Deployment Analysis: exploring how rapidly biofuel technologies might be deployed to make a significant contribution to the country’s transportation energy

- Generate plausible scenarios
- Understand the transition dynamics
- Investigate potential market penetration scenarios
- Analyze prospective policies and incentives
- Identify high-impact drivers and bottlenecks
- Study competition for biomass resources
- Assess R&D and deployment strategies
- Enable and facilitate focused discussion among stakeholders
Example of Influences/Feedbacks

- Financial incentives for growing cellulosics
- Financial incentives for ethanol conversion plants
- Financial incentives for stations owners to supply ethanol
- Financial attractiveness of growing cellulosics
- Financial attractiveness of biofuel conversion plants
- Biofuel conversion capacity
- Biofuel conversion costs
- Technology maturity
- Feedstock demand
- Feedstock price
- Cellulosic crop production
- Land allocated to cellulosics
- Biofuel price relative to petroleum fuels
- Biofuel demand
- Biofuel consumers
- Gas tax

**KEY**

- "-" = negative (balancing/counteracting) loop
- "+" = positive (reinforcing) loop

**Notes:**

- Biofuel demand
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Key Characteristics of BSM Modules

SUPPLY CHAIN

Feedstock Production
Feedstock Logistics
Biofuels Production
Biofuels Distribution
Biofuels End Use

Feedstock Logistics Module
- Multiple logistics stages
- Cost breakdowns
- Transportation distance
- Land eligibility

Conversion Module
- 15 conversion platforms
- 4 development stages
- 6 learning attributes
- Cascading learning curves
- Project economics
- Industry growth and investment dynamics

Vehicle Scenario Module
- Cars and Light Trucks
- Multiple (9+ scenario) vehicle technologies
- Fleet vintaging
- Vehicle choice scenarios
- E10/E20/E85 potential

Feedstock Supply Module
- 6 Feedstock types
- 10 geographic regions
- 10+ land uses
- Farmer decision logic
- Land allocation dynamics
- New agriculture practices
- Markets and prices

Distribution Logistics Module
- Distribution terminal focus
- Differential cost structure, based on infrastructure (storage and intra/inter-region transport costs)

Fuel Use Module
- Non-, occasional, and frequent users
- Relative price/fuel choice dynamics

Dispensing Station Module
- Fueling-station economics
- Tankage and equipment investment decision
- Distribution-coverage effects

DYNAMIC MODELS OF SUPPLY INFRASTRUCTURE, PHYSICAL CONSTRAINTS, MARKETS, AND DECISION MAKING

POLICIES
INCENTIVES
EXTERNALITIES
BSM Regionalization

- Pacific
- Mountain
- Northern Plains
- Lake States
- Corn Belt
- Appalachia
- Delta States
- Southeast
- Southern Plains
- Northeast
Categorization of Cropland

- **All Cropland**
  - **Active Cropland**
    - **Available for Traditional and Cellulosic Crops**
      - **Annuals**
        - **Herbaceous**
          - Immature
          - Mature
        - **Woody**
          - Immature
          - Mature
      - **Perennial Energy Crops**
    - **Growing as Pasture**
    - **Planted with Energy Crops**
    - **Harvested for Cellulose**
    - **Used as Forage**
    - **Harvested for Cellulose**
    - **Immature**
    - **Mature**
  - **Pasture**
    - **Growing as Pasture**
    - **Planted with Energy Crops**
    - **Harvested for Cellulose**
  - **CRP**
    - **Unharvested**
  - **Excluded from FSM**
    - **High value cash crops, etc.**

- **Corn**
  - With residue collection
  - With secondary crop
- **Soy**
- **Wheat**
  - With residue collection
  - With secondary crop
- **Other Grains**
  - With residue collection
  - With secondary crop
- **Cotton**
  - With residue collection
  - With secondary crop
Biofuel Pathways in the BSM

