Compliance Pathways for Meeting the Low Carbon Fuel Standard in California

*Biofuel Supply Curves*

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Outline

• Overview
• Analysis Framework
• Feedstock resource availability and cost assumptions
• Conversion technologies and costs
• Results
Goals of Research

• Assess the quantity of biofuels that could be produced from resources in California and the western U.S.

• Describe the biofuel supply by the contributions of various resources.
Biofuel Supply in the WGA Region

• US. Biofuels could provide between 5 and 10% of the projected transportation fuel demand in the WGA region with fuel price between $2.20 and $3.00 per gasoline gallon equivalent (gge) excluding local distribution costs and taxes.

• A diverse resource based is relied on to provide this fuel with significant contributions from municipal solid waste, agricultural residue, herbaceous energy crop, forest thinning, corn, and tallow resources.

• Major uncertainties include the economic performance of the different conversion technologies, the adequacy of the supporting feedstock and biofuel delivery infrastructure, and the overall sustainability of many of the biomass resources considered.
Framework for Analysis

- Using GIS tool to locate and size biorefineries based on distribution of biomass resource at county or municipality level, and optimize biofuel supply chains from the field or other biomass sources to the fuel distribution terminals.
Primary Costs Evaluated in This Work

• **Feedstock cost**: Market clearing price

• **Harvest or collection cost**: The cost to procure feedstock from the site of origin.

• **Transport cost**: The cost to load and transport feedstock from its origin to the biorefinery, and the cost to transport the final product from the biorefinery to the distribution terminal.

• **Conversion cost**: The cost to convert the raw feedstock into a usable liquid fuel.

• **Distribution cost**: The cost to bring the biofuel to market at a fuel distribution terminal.
## Biomass Feedstocks

<table>
<thead>
<tr>
<th>Feedstock Class</th>
<th>Specific Feedstock</th>
<th>Geography</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agricultural Resources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residues</td>
<td>Corn stover, small grain straws</td>
<td>County</td>
<td>Dr. Richard Nelson, Kansas State University [1]</td>
</tr>
<tr>
<td>Grains</td>
<td>Corn</td>
<td>County</td>
<td></td>
</tr>
<tr>
<td>Herbaceous Energy Crops</td>
<td>Switchgrass</td>
<td>County</td>
<td></td>
</tr>
<tr>
<td>Oilseed Crops</td>
<td>Soy, canola</td>
<td>County</td>
<td></td>
</tr>
<tr>
<td><strong>Forest Resources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest Thinnings</td>
<td>Public and Private lands includes juniper and pinyon pine</td>
<td>County</td>
<td>USFS Forest Products Lab [1]</td>
</tr>
<tr>
<td><strong>Residues and Byproducts</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal Fats &amp; Waste Greases</td>
<td>Beef Tallow, Pork Lard, Yellow Grease</td>
<td>County &amp; municipality (waste greases)</td>
<td>Dr. Richard Nelson, Kansas State University [1]</td>
</tr>
<tr>
<td>Municipal Solid Waste (MSW)</td>
<td>Wood residues, paper, yard waste, etc</td>
<td>municipality</td>
<td>WGA CDEAC (Bioenergy) [2]</td>
</tr>
<tr>
<td>Woody Residues</td>
<td>Orchard and vineyard waste</td>
<td>County</td>
<td>WGA CDEAC (Bioenergy) [2]</td>
</tr>
</tbody>
</table>


• Corn resource has a maximum of 85.7 million dry tons available at $108.75 per ton ($3.05/bushel) constituting roughly 30% of the U.S. corn crop.
California’s in-state corn resource has a maximum of 3.13 million dry tons available at $108.75 per ton ($3.05/bushel).
Feedstock Mapping

Lignocellulosics

- [dry tons]
  - ~1000
  - 1000 - 27500
  - ~27500 - 50000
  - ~50000 - 750000
  - ~750000 - 1000000
  - ~1000000 - 2000000
  - ~2000000 - 3000000
  - ~3000000 - 4000000
  - ~4000000 - 5000000
  - ~5000000 - 6000000
  - > 6000000

- Clean Lignocellulosics @ $30/dry ton

Lipids

- [wet tons]
  - ~2500
  - 2500 - 75000
  - 75000 - 100000
  - 100000 - 200000
  - 200000 - 400000
  - 400000 - 600000
  - 600000 - 900000
  - > 900000

- Oil @ $400/ton

Clean Lignocellulosics @ $50/dry ton
Summary of Conversion Cost Models

• Conversion technology cost and performance are adapted from literature

• Biorefineries are assumed to operate at design capacity for an economic lifetime of 20 years.

