Impacts of New Technologies and Policies on Biofuels Production and Trade

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AIChe Annual Meeting
• Policies - U.S. and worldwide
• Model Methodology
• Technologies for Biofuels
• Results
  – Reference Case
  – Scenario Cases
    • CO₂ price, oil price, E20
• Conclusions

• Renewable fuel standards for feedstocks & GHG emissions:
  – Renewable Fuel: Fuel derived from renewable biomass (Including corn starch)
  – Advanced Biofuel: Renewable fuel (not from corn starch) with fewer GHG emissions
  – Cellulosic Biofuel: Advanced biofuel from cellulose, hemicellulose or lignin
  – Biomass-based Diesel: Advanced biofuel replacing diesel

• Requirements are nested:
  – Firm requirements for cellulosic biofuels and bio-diesel.
  – Advanced biofuels may be all cellulosic and bio-diesel.
  – Renewable fuels may be all advanced biofuels.

• Waivers available – financial buyout for cellulosic biofuels.
EISA’07 RFS Restrictions

- **Minimum GHG Reductions:**
  - Renewable Fuel: 20%
  - Advanced Biofuel: 50%
  - Cellulosic Biofuel: 60%
  - Biomass-Based Diesel: 50%

- **Land Use Must Be:**
  - Cleared or under cultivation & non forested prior to EISA’07 (crops)
  - Managed plantations (trees)

- **Feedstocks May Include:**
  - Crops from previously cleared, non-forested land
  - Biomass from private forest lands*
  - Algae
  - Separated yard and food wastes

- **Feedstocks Do Not Include:**
  - Biomass from ecologically sensitive, protected lands
  - Biomass from federal forest lands

*Includes native-American lands, privately held forests and tree plantations
## Worldwide National Policies

<table>
<thead>
<tr>
<th>Country/region</th>
<th>Gasoline tax</th>
<th>2010 Biofuel tax exemption</th>
<th>Ethanol tariffs</th>
<th>Other, modeled</th>
<th>Other, not-modeled in current study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>$1.40/gal</td>
<td>100%</td>
<td>90¢/gal</td>
<td></td>
<td>5% market share by 2010</td>
</tr>
<tr>
<td>Canada</td>
<td>$0.25/gal</td>
<td>100%</td>
<td>20¢/gal</td>
<td></td>
<td>15% market share 2015</td>
</tr>
<tr>
<td>China</td>
<td>$0.15/gal</td>
<td>100%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central &amp; S. America</td>
<td>$0.70/gal</td>
<td>50%</td>
<td>27¢/gal</td>
<td>Subsidy for hydrous ethanol &amp; FFV; Brazil blending requirement of 20-25%</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>$2.80/gal</td>
<td>90%</td>
<td>90¢/gal</td>
<td>5.5% market share 2010 10% market share 2020</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>$1.90/gal</td>
<td>0%</td>
<td>200%</td>
<td></td>
<td>5% market share by 2015</td>
</tr>
<tr>
<td>Japan</td>
<td>$1.85/gal</td>
<td>90%</td>
<td>17%</td>
<td>500 million liters gasoline equivalent by 2010</td>
<td></td>
</tr>
<tr>
<td>S. Korea</td>
<td>$3.02/gal</td>
<td>90%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>$0.42/gal</td>
<td>51¢/gal</td>
<td>54¢/gal</td>
<td>36 billion gallons renewable fuels 2022</td>
<td></td>
</tr>
</tbody>
</table>
MARKAL Model Structure

Energy Technology Perspectives Model

- Technology Characteristics
  - Energy Sources Used
  - Efficiency
  - Costs (Capital and O&M)
  - Availability

- Energy Resources
  - Cost and Availability

- Energy Service Demands
  - By Sector/Region

- Other Assumptions
  - Long-Term Discount Rate
  - System Reserve Requirements

- Other Constraints
  - Max. CO₂ Emissions by Time Period

Dynamic LP Optimization

Technology Mix for Each Time Period That Satisfies Energy Demand Given Constraints
Updates to ETP Model-Feedstocks

* Countries/feedstocks that have only a single data point, rather than a stepped projection.