Biomass Feedstocks
- Lignocellulosic Biomass
- Energy crops (herbaceous and woody)
- Residues (herbaceous, woody, urban)
- Corn
- Natural Oils (Oilseeds and Algae)

Biorefinery Processing
- Gasification
- Pyrolysis
- Pretreatment & Hydrolysis
- Hydrolysis
- Extraction

Syn Gas
- Catalytic synthesis (TC)
- Fischer-Tropsch synthesis
- Methanol Synthesis, Methanol-to-Gasoline

Bio-Oils
- Hydro-processing
- Aqueous Phase Reforming

Sugars
- Fermentation (BC)
- Fermentation

Sugars
- Fermentation

Oils
- Hydrodeoxygenation

Petrochemical Refining
- Ethanol and Mixed Alcohols
- Gasoline

Blending at Refinery
- Gasoline
- Diesel
- Jet

Finished Fuels
- Ethanol
- Butanol
- Ethanol
- Diesel and Jet

“Drop In” points for infrastructure-compatible fuels:
- Processing at biorefinery
- Optional processing
Appropriate Uses of the BSM

- The BSM is an excellent tool for generating and evaluating scenarios and relative impacts of cost targets, policy drivers, tipping points, etc. High-level system models such as the BSM cannot provide absolutes to a high degree of precision.

<table>
<thead>
<tr>
<th>Designed to . . .</th>
<th>Not Designed to . . .</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generate scenarios to explore future biofuel landscapes.</td>
<td>Generate $x$ gallons in $y$ years with $z$ dollars investment.</td>
</tr>
<tr>
<td>Identify areas of potential high leverage.</td>
<td>Identify specific numerical values of particular investments.</td>
</tr>
<tr>
<td>Assess relative merits of technologies and logistics in a gross sense, given solid technological assumptions.</td>
<td>Make fine distinctions between potential of technologies.</td>
</tr>
<tr>
<td>Explore the potential for tipping-point and lock-in/lock-out dynamics.</td>
<td>Predict tipping points precisely and pin them to specific times.</td>
</tr>
<tr>
<td>Build intuition, insight, and knowledge around the supply chain.</td>
<td>Represent a definitive embodiment of knowledge.</td>
</tr>
<tr>
<td>Think through the relative efficacy of different policy prescriptions.</td>
<td>Determine recommended policies in isolation.</td>
</tr>
</tbody>
</table>
Scenario Analyses Completed

Individual policies
- Influence of ethanol tariffs
- Tradeoffs between grants and loan guarantees
- Effects of reverse-auctions for volumetric credits
- Conditions for achieving RFS or other targets
- Effect of Biomass Crop Assistance Program

System characteristics

Competing technologies
- Most effective points for volumetric subsidies
- Methods for reducing bottlenecks from lack of distribution or dispensing infrastructure
- Extent to which policy exacerbates instabilities
- Likelihood of boom/bust cycles

Pricing
- Coupling of petroleum and biofuels prices
- Nature of price fluctuations in various elements of the supply chain
- Impacts of petroleum price scenarios and price shocks
- Conditions under which conversion technologies compete
- Effects of industrial learning rates

Coordinating policies
- Policy mixes with high benefits for low cost
- Synergies between volumetric and capital-oriented policies
- Effects of phasing out supportive policies
- Price-stabilizing influence of forest and crop residues
- Sensitivity of feedstock and ethanol production to plant-gate feedstock prices
- Differential investment in competing conversion technologies
- Conditions under which policies
- Coupling of petroleum and biofuels prices

Methods for reducing bottlenecks from lack of distribution or dispensing infrastructure
- Extent to which policy exacerbates instabilities
Insights along the Cellulosic Ethanol* Supply Chain

The availability of forest residue helps stabilize feedstock prices in early years, as herbaceous energy crops are brought into production; crop residues, urban residues, and woody perennials play smaller roles.