• Cost curves are fitted to match the economies of scale from the detailed model of conversion costs.
## Key Technology Assumptions

<table>
<thead>
<tr>
<th>Technology</th>
<th>Feedstock</th>
<th>Feedstock Input (ton/yr)</th>
<th>Yield (gal/ton)</th>
<th>Capital Cost ($/gal)</th>
<th>O&amp;M Cost ($/gal/yr)</th>
<th>By-Product Credit ($/gal/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain Ethanol - Dry Mill</td>
<td>Corn</td>
<td>1,000,000</td>
<td>100</td>
<td>$1.67</td>
<td>$0.50</td>
<td>($0.34)</td>
</tr>
<tr>
<td>Grain Ethanol - Wet Mill</td>
<td>Corn</td>
<td>1,000,000</td>
<td>89</td>
<td>$2.21</td>
<td>$0.59</td>
<td>($0.52)</td>
</tr>
<tr>
<td>FAME Biodiesel</td>
<td>Virgin Oil</td>
<td>200,000</td>
<td>258</td>
<td>$0.59</td>
<td>$0.26</td>
<td>($0.04)</td>
</tr>
<tr>
<td>LCE Fermentation/Hydrolysis (Dilute Acid)</td>
<td>Hardwood (poplar)</td>
<td>700,000</td>
<td>86</td>
<td>$3.39</td>
<td>$0.29</td>
<td>($0.12)</td>
</tr>
<tr>
<td>LCMD - Fischer Tropsch</td>
<td>Hardwood (poplar)</td>
<td>700,000</td>
<td>41</td>
<td>$23.54</td>
<td>$1.01</td>
<td>($1.73)</td>
</tr>
<tr>
<td>LCG - Upgrading/Pyrolysis</td>
<td>Hardwood (poplar)</td>
<td>700,000</td>
<td>17</td>
<td>$8.59</td>
<td>$2.62</td>
<td>($1.16)</td>
</tr>
<tr>
<td>FAHC - Hydrotreatment (stand alone)</td>
<td>Virgin Oil</td>
<td>500,000</td>
<td>255</td>
<td>$1.39</td>
<td>$0.17</td>
<td>($0.06)</td>
</tr>
</tbody>
</table>

**Definitions:**
- FAME = Fatty Acid Methyl Ester
- LCE = LignoCellulosic Ethanol
- LCMD = LignoCellulosics to Middle Distillates
- LCG = LignoCellulosics to Gasoline
- FAHC = Fatty Acid to HydroCarbon
Results

- Regional Results
- State-specific results
- Lands Converted to Biofuels
- Sensitivity Analysis
Disclaimers

• Results are for biofuel delivered to fuel distribution terminals
  ▪ Local distribution, marketing and taxes will add roughly 35 - 60 cents per gallon of gasoline equivalent
• Current subsidies are not included
Supply Curve for All Biofuels in WGA Region
Supply Curve for All Biofuels using California’s Resources
Type of Biomass Consumed – California
Resulting Biofuel System at $2.40/gge
Lands used for Biofuel Production - Western Region

- Lands in Corn for Ethanol
- Lands in Herbaceous Energy Crops

Marginal Cost of Biofuels ($/gge)
Western Region without Dedicated Crops

![Graph showing marginal cost of biofuel (S/gge) against quantity of biofuel (million gge/year). The graph compares 'no crops' and 'baseline' scenarios.](image)

- Marginal Cost of Biofuel (S/gge)
- Quantity of Biofuel (million gge/year)
California without Dedicated Crops

Biofuel Produced (million gge per year)
Sensitivity to Corn Price

Quantity of Biofuel (million gge/year)

- $2.55 per bushel
- $3.55 per bushel
- $5.05 per bushel
- Baseline
Competing Uses for Biomass in CA - Electricity

• RPS is resource neutral, no specific quotas for biomass or other renewable resources

• In addition to biofuel objectives, Bioenergy Action Plan calls for 20% of RPS to be met by biomass in 2010 and 2020
  ▪ No specific sustainability metric included in policy for either electricity or biofuels

• Integrated model analysis pending
**Study Limitations**

- The status and development of the included technologies is uncertain at this time and the results should be interpreted as reflecting the potential from any biofuel with the specified characteristics.

- The model at present ignores imports of both biomass feedstock and finished biofuels from outside the region.

- Significant infrastructure expansion cost such as unit train and pipeline infrastructure and spatial distribution of demand and local fuel delivery to refueling stations are not included in the analysis.
In summary

• There is a limited potential for biofuels production from resources in the western U.S.
• More than two-thirds of the potential in the WGA region requires production of energy crops on agricultural lands
• Share of biomass in residue and waste sources larger in California compared to rest of western region
• Large biomass potential in algae production but feasibility not yet established
• Substantial research underway for increasing crop yields, but future projections highly speculative.
• Costs of production from advanced conversion technologies still largely uncertain due to lack of commercial demonstration
• Carbon impacts to be developed, conclusions regarding sustainability and design of sustainability standards still preliminary
Thank you for your attention.

Questions?