Goal Statement

- **Why**: Program-wide need for information on feedstock supplies (quantity, cost, quality).
- **How**: Economic, logistic, and environmental models.
- **Outcome**: Estimates of the potential economic availability of biomass resources (by type, price, year, and production scenario), and a first-time assessment of environmental effects.

*2040, combined potential supplies, at $60 or less, roadside, base-case scenario, including wastes. Source: https://www.bioenergykdf.net/billionton2016/1/2/tableau*
Quad Chart Overview

Timeline
- Project start date: FY07
- Current AOP project end date: Ongoing
- Percent complete: N/A

Barriers
- (A)Ft-A. Feedstock Availability and Cost
- At-C. Data Availability across the Supply Chain
- (A)Ft-B. Sustainable Production
- Ft-H. Biomass Material Handling and Transportation

Partners
- INL, PNNL, NREL, ANL
- Agricultural Policy Analysis Center (APAC) University of Tennessee,
  Oregon State PRISM Climate Group
- Monsanto, Weyerhaeuser, ArborGen, GreenWood Resources, FDCE
- Other agencies: USDA Forest Service, USDA-ARS
- Sun Grant Regional Feedstock Partnership
- Southern Forest Analysis Consortium

Budget

<table>
<thead>
<tr>
<th></th>
<th>FY 12 Costs (FY 12–FY 14)</th>
<th>FY 15 Costs</th>
<th>FY 16 Costs</th>
<th>Total Planned Funding (FY 17-Project End Date)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Funded</td>
<td>$3.1</td>
<td>$1.4</td>
<td>$2.3</td>
<td>$1.9</td>
</tr>
</tbody>
</table>
1 - Project Overview

• History and accomplishments
  o Identified adequate supply to displace 30% of petroleum consumption; i.e., physical availability (Billion-Ton Study, 2005).
  o Quantified potential economic availability of feedstocks (Billion-Ton Update, 2011, 2016).
  o Disseminated county-level data (feedstock quantities, by scenario, price, year) through Bioenergy Knowledge Discovery Framework (Billion-Ton Update, 2011, 2016).

• Recent Objectives
  o Full farm-to-reactor analysis.
  o Adding algae, miscanthus, and energy cane to feedstocks.
  o Addressing environmental sustainability, climate variability/change, and uncertainty.
2 – Approach (Management)

- **Critical success factors**: resource assessments with credible economics and latest available information (e.g., agronomics, logistics, sustainability).
- **Challenges**: breadth, depth, and interfaces with other projects.
- **Teamwork and Collaboration**: Weekly calls with team, BETO, and other labs; coordination with USFS, Southern Forest Resource Consortium, Algae Biomass Organization, and others.
- **Review process**: for modeling assumptions and results.
- **Go/No-Go**: Q3 2015: Decision to publish BT16.
2 – Approach (Technical, Volume 1)

- **Objective:** Quantify the economic availability of biomass feedstocks.
- **Data:** NASS Census of Agriculture, USDA Baseline Projections, Forest Inventory and Analysis, Sun Grant Initiative, and USFS Forest Products Lab.
- **Economic models:** BETO version of POLYSYS for agriculture and ForSEAM for forest resources, both operating at a county-level.

**Output: Feedstock Supply and Price Assessments**
- Grower payments (crop residues & energy crops) and stumpage (forest residues)
- Costs of major feedstocks with delivery and preprocessing to the biorefinery throat
3 – Technical accomplishments (Vol. 1)

2016 Billion-Ton Report, Volume 1: The Economic Availability of Feedstocks


https://www.bioenergykdf.net/billionton2016/overview
3 – Technical accomplishments: Volume 1

Current and Potential, Base-case, $60/dt

Billions of Dry Tons per year

- Long-term potential
  - Agricultural Residues
  - Forestland resources
  - Wastes
  - Currently used

- Near-term potential
  - 2017
  - 2020
  - 2022
  - 2025
  - 2030
  - 2035
  - 2040

- Currently used
  - 2017
  - 2020
  - 2022
  - 2025
  - 2030
  - 2035
  - 2040

Currently used Waste:
- 2017: 0.365
- 2020: 0.365
- 2022: 0.365
- 2025: 0.365
- 2030: 0.365
- 2035: 0.365
- 2040: 0.365