Regional feedstock market prices tend to support growth of the cellulosic ethanol industry more than either constant-price or price-floor regimes.

Without sufficient external support (e.g., counter-cyclical policies), “boom and bust” development of ethanol production capacity is likely.

Competition between the different technologies is very noticeable in favorable cellulosic biofuels scenarios.

Bottlenecks in downstream distribution and dispensing infrastructure may significantly impede the growth of the cellulosic biofuels industry.

Due to the small operating margins of refueling stations, comprehensive subsidies are essential in fostering the installation of high-blend ethanol refueling capacity.

Dramatic gasoline price shocks are required to significantly shift the ethanol consumption curve.

Aggressive E85 penetration scenarios require FFV adoption substantially beyond AEO forecasts.

In most geographic regions, moderate feedstock prices are sufficient to meet near-term targets by 2015, but higher prices are necessary to meet aggressive targets by 2030. Prices are subject to periodic fluctuations in early years.

The prices of annual commercial crops, such as wheat and corn, are not unduly affected by EISA targets.

Sixty miles is the typical economical radius for crop residue and energy crop feedstock collection.

There is a “tipping point” related to levels of initial investment in pilot and demonstration plants: investment must cross a threshold of approximately ten demo plants for a pathway to flourish.

The balance between industry learning and implemented policies is vital to maintain industry growth.

Favorable ethanol selling prices substantially accelerate industry development.

There is a strong tension between maintaining high feedstock prices for farmers and high ethanol mark-ups for producers, distributors, and dispensers while keeping ethanol prices low for end users.

The market for E85 does not persist in cases where E85 price advantage or parity is lost: consumption quickly reverts mostly to gasoline when the price gap with E85 closes.

Aggressive initial investment in conversion plants combined with sustained support policies in downstream portions of the ethanol supply chain effectively underwrites industry takeoff.

* Most of these insights hold for other biofuels in addition to cellulosic ethanol.
Policies Implemented in Isolation Are Not as Effective as Certain Policies Implemented in Coordination

Dynamic Interaction: the point-of-use subsidy decreases financial risk for gas station owners, causing more E85 tankage to be installed. The resulting increase in ethanol demand, in conjunction with the point-of-production subsidy, decreases the risk for those wanting to invest in biorefineries. This increased confidence results in more biorefineries being built and increased cellulosic ethanol production.
Key Insights from Biofuels Supply-Chain Analyses

Four keys to industry development:
1. Profitability at point of production
2. High rates of industry learning
3. An aggressive start in building pilot, demo, and pioneer-scale plants
4. For ethanol, a high level of infrastructure investment to sustain low enough point-of-use prices

The “take off” is likely to be wild and wooly:
1. Unstable, higher than anticipated, feedstock prices
2. Boom/bust development of production capacity
3. Potential for biofuel price instability

Significant production volumes are feasible.
1. RFS2 volumes are achievable in 2030 with heavy startup subsidies.
2. When subsidies are limited to promoting the most economically attractive pathway, production levels can be greater than RFS2 levels.
3. Technologies with favorable long-term economic cost structures can succeed if subsidies are deliberately designed to overcome initial maturity deficiencies.

