U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) 2017 Project Peer Review

1.2.3.1
Feedstock Supply Modeling

March 8, 2017

Feedstocks Supply and Logistics

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Goal Statement

Build and apply simulations of biomass supply chains

Expanding biomass availability and cost projections to the reactor throat

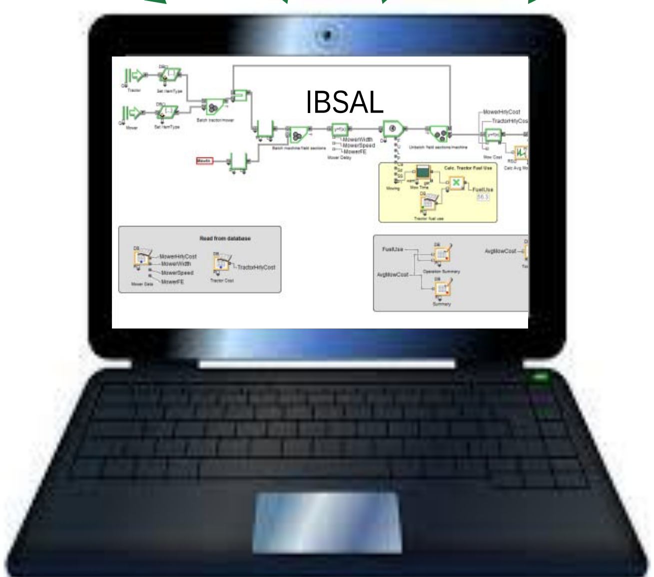
Harvest, storage, handling, & preprocessing

Spatial distribution of feedstocks

Machine performance data

Weather data

Purchase prices



Costs

Energy input

CO_2 from fuel

Resources required

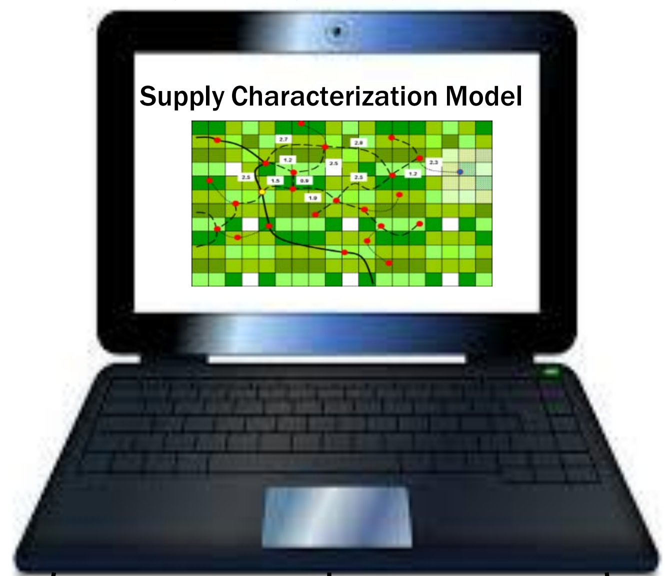
Spatial analysis of transportation and use

Logistics costs

Overcontracting buffer

Roadside quantity and cost

Losses



Transport Distances

Transport costs

Reactor throat cost

Quad Chart Overview

Timeline

- 10/1/2015
- 9/30/18
- 60%

Barriers

- Ft-A Feedstock Availability and Cost
- Ft-L Biomass Handling and Transport
- Ft-M Overall Integration and Scale-Up

Budget

	FY 15 Costs	FY 16 Costs	Total Planned Funding (FY 17-Project End Date)
DOE Funded	$760K	$1,050K	$1,900K

Partners

Collaborations

- Idaho National Laboratory
- University of British Columbia
- University of Tennessee
- Virginia Tech
- University of Texas at San Antonio

1 - Project Overview

Simulation analyses of biomass supply chains

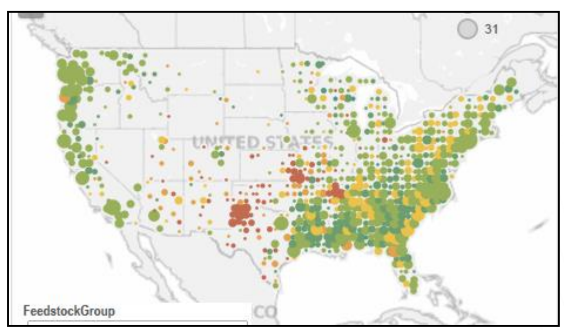
IBSAL Algae: Feasibility assessment of pelletizing algae biomass