Forestland resources:
- 2017: 0.138
- 2020: 0.139
- 2022: 0.14
- 2025: 0.14
- 2030: 0.141
- 2035: 0.141
- 2040: 0.142

Agricultural Residues:
- 2017: 0.104
- 2020: 0.116
- 2022: 0.123
- 2025: 0.135
- 2030: 0.149
- 2035: 0.163
- 2040: 0.176

Wastes:
- 2017: 0.103
- 2020: 0.109
- 2022: 0.109
- 2025: 0.101
- 2030: 0.097
- 2035: 0.101
- 2040: 0.097

- Currently used
### 3 – Technical accomplishments: Volume 1

**Current and Potential, Base-case, $60/dt**

Billions of Dry Tons per year

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy Crops</th>
<th>Agricultural Residues</th>
<th>Forestland resources</th>
<th>Wastes</th>
<th>Currently used</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>0.0104</td>
<td>0.0116</td>
<td>0.0123</td>
<td>0.0130</td>
<td>0.365</td>
</tr>
<tr>
<td>2020</td>
<td>0.0103</td>
<td>0.0109</td>
<td>0.0109</td>
<td>0.0101</td>
<td>0.365</td>
</tr>
<tr>
<td>2022</td>
<td>0.0138</td>
<td>0.0139</td>
<td>0.0140</td>
<td>0.0140</td>
<td>0.365</td>
</tr>
<tr>
<td>2025</td>
<td>0.0135</td>
<td>0.0135</td>
<td>0.0149</td>
<td>0.0141</td>
<td>0.365</td>
</tr>
<tr>
<td>2030</td>
<td>0.0163</td>
<td>0.0163</td>
<td>0.0163</td>
<td>0.0141</td>
<td>0.365</td>
</tr>
<tr>
<td>2035</td>
<td>0.0176</td>
<td>0.0176</td>
<td>0.0176</td>
<td>0.0142</td>
<td>0.365</td>
</tr>
<tr>
<td>2040</td>
<td>0.0176</td>
<td>0.0176</td>
<td>0.0176</td>
<td>0.0142</td>
<td>0.365</td>
</tr>
</tbody>
</table>

**Scenarios to delivered analysis**

[Link: bioenergykdf.net/billionton2016/overview]
3 – Technical accomplishments: Volume 1

Current and Potential, High-yield, $60/dt
Billions of Dry Tons per year

- Energy Crops
- Agricultural Residues
- Forestland resources
- Wastes
- Currently used

Scenario to delivered analysis

2040, $60/dt, High-yield

Current and Potential, High-yield, $60/dt

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy Crops</th>
<th>Agricultural Residues</th>
<th>Forestland resources</th>
<th>Wastes</th>
<th>Currently used</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>0.105</td>
<td>0.103</td>
<td>0.138</td>
<td>0.365</td>
<td>0.365</td>
</tr>
<tr>
<td>2020</td>
<td>0.123</td>
<td>0.109</td>
<td>0.139</td>
<td>0.365</td>
<td>0.365</td>
</tr>
<tr>
<td>2022</td>
<td>0.192</td>
<td>0.109</td>
<td>0.140</td>
<td>0.365</td>
<td>0.365</td>
</tr>
<tr>
<td>2025</td>
<td>0.192</td>
<td>0.109</td>
<td>0.140</td>
<td>0.365</td>
<td>0.365</td>
</tr>
<tr>
<td>2030</td>
<td>0.380</td>
<td>0.140</td>
<td>0.141</td>
<td>0.365</td>
<td>0.365</td>
</tr>
<tr>
<td>2035</td>
<td>0.559</td>
<td>0.141</td>
<td>0.141</td>
<td>0.365</td>
<td>0.365</td>
</tr>
<tr>
<td>2040</td>
<td>0.736</td>
<td>0.142</td>
<td>0.142</td>
<td>0.365</td>
<td>0.365</td>
</tr>
</tbody>
</table>
3 – Technical accomplishments: Volume 1

Results, delivered (production and harvest, preprocessing, and transportation to biorefinery throat). Collaboration with 1.2.3.1 Feedstock Supply Modeling.