Caveat: The results depend on details of the policy, incentive, and subsidy parameters for the scenarios and on a variety of state-of-technology assumptions; this chart just presents a few of the many potential scenarios.
**Scenario Library Examples**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Subsidize …</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1: Minimal Policy</strong></td>
<td>Starch until 2012</td>
<td>Apply only existing subsidies and policies</td>
</tr>
<tr>
<td><strong>2: Ethanol Only</strong></td>
<td>Ethanol pathways only</td>
<td>Provide support for ethanol only</td>
</tr>
<tr>
<td><strong>3: Equal Access</strong></td>
<td>All pathways in order to produce 36 billion gallons/year by 2031</td>
<td>Allow all fuel types equal access to generous scenario subsidies</td>
</tr>
<tr>
<td><strong>4: Output-Focused, Constrained</strong></td>
<td>To maximize growth restricted to $10 billion per year</td>
<td>Target most promising technology and withhold most subsidy access from other pathways</td>
</tr>
<tr>
<td><strong>5: Pathway Diversity</strong></td>
<td>To maximize pathways restricted to $10 billion per year</td>
<td>Design subsidy timeline to enable take-off of multiple fuel pathways by staggering start and end dates based on pathway progress and potential</td>
</tr>
<tr>
<td><strong>6: Output-Focused, Unconstrained</strong></td>
<td>To maximize growth with no spending limit</td>
<td>Design a subsidy scheme to most rapidly produce the maximum volume of biofuels that the system can produce</td>
</tr>
</tbody>
</table>
### Different subsidy levels shape scenarios

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
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<tr>
<td></td>
<td>Minimal Policy</td>
<td>Ethanol Only</td>
<td>Equal Access</td>
<td>Output-focused</td>
<td>Diverse pathways</td>
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<tr>
<td>Cellulosic Ethanol</td>
<td>1 Existing starch ethanol subsidy</td>
<td>2 Ethanol subsidies sufficient for modest growth to blend wall</td>
<td>3 Generous subsidies for all pathways, give windfalls</td>
<td>4 Focused subsidy investment on top pathway</td>
<td>5 Staging and weighting to retain diversity</td>
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<tr>
<td>Starch Ethanol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Ethanol</td>
<td></td>
<td></td>
<td></td>
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### Key Points
- **Scenario 1 (Minimal Policy):**
  - 1 Existing starch ethanol subsidy

- **Scenario 2 (Ethanol Only):**
  - 2 Ethanol subsidies sufficient for modest growth to blend wall

- **Scenario 3 (Equal Access):**
  - 3 Generous subsidies for all pathways, give windfalls

- **Scenario 4 (Output-focused):**
  - 4 Focused subsidy investment on top pathway

- **Scenario 5 (Diverse pathways):**
  - 5 Staging and weighting to retain diversity

### Subsidy Levels
- **Starch Ethanol:**
  - 0.45
  - 0.6
  - 0
  - 1.0

- **All Ethanol:**
  - 0.15
  - 0.5
  - 0

- **Fixed Capital Investment (FCI):**
  - 2.65
  - 0.6
  - 0.7
  - 2.65

- **Loan for Pioneer [%]:**
  - 1.0
  - 0.6
  - 0.7
  - 1.0

- **Loan for Commercial [%]:**
  - 0
  - 0
  - 0
  - 0

- **Downstream Distribution and storage [$/gallon]:**
  - 0
  - 0
  - 0
  - 0

- **Downstream Point of use [$/gallon]:**
  - 0
  - 0
  - 0
  - 0

### Summary
- Some values may vary slightly from current runs.

---

**NATIONAL RENEWABLE ENERGY LABORATORY**
2. EtOH only: Intra-EtOH competition for market share

- **Pathway**
  - Downstream ethanol
  - Fischer-Tropsch
  - Fast pyrolysis
  - Methanol to gasoline
  - Fermentation
  - Cellulosic ethanol
  - Starch ethanol

- **Graphs**
  - **Annual production (billion gal/year)**
    - 2012: Equal Access
    - 2020: Cellulosic EtOH has adequate bidding power and can meet demand.
    - Vol for pop subs met, reduced to background level
    - Dist & storage subs turned off
  - **Subsidy spending (USD, $B)**
    - FCI and pioneer loan subsidies are turned off
    - Vol for pop subs met, reduced to background level
    - Dist & storage subs turned off

- **Legend**
  - Equally Access
  - Diverse pathways
  - Ethanol only
  - Output focused
  - Annual spending by scenario in time

- **Note**
  - When cellulosic subsidies are reduced, starch-based EtOH is advantaged and regains some market share.
4. Output focused: competition for market and feedstock