Regional feasibility of field drying stover

Equipment to utilize available corn stover

Validation of logistics demonstration projects

Spatial analysis to estimate delivered costs for BT16



Assessing industrial relevance of feedstock combinations

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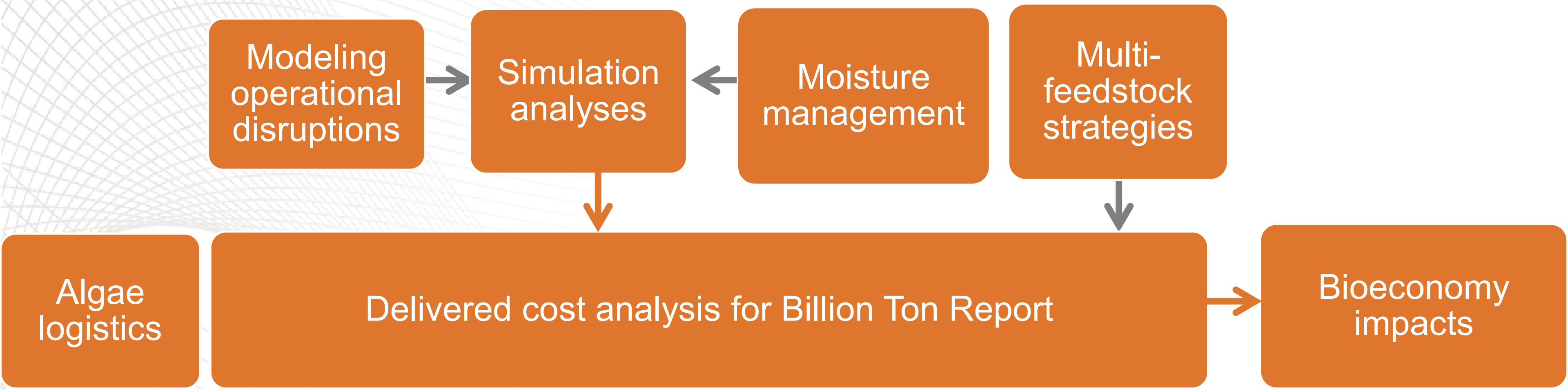
2 – Approach (Management)



Addressing project challenges

- Integrity of simulations
  - Assemble a diverse, multi-disciplinary team to avoid bias
- Relevance
  - Consistent communication with industry partners to maintain awareness of challenges encountered in industry development
- Simulation accuracy
  - Rigorous model verification and validation

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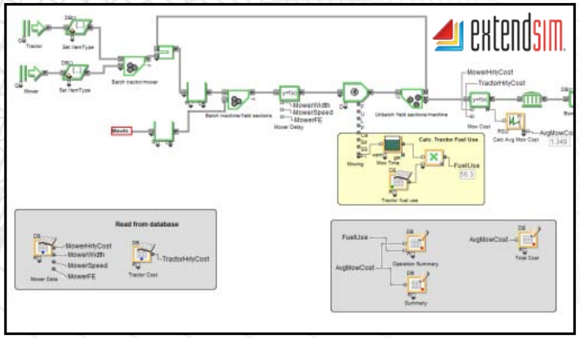
2 – Approach (Technical)

Integrated Biomass Supply and Logistics Model (IBSAL)



A discrete-event modeling platform that includes:

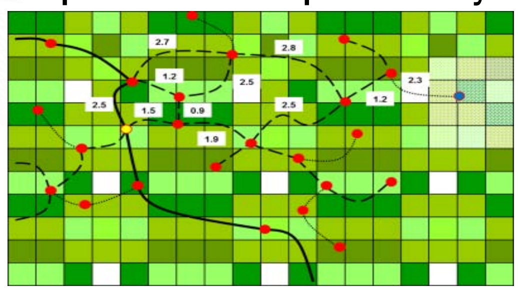
- Lost time due to weather
- Field drying of herbaceous biomass
- Tracking biomass moisture
- Stochastic inputs

Costs, throughput by operation

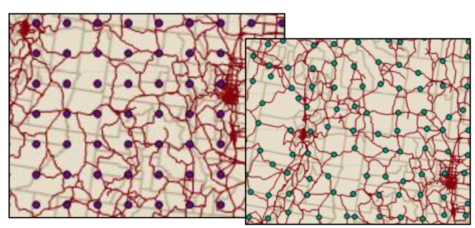
Supply Characterization Model (SCM)

- Site utilization facilities to minimize delivered feedstock cost
- Estimate distance, cost to move biomass from source to destination

Transportation and spatial analysis



Potential facility locations limited to a 50-mi grid snapped to nearest highway network node