Cellulosic feedstocks also generally have limited price points.
### Updates to ETP Model-Technologies

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Source</th>
<th>Conversion Technology</th>
<th>Product</th>
<th>Distribution/Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Sugarcane</td>
<td>Sugar-ethanol mill</td>
<td>Ethanol</td>
<td>• New distribution infrastructure required&lt;br&gt;• Consumption limited to E10 for most of existing vehicle fleet&lt;br&gt;• Higher blends (i.e. E85) can be used in small portion of fleet</td>
</tr>
<tr>
<td>Starch</td>
<td>Corn</td>
<td>Dry mill</td>
<td>Ethanol</td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>Wheat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>Bagasse/other agricultural residues</td>
<td>Biochemical conversion</td>
<td>Ethanol</td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>Forest residues</td>
<td>Thermo-chemical alcohol synthesis</td>
<td>Ethanol/ higher alcohols</td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>Energy crops</td>
<td>Fischer-Tropsch synthesis</td>
<td>Distillates, naphtha</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>Oil Palm</td>
<td>Transesterification</td>
<td>Biodiesel (FAME)</td>
<td>• Products are refining feedstocks&lt;br&gt;• Compatible with conventional fuel infrastructure&lt;br&gt;• Can be blended with petrodiesel at high ratios in most applications</td>
</tr>
<tr>
<td>Oil</td>
<td>Soybean</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conversion Technologies

- **Ethanol**
  - Sugarcane
  - Dry Mill – Corn, Wheat
  - Thermo-chemical Process for Cellulosic Feedstocks (Alcohol Synthesis)
  - Biochemical Process for Cellulosic Feedstock
- **Biodiesel**
  - Soy Oil
  - Palm Oil
- **Biomass-to-Liquids products**
  - Thermo-chemical Process for Cellulosic Feedstocks (Fischer-Tropsch)
Dry Corn Mill

1 tonne corn

Milling → Liquefaction → Saccharification

Rectification/dehydration

Steam

Distillation

Yeast

Fermentation

Whole stillage

Centrifugation

Condensate

Thin stillage

Evaporation

Wet grains

Ethanol storage

330 kg dry DDG

90 kWh electricity

Steam

Enzyme

Acid

112 gallon ethanol

Enzyme

4 MMBtu natural gas
1 tonne cane →

**Receiving/Preparation** → **Extraction** → **Sugar process** → 57 kg Sugar

**Steam boiler**

Steam → **Electricity generation**

Bagasse → **Ethanol process** → 12.3 gallons ethanol

Juice → Molasses

Excess bagasse → Stillage
**Bio-chemical Conversion**

1 tonne biomass

- **Feed handling**
- **Pretreatment conditioning**
- **Saccharification co-fermentation**

- **Nutrients/Enzyme**
- **Lime/Steam/Acid**
- **Gypsum**

**Wastewater treatment**

- **Nutrients**
- **Recycled Water**
- **Wastewater**

**Burner/boiler turbogenerator**

- **Methane**
- **Solids/Syrup**

**Ethanol process**

- **Steam**

**Wastewater treatment**

- **Nutrients**

**99 gallons ethanol**

- **216 kWh net electricity**
Thermo-chemical Conversion

1 tonne biomass

- Gasification
- Syngas cooling & cleaning
- Two-stage water gas shift
- Acid gas removal
- F-T synthesis & refining

74 gallons of naphtha and distillates

Unconverted syngas + C₁-C₄ gases

70 kWh process electricity

Power island

Air separation unit

Air

O₂
Reference Case Assumptions

- EISA Renewable Fuel Standard
- $1.01/gallon cellulosic biofuel subsidy extended until cost competitive
- $1.00/gallon biodiesel subsidy
- Blenders' ethanol credit of $0.51/gallon and Tariff of $0.54/gallon expire in 2010
- Includes existing national biofuels policies worldwide