**Pathway**
- Downstream ethanol
- Fischer-Tropsch
- Fast pyrolysis
- Methanol to gasoline
- Fermentation
- Cellulosic ethanol
- Starch ethanol

**Graphs**
- **Graph 1**: Annual production of ethanol (billion gal/year) from 2012 to 2030. Key points:
  - Cellulosic is advantaged over Starch because of subsidies.
  - FP has better economics than cellulosic EtOH and can afford to pay higher prices for feedstocks.
  - Starch EtOH is more mature than cellulosic and hence can regain market share.

- **Graph 2**: Subsidy spending (USD, billion/year) from 2012 to 2030. Key points:
  - FP FCI for pioneer stops.
  - FP FCI for commercial stops.
  - Downstream EtOH subsidies end.

**Output focused scenario in time**
- **Equal Access**
- **Diverse pathways**
- **EtOH only**
- **Output focused**
5. Diverse pathways: competition for market and feedstock

**Pathway**
- Downstream ethanol
- Fischer-Tropsch
- Fast pyrolysis
- Methanol to gasoline
- Fermentation
- Cellulosic ethanol
- Starch ethanol

**Graph 1:**
- Annual production in billion gal/year.
- **2012** to **2030**.
- **17.8 B gal/yr drop-in production**.
- **Cellulosic is advantaged over Starch because of subsidies**.
- **Starch EtOH is more mature than cellulosic and hence can regain market share.**

**Graph 2:**
- Subsidy spending in USD.
- **2012** to **2030**.
- **Annual expenditures are < $10B/yr peak = $9B**.
- **FP-PoP subsidy is turned off.**
- **MTG-PoP subsidy is turned off.**
- **F-T PoP subsidy is turned off.**
- **F-T Loan guarantees for pioneer and commercial and FCI is turned off.**
- **Output focused**.
- **Diverse pathways**.
- **Equal Access**.
- **ETOH only**.
- **Annual spending b scenario in tim**.
**Insights Related to a Transition from E10 to E15**

- Widespread E15 adoption moves the “blend wall” and can greatly alter the proportion of cellulosic ethanol in the mix of biofuels.

<table>
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<tr>
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<th>c. 100% E15 by 2015</th>
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<td>Oilseed Drop-In</td>
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<td></td>
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<tr>
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<td></td>
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<td></td>
</tr>
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**E15 Schedule**

<table>
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<th>Year</th>
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<tbody>
<tr>
<td>2015</td>
<td>0B</td>
</tr>
<tr>
<td>2020</td>
<td>10B</td>
</tr>
<tr>
<td>2025</td>
<td>20B</td>
</tr>
<tr>
<td>2030</td>
<td>30B</td>
</tr>
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</table>

- **Base Scenario**
  - Equal Access Biofuel [gal/yr]:
    - 2015: 20B
    - 2020: 30B
    - 2025: 40B
    - 2030: 50B

- **Output Focus**
  - Biofuel [gal/yr]:
    - 2015: 5B
    - 2020: 10B
    - 2025: 20B
    - 2030: 30B
Library of Biomass Supply Curves

Users can create scenarios of how biomass price evolves with time.

The BSM estimates production quantities and supply curves.
Conclusion

• Selected publications
  • Ethanol Distribution, Dispensing, and Use: Analysis of a Portion of the Biomass-to-Biofuels Supply Chain Using System Dynamics
    <http://dx.doi.org/10.1371/journal.pone.0035082>
  • Understanding the Developing Cellulosic Biofuels Industry through Dynamic Modeling
    <http://dx.doi.org/10.5772/17090>
  • Using System Dynamics to Model the Transition to Biofuels in the United States
    <http://dx.doi.org/10.1109/SYSOSE.2008.4724136>

• Invitation:
  – We are seeking input and collaboration on the development of biofuels scenarios.

• Questions?