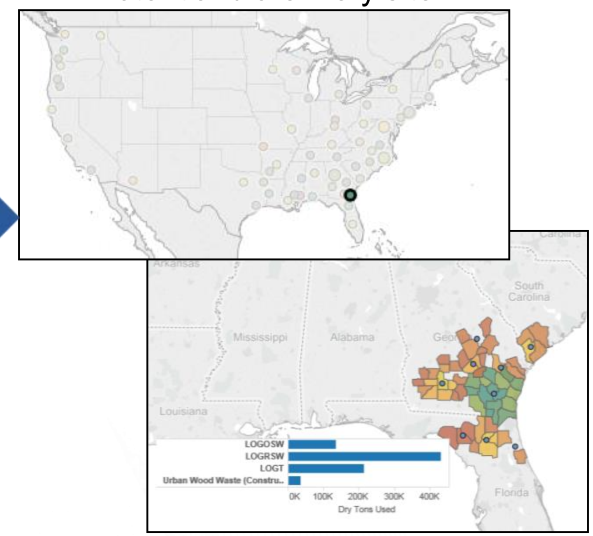


Transportation distance and cost
Total cost

Interactive Data Visualizations

- Results are large, complex datasets
- Interactive visualization useful in quality control and analysis

Potential biorefinery site



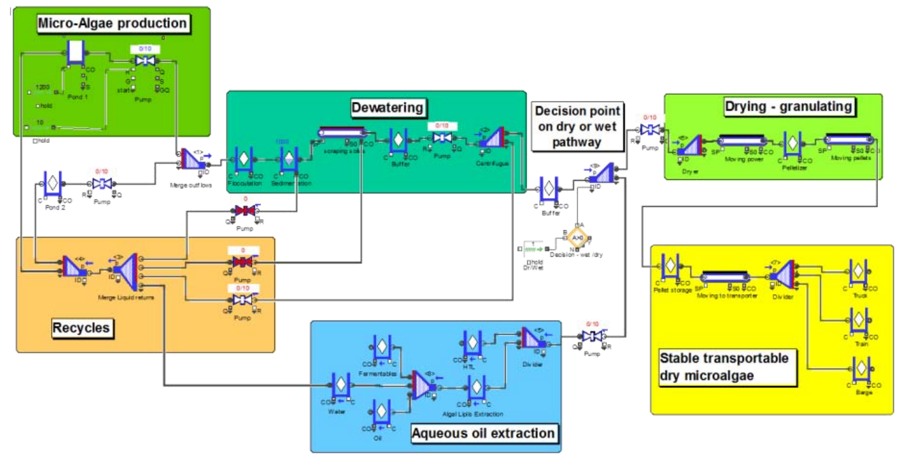
Counties and preprocessing depots supplying selected biorefinery

Explore results at county-scale,
Dissemination of results

3 – Technical Accomplishments/ Progress/Results

IBSAL Algae: Feasibility assessment of pelletizing algae biomass

- Achieving the BETO cost goal of $3/GGE for algae-derived biofuel requires improvements in supply chain efficiency
- Pelletization also promising for:
  - Using algae biomass as a blendstock
  - Using algae residuals
  - Increase storability to provide buffer in case of pond crash and time of low yields



	Lipid Extraction	Hydrothermal Liquefaction	Pellet
	$/ash-free dry weight ton		
Feedstock production to 20% solids	$543	$761	$543
Conversion cost	$156	$102	$43
Storage	$2.77	$2.77	$2.50
Transport by truck (100 km)	$13	$13	$19
TOTAL	$714	$878	$608

Using the IBSAL-algae model, an alternative supply chain option to dry and densify algae biomass was shown to be potentially viable