County-level roadside supplies

Feedstock-specific prices

Transportation network to potential biorefinery locations

Supply curves of delivered supplies (average prices)

Summary of delivered results

<table>
<thead>
<tr>
<th>Price per dry ton</th>
<th>Near term</th>
<th>Long term base case</th>
<th>Long term high yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadside ≤$60</td>
<td>310</td>
<td>679</td>
<td>985</td>
</tr>
<tr>
<td>Delivered ≤$84</td>
<td>217</td>
<td>467</td>
<td>825</td>
</tr>
<tr>
<td>Delivered ≤$100</td>
<td>217</td>
<td>564</td>
<td>825</td>
</tr>
<tr>
<td>Unused</td>
<td>93</td>
<td>114</td>
<td>160</td>
</tr>
</tbody>
</table>
3 – Technical accomplishments: Volume 1

Potential economic availability of algal biomass, collaboration with 1.3.1.500 (ORNL), 1.3.1.102 (PNNL), and 1.3.1.200 (NREL).

Spatial co-location

Supply curves (current, fresh water)

Millions of tons of biomass and price ranges

<table>
<thead>
<tr>
<th>Productivity &amp; media</th>
<th>Ethanol plant</th>
<th>Coal power plant</th>
<th>Natural gas power plant</th>
<th>Range of min prices per dry ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current, freshwater</td>
<td>12</td>
<td>19</td>
<td>15</td>
<td>$719-$2030</td>
</tr>
<tr>
<td>Current, saline</td>
<td>10</td>
<td>54</td>
<td>21</td>
<td>$755-$2889</td>
</tr>
<tr>
<td>Future, freshwater</td>
<td>13</td>
<td>10</td>
<td>N/A</td>
<td>$490-$1327</td>
</tr>
<tr>
<td>Future, saline</td>
<td>11</td>
<td>12</td>
<td>N/A</td>
<td>$540-$2074</td>
</tr>
</tbody>
</table>
2 – Approach (Technical, Volume 2)

Three scenarios evaluated

13 Indicators applied

- Air quality
- Biological diversity
- Soil quality
- Sustainability indicators
- Water quality & quantity
- Productivity
- Greenhouse gas emissions

• Applied to 2017, 2040 base-case, and 2040 high-yield scenarios
• Address thirteen indicators in 6 indicator categories
• Models specific to indicators (SWAT, Century, GREET, F-PEAM, species distribution model) with several national labs and USFS
• Output: environmental effects of three scenarios from vol 1.
## Methodology for environmental sustainability

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil quality</strong> (ANL)</td>
<td><strong>Greenhouse gases</strong> (ANL)</td>
</tr>
<tr>
<td>1. Total organic carbon (TOC)</td>
<td>12. CO₂ equivalent emissions (CO₂ and N₂O)</td>
</tr>
<tr>
<td>2. Total nitrogen (N)</td>
<td></td>
</tr>
<tr>
<td>3. Extractable phosphorus (P)</td>
<td></td>
</tr>
<tr>
<td>4. Bulk density</td>
<td></td>
</tr>
<tr>
<td><strong>Water quality and quantity</strong> (ANL, ORNL, USFS)</td>
<td><strong>Biodiversity</strong> (ORNL, USFS)</td>
</tr>
<tr>
<td>5. Nitrate loadings to streams (and export)</td>
<td>13. Presence of taxa of special concern</td>
</tr>
<tr>
<td>6. Total phosphorus (P) loadings to streams</td>
<td>14. Habitat area of taxa of special concern</td>
</tr>
<tr>
<td>7. Suspended sediment loadings to streams</td>
<td></td>
</tr>
<tr>
<td>8. Herbicide concentration in streams (and export)</td>
<td></td>
</tr>
<tr>
<td>9. Storm flow</td>
<td></td>
</tr>
<tr>
<td>10. Minimum base flow</td>
<td></td>
</tr>
<tr>
<td>11. Consumptive water use (incorporates base flow)</td>
<td></td>
</tr>
<tr>
<td>Addition: Water yield</td>
<td></td>
</tr>
<tr>
<td><strong>Air quality</strong> (NREL)</td>
<td><strong>Productivity</strong></td>
</tr>
<tr>
<td>15. Tropospheric ozone</td>
<td>19. Aboveground net primary productivity or Yield</td>
</tr>
<tr>
<td>16. Carbon monoxide</td>
<td></td>
</tr>
<tr>
<td>17. Total particulate matter less than 2.5 μm diameter (PM₂.₅)</td>
<td></td>
</tr>
<tr>
<td>18. Total particulate matter less than 10 μm diameter (PM₁₀)</td>
<td></td>
</tr>
<tr>
<td>Additions: VOCs, SOₓ, NOₓ, NH₃</td>
<td></td>
</tr>
</tbody>
</table>

