Prices
If difference, adjust price. If no difference, quit.

If Ethanol Demand not filled, Fill with Corn Grain

Use all Biomass to Fill Ethanol Demand

Biomass Supply
To displace 25% of liquid fuel* use by 2025, we will need to produce...

- 86 billion gallons of ethanol
- 1.1 billion gallons of biodiesel

Can agriculture do it?

What feedstocks would fill it?

What would commodity prices look like?

*different from scenarios reported in 25x25’ document
Expansion Assumption

Years

- EIA Projected Gasoline
- Ethanol at 25% energy equivalent

Billion Gallons

2005 2010 2015 2020 2025

86 Billion
Scenario Assumptions

• Yields by 2025:
  • Major crops continue w/ trend line: corn (195 bu/ac), soybeans (51 bu/ac), wheat (53 bu/ac)
  • Energy crops (6 to 12 dt/acre)

• Management practices by 2025:
  • Corn: no-till (20% to 50%); reduced till (20% to 30%)
  • Wheat: no-till (12% to 50%); reduced till (20% to 30%)

• Land:
  • 60 million pasture acres available (33 come in)
  • +15 million CRP acres into biomass production
Scenario Assumptions

• Commodity Programs:
  • Remain as specified in 2006

• Conversion Efficiency:
  • Improved cellulosic ethanol to 89 gallons/ton by 2025 and corn ethanol conversion to 3 gallons/bushel by 2015
# Average Commodity Prices

<table>
<thead>
<tr>
<th></th>
<th>Projected Change in Avg Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>Corn</td>
<td>6%</td>
</tr>
<tr>
<td>Wheat</td>
<td>-4%</td>
</tr>
<tr>
<td>Soybeans</td>
<td>2%</td>
</tr>
<tr>
<td>Cotton</td>
<td>0%</td>
</tr>
<tr>
<td>Ded. Energy Crop ($/ton)</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Ethanol Sources

Ethanol from Feedstocks

Wood Residues
Switchgrass
Corn Stover
Wheat Straw
Corn Grain

Year
Mil Gal
0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00 80.00 90.00 100.00
Acreage Changes

The chart illustrates the changes in acreage for various crops and land uses from 2006 to 2025. The acreage values are shown in millions of acres for each year and are color-coded for different crop types.

- **Corn** is represented by yellow bars.
- **Wheat** is represented by green bars.
- **Soybeans** are shown in purple bars.
- **Hay** is indicated by blue bars.
- **Other Crops** are highlighted in red.
- **Switchgrass** is depicted in black.
- **Conservation Reserve Program (CRP)** is shown in orange.
- **Pasture** is indicated in white.

Key observations:
- **2006**: Corn acreage is the highest among the listed crops, followed by Wheat, Soybeans, Hay, Other Crops, Switchgrass, CRP, and Pasture.
- **2010**: Similar trend with slight variations in acreage.
- **2015**: Consistent with previous years, but with minor fluctuations in acreage.
- **2020**: A slight decrease in total acreage compared to 2015.
- **2025**: Projected acreage showing a potential decrease in corn and an increase in other crops and pasture.

The chart provides a visual representation of how the distribution of farmland has shifted over the years, indicating trends and changes in agricultural practices and policies.
Change in Net Returns, 2010
Change in Net Returns, 2015
Change in Net Returns, 2020

Dollars
- zero
- up to 25 million
- up to 50 million
- up to 100 million
- over 100 million
Change in Net Returns, 2025

Dollars
- zero
- up to 25 million
- up to 50 million
- up to 100 million
- over 100 million
Changes in Farm Income and Government Payments

(million $)

<table>
<thead>
<tr>
<th>Year</th>
<th>Net Income (Million dollars)</th>
<th>Govt. Payments (Million dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>-1,600</td>
<td>-1,600</td>
</tr>
<tr>
<td>2009</td>
<td>-1,400</td>
<td>-1,400</td>
</tr>
<tr>
<td>2012</td>
<td>-1,200</td>
<td>-1,200</td>
</tr>
<tr>
<td>2015</td>
<td>-1,000</td>
<td>-1,000</td>
</tr>
<tr>
<td>2018</td>
<td>-800</td>
<td>-800</td>
</tr>
<tr>
<td>2021</td>
<td>-600</td>
<td>-600</td>
</tr>
<tr>
<td>2024</td>
<td>0</td>
<td>-400</td>
</tr>
</tbody>
</table>
Simulation Conclusions

- 25% liquid fuels displacement can occur within ‘acceptable’ crop price increases.

- Corn grain ethanol will play a decreasing role in ethanol growth.