Oil prices are OECD import basket prices (typically much lower than NYMEX oil prices).
• Grain production levels off after 2015
• Large growth in cellulosic biofuels
• Subsidy for early cellulosic plants is crucial to this growth
• We project more imports than EIA’s Annual Energy Outlook.
• Both domestic & imported cellulosic biofuels will contribute to meeting the mandate.
• Main challenge is building cellulosic plants fast enough.
**Scenarios Modeled**

**Policy Scenarios**
- Tariff/Credit Extension
- Credit Extension
- $50/tCO₂ (global)
- E20 Certification
- Grower’s payment

**Market Scenarios**
- High/Low Feedstock Supply
- Low/High/Higher Oil Price
- Higher share of Brazilian sugar to ETOH
- High Oil Price + High Feed
- Low Oil Price + Low Feed

**Global CO₂ Price**

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ Price (2005$/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>$0</td>
</tr>
<tr>
<td>2010</td>
<td>$5</td>
</tr>
<tr>
<td>2015</td>
<td>$10</td>
</tr>
<tr>
<td>2020</td>
<td>$20</td>
</tr>
<tr>
<td>2025</td>
<td>$30</td>
</tr>
<tr>
<td>2030</td>
<td>$50/60</td>
</tr>
</tbody>
</table>

**2017 Brazil Feedstock Curve**

![Graph showing cumulative production and average value over time.](image)
• **Global CO₂ price:**
  - RFS is met after 2025
  - High oil price: little change from reference because buy-out for cellulosic varies with oil price
- **Global CO₂ price:**
  - Closer to meeting RFS than Reference Case
  - Sugar replaces corn and fills in RFS gap in 2025
  - Cellulosic replaces sugar and corn in 2030
- **High oil price:** slightly more corn in place of sugar
The barrier to meeting RFS?

Biofuels Supply or Infrastructure

- We used the E20 certification scenario to investigate whether ethanol infrastructure was the barrier to meeting the RFS.

- The E20 scenario is a hypothetical scenario that allows increased use of ethanol without new pipelines, fueling stations, and flex fuel vehicles.
E20 Scenario: U.S. Supply

U.S. Biofuels Supply

- Only case to meet RFS
- Illustrates E85 infrastructure constraints
  - Pipelines, fueling stations, flexible fuel vehicles
E20 Scenario: U.S. Supply Shares

- Significant increase in ethanol use.
- E20 allows lower cost ethanol to replace some F-T liquids and compliance credits (gasoline).
- E20 case shows benefits to reduce ETOH distribution constraints (e.g., expanded E85 retail outlets & more fuel-flexible vehicles).

E20 (2020)

- Ethanol replacing compliance credits/gasoline
- Ethanol replacing F-T Liquids
- F-T Liquids
- Biodiesel

Total: 28 B gallons in Ref
30 B gallons in E20
E20 Scenario: U.S. Supply Shares

- Increase in ethanol is partly made possible by imports.
- Imports increase by 60%.
Conclusions

• Cellulosic biofuels are crucial share of RFS
  – Importance of learning investment and technology penetration
• E85 infrastructure constraints
  – Demonstrated by E20 scenario
  – Switch between biochemical and Fischer-Tropsch cellulosic
• Large volumes mandated, production is at inelastic portion of feedstock supply curve
  – Additional subsidies have little impact
• Sizeable role of imports (sugar and cellulosic)
• Implicit global price on CO₂, decline in grain ethanol
• High oil price, lower exports to U.S.
World Biofuels Study (WBS)

Collaboration

Project Management by Office of Policy and International Affairs

With Funding Support from EERE / Office of Biomass Programs

Feedstock Resource Potential

Conversion Process

Integrated Assessment

ORNL & NREL reports at http://www.osti.gov/bridge/ search 924080, 921804