McBride et al. (2011) *Ecological Indicators* 11:1277-1289

Yellow—indicators in Billion Ton 2016

White—other BETO- and ORNL-recommended indicators
2 – Approach (Review process)

• Workshop titled “Presentation and Expert Review of the 2016 Billion-Ton Report” was held December 9–10, 2015, in Washington, D.C.
  – 25 Institutions and 28 individuals

• Workshop titled “Presentation and Expert Review of the 2016 Billion-Ton Report Volume 2” was held May 11, 2016, in Washington, D.C.
  – 34 Institutions and 46 individuals; representatives from agencies and industries

• Written review of volume 2, July-Sept. 2016.

• Review by the Algae Biomass Organization
  – 6 reviewers
3 – Technical accomplishments

2016 Billion-Ton Report, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1

MYPP Sustainability Strategic Goal: To understand and promote the positive environmental, economic, and social effects and reduce the potential negative impacts of bioenergy production activities.

MYPP 2016 milestone: By 2016, evaluate environmental sustainability indicators for updated assessment of potentially available feedstock supplies and identify conditions or conservation practices under which feedstock production scenarios are likely to maintain or improve soil quality, biodiversity, and water quality in major feedstock production regions while meeting projected demands for food, feed, and fiber production.
Changes in perennial cover under the base-case (BC1) scenario

Potential increase in perennial cover of 24-45 million acres from 2015 (ORNL, project 4.2.1.41).

Potential GHG and SOC changes: dependent on yield, local soil characteristics, and weather (ANL, project 4.1.1.10).

Most counties might not see significant challenges in meeting air-quality standards, but 25% are estimated to emit ~1-10% of the NEI (NREL, project 4.2.1.30).
3 – Technical accomplishments: Data availability

Thousands of hits, visualizations, and downloads on www.bioenergykdf.net/billionton2016/overview
4 – Relevance

• Feedstocks represent about one-third of the cost of production of biofuels (Aden et al, 2009; Davis et al, 2011).
• Results inform biofuels commercialization strategies with feedstock quantities, prices, types, and spatial distribution.
• Analysis extends beyond the farmgate to delivered scenarios to better reflect potential industry.
• Work referenced by EIA, IRENA, DOE, and others

*Source: https://www.bioenergykdf.net/billionton2016/6/2/tableau
5 – Future Work

Future research:

1) Supply push
   a) Crop improvement
   b) Advanced logistics
   c) Precision agriculture

2) Market pull
   a) Conversion processes
   b) Commoditization
   c) Co-optimization
   d) Co-products
   e) Aviation biofuels
   f) International markets
   g) Policy impacts
5 – Future Work
5 – Future Work

- Supply push
  - Quantify annual supply variability
  - Alternative supply scenarios
  - Oilseed crops
- Market pull
  - Spatially explicit demand runs
  - Market evolution
  - Custom assessments for design cases
  - Evaluate trade
5 – Future Work

Economic availability of feedstocks (source https://www.bioenergykdf.net/billionton2016/1/9/tableau):
Summary

1. Overview: Critical need for up-to-date information on feedstock supplies, prices, and environmental effects.

2. Approach: Improve established modeling approach, collaborate with other projects.

3. Technical Accomplishments/Progress/Results: *2016 Billion-Ton Report, Advancing Domestic Resources for a Thriving Bioeconomy*, volumes 1 and 2, and online companion material.

4. Relevance: Feedstock is about 1/3 of biofuels price. Supply information is needed.

Additional Slides
Responses to Previous Reviewers’ Comments

• “The double cropping idea needs to be explored further as it may allow us to produce much more biomass more sustainably without additional acres.” We will evaluate inclusion of double cropping in future analyses.

• “This is a critically important project that is well carried out. The way this information is characterized is very important to the project’s credibility because real experiences in these early developmental days of the industry will not be consistent with this work.” It is important to characterize these supplies as potential, contingent upon demand, particularly for the energy crops.

• “Good project and important level of analysis to get closer to potential delivered costs and supply curves.” … “Excellent project. Well done, with high impact.”
Publications, Patents, Presentations, Awards, and Commercialization