- Feedstock production and income benefits will be spread throughout nation.
Model Expansion: Carbon Sequestration

POLYSYS County Regions (3111)
Overall Objective

• To simulate changes in management practices and their implications upon,
  • National and regional soil carbon levels
  • National and regional emitted carbon

• Use satellite data to make estimation as geographically specific as possible – by knowing what soils underlie crops.
Data Layer Integration

Final product:
Simulate changes in net carbon flux with high degree of spatial resolution

- 30x30 meter Resolution Of land use
- Soil carbon
- County boundaries
- Land cover
- Carbon dynamics based on analyses of field data
- County Crop acres, tillage use, yield, and emissions
- MUID level Soil organic matter
## Energy Use and Emissions Tied to each Budget

<table>
<thead>
<tr>
<th>POLYSYS Crop</th>
<th>Direct Energy Use (Btu/ac)</th>
<th>CO2 Emissions from Direct Energy Use, tons per acre</th>
<th>Embodied Energy Use - Fertilizers (Btu/ac)</th>
<th>CO2 Emissions from Embodied Energy Use - Fertilizers (tons per acre)</th>
<th>Embodied Energy Use - Herbicides, Pesticides, Fungicides (Btu/ac)</th>
<th>CO2 Emissions from Embodied Energy Use - Herbicides, Pesticides, Fungicides (tons per acre)</th>
<th>Embodied Energy Use - Seeds (Btu/ac)</th>
<th>CO2 Emissions from Embodied Energy Use - Seeds (tons per acre)</th>
<th>CO2 from N2O emissions (tons per acre)</th>
<th>CO2 from Agricultural Lime emissions (tons per acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CornCT121</td>
<td>1,580,873</td>
<td>0.128</td>
<td>4,160,713</td>
<td>0.275</td>
<td>307,876</td>
<td>0.006</td>
<td>382,365</td>
<td>0.009</td>
<td>0.586</td>
<td>0.000</td>
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<tr>
<td>CornNT121</td>
<td>618,881</td>
<td>0.050</td>
<td>2,116,663</td>
<td>0.139</td>
<td>866,534</td>
<td>0.017</td>
<td>353,688</td>
<td>0.008</td>
<td>0.329</td>
<td>0.000</td>
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<tr>
<td>CornRT121</td>
<td>836,949</td>
<td>0.068</td>
<td>1,795,426</td>
<td>0.116</td>
<td>1,028,433</td>
<td>0.020</td>
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<td>0.008</td>
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<td>OatCT121</td>
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<td>1,502,888</td>
<td>0.096</td>
<td>35,107</td>
<td>0.001</td>
<td>149,518</td>
<td>0.003</td>
<td>0.243</td>
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<td>SoybeanCT121</td>
<td>1,379,197</td>
<td>0.111</td>
<td>669,502</td>
<td>0.047</td>
<td>53,751</td>
<td>0.001</td>
<td>331,746</td>
<td>0.008</td>
<td>0.000</td>
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<tr>
<td>SoybeanNT121</td>
<td>1,467,789</td>
<td>0.118</td>
<td>669,502</td>
<td>0.047</td>
<td>153,868</td>
<td>0.003</td>
<td>331,746</td>
<td>0.008</td>
<td>0.000</td>
<td>0.054</td>
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<td>SoybeanRT121</td>
<td>1,602,822</td>
<td>0.129</td>
<td>795,653</td>
<td>0.070</td>
<td>307,737</td>
<td>0.006</td>
<td>331,746</td>
<td>0.008</td>
<td>0.000</td>
<td>0.110</td>
</tr>
</tbody>
</table>

- Direct BTU and CO2 Emissions
- Embodied BTU and CO2
  - Fertilizers
  - Chemicals
  - Seeds
  - CO2 from N20
  - CO2 from Lime

Thanks to Richard Nelson, Kansas State for developing this database that links to APAC budgets
Direct Energy Consumption
Crop Agriculture, 2015

Energy BTU's
- 0.000000000
- up to 5 billion
- up to 25 billion
- up to 50 billion
- up to 100 billion
- up to 150 billion
- up to 250 billion
- over 250 billion
Direct Carbon Emissions
Crop Agriculture, 2015

[Map showing carbon emissions by county in the United States, with color coding for tons of carbon.]
New version can help answer -

- What will be the effect of biofuel production on *net energy use* in agriculture?
- What will be the effect of energy cost changes upon *operation expenses* and therefore planting decisions?
- What conflicts or synergies may exist between biofuel production and carbon sequestration?
Questions Please!

Agricultural Policy Analysis Center

The University of Tennessee
310 Morgan Hall
2621 Morgan Circle
Knoxville, TN 37996-4519

www.agpolicy.org
Byproducts

- Distiller’s dry grains from ethanol production and soybean meal from biodiesel production are integrated within the model to evaluate how their quantities and prices affect the final market equilibrium. For every bushel of corn grain used in ethanol production, 18.3 lbs of distiller dry grains are produced. It is assumed that distillers dry grains substitutes for livestock corn grain demand. One ton of distillers dry grain displaces 35.65 bushels of corn feed demand.

- $\text{DDGPRC} = 22.7 + 30.8 \times \text{CornPrice}$

! BURT ENGLISH REGRESSION
Impacts on Livestock Industry

• Various components of the livestock industry react differently.

• The cattle sector is forecast to experience an increase in net returns.

• The hog and poultry industries are forecast to experience decreases in net returns, however the model is not fully capable of capturing the high degree of vertical integration in these industries making market adjustment predictions difficult.
Cropland in Pasture

\[
Pout = \%Hav\text{ail} \times Hac\text{res} \times Hyield / Pyield
\]

\[
Hin = Pout \times Pyield / Hyield
\]

\[
NGpot = Pout - Hin
\]

• Where,
  – \text{Pout} \quad \text{is the amount of pasture that can come out of pasture if available.}
  – \%\text{Hav\text{ail}} \quad \text{is the percentage of current hay total acreage that can expand.}
  – \text{Hac\text{res}} \quad \text{is the current hay total acreage.}
  – \text{Hyield} \quad \text{is the yield per acre of hay.}
  – \text{Pyield} \quad \text{is the yield per acre of pasture.}
  – \text{Hin} \quad \text{is the acres of hay that will come in to replace Pout.}
  – \text{NGpot} \quad \text{is the potential net gain in acreage.}
Ethanol Sources in Tons

* Does not include standing forest harvest
## Conventional Corn Operations
### Central Iowa

<table>
<thead>
<tr>
<th>Month</th>
<th>Day</th>
<th>Machinery</th>
<th>Power</th>
<th>Labor</th>
<th>Machine</th>
<th>Fert</th>
<th>Ibs</th>
<th>Chem</th>
<th>Amount</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>10</td>
<td>Tandem Disk (reg) GE19ft</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.1074</td>
<td>0.1181</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>10</td>
<td>Dry Fert Spreader (trailer mtd)</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.0873</td>
<td>0.096</td>
<td>490</td>
<td>0</td>
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<tr>
<td>5</td>
<td>1</td>
<td>Field Cultivator GE15ft</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.063</td>
<td>0.0693</td>
<td>0</td>
<td>0</td>
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<td></td>
<td></td>
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<tr>
<td>5</td>
<td>9</td>
<td>Chem Applicator GE30ft (trailer mtd)</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.0391</td>
<td>0.043</td>
<td>0</td>
<td>0</td>
<td>Atrazine 90DF</td>
<td>2.5 LB</td>
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</tr>
<tr>
<td>5</td>
<td>9</td>
<td>Chem Applicator GE30ft (trailer mtd)</td>
<td>--</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Lasso 4E (Alc)</td>
<td>0.2 GAL</td>
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<tr>
<td>5</td>
<td>14</td>
<td>8 Row Planter (regular)</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.2619</td>
<td>0.3274</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>14</td>
<td>Fert Applicator (attached to impl)</td>
<td>Multiple Operation</td>
<td>0.2619</td>
<td>0 N</td>
<td>44</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>14</td>
<td>Fert Applicator (attached to impl)</td>
<td>--</td>
<td>0</td>
<td>0 P2O5</td>
<td>45</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>Fert Applicator (attached to impl)</td>
<td>--</td>
<td>0</td>
<td>0 K20</td>
<td>36</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>Row Cultivator GE15ft</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.1281</td>
<td>0.1409</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>Row Cultivator GE15ft</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.1281</td>
<td>0.1409</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>Anhyd Fert Applicator (trailer mtd)</td>
<td>Tractor 2wd 135 hp (diesel)</td>
<td>0.1058</td>
<td>0.1164 Anhydrous</td>
<td>122</td>
<td>0</td>
<td></td>
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<tr>
<td>10</td>
<td>29</td>
<td>Combine w/ Row Header-2wd (self-prop)</td>
<td>--</td>
<td>0.1637</td>
<td>0.1801</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>29</td>
<td>Single-axle Truck 2 ton (gas) (self-prop)</td>
<td>--</td>
<td>0.33</td>
<td>0.363</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How specific can we get?

100 Corn Acres in County

With Satellite Data we can place corn acres in right soil.

Soil A: 10,000kgC/ac

Soil B: 5,000kgC/ac
POLSYS Supply Model

**NASS Crop Data:**
- Crop area
- Crop yields

**CTIC Tillage Data:**
- % crop area in CT, RT, & NT in each county

**Experiment Data:**
- CT, RT, & NT practices
- Yield differences by crop and region over time

**Weighted and Merged Model Data:**
- CT, RT, & NT yields
- CT, RT, & NT areas

**Project Tillage Trends:**
- % crop area in CT, RT, & NT in each county

**Risk:**
- Net revenues adjusted for risk

**POLSYS County Level LP Model**

**Budgets:**
- CT, RT, & NT practices
- 3,037 ASD budgets
- Operations, timing, labor, input quantities, & costs

**Emissions Data:**
- CO² and BTU’s of each operation
- Total per acre per practice

**Output:**
- Change in crop mix and tillage practices
- County level emissions from agriculture—CO² and energy
Output

• County Level
  • Annual change in acres of each major crop (and hay)
  • Annual changes in tillage practice used
  • Annual change in emissions and energy associated with each crop and management practice
  • (Satellite data will place crop acres into specific soil)

• National Level
  • Annual Emissions from agriculture
  • Price, production, income, government payments
  • Incentive program costs
Flexibility in Model Design

• May Want to Simulate:
  – $ per acre incentive to a management practice
  – $ per ton carbon sequestered
    • Permanence?
    • Leakage?
    • Incentive to All Users or just New Adopters?
    • Tax on land use change that emits?
  – $ per ton net carbon flux