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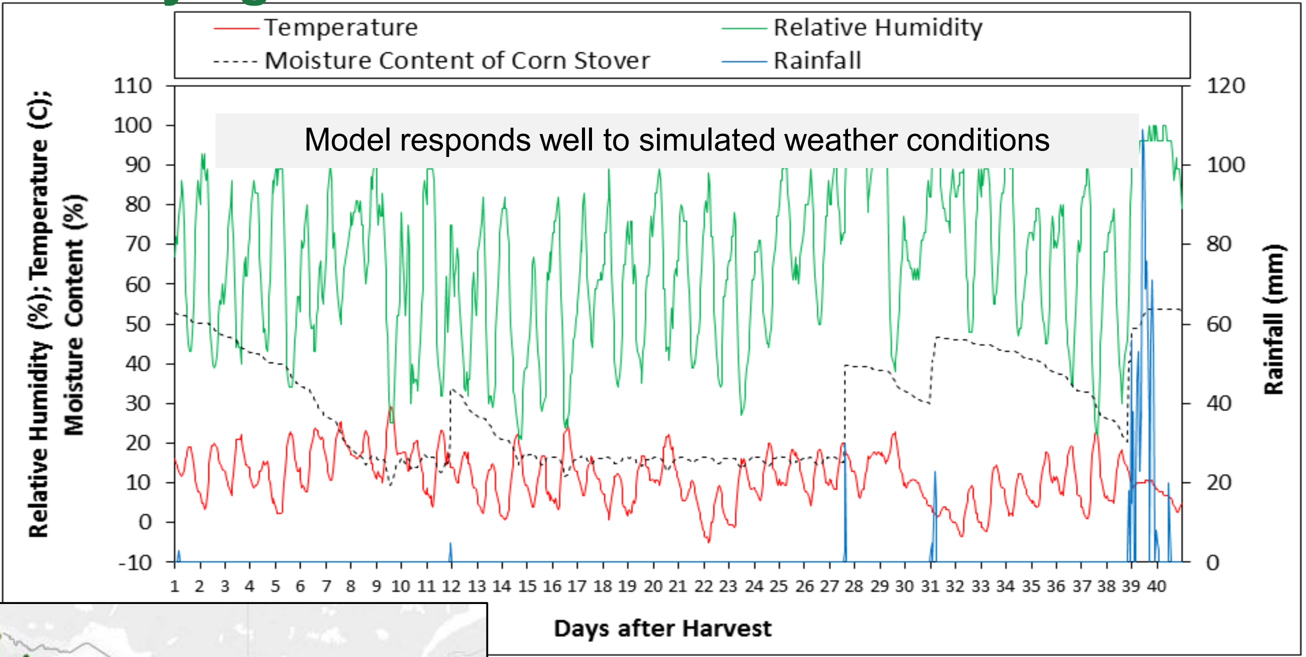
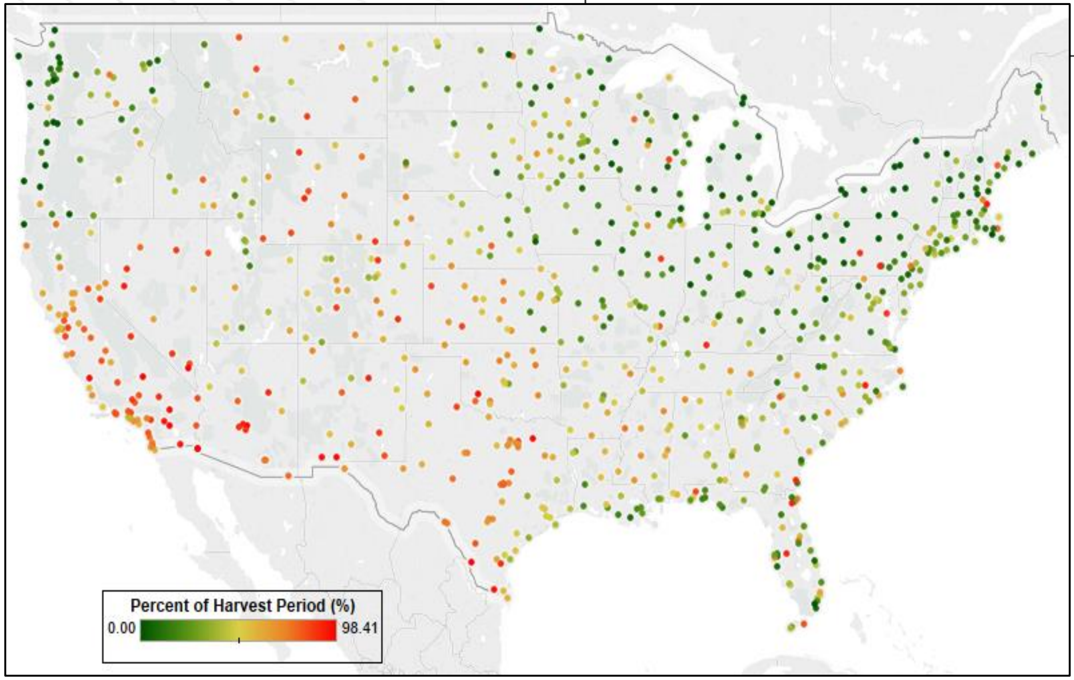
3 – Technical Accomplishments/ Progress/Results
Regional feasibility of field drying corn stover

- Initial moisture: 53%
- Harvest timing based on USDA data for corn harvest progress, by state
- Typical year weather data
- Stover wetting/drying model from Manstretta and Rossi (2015)





From Oyedeji et al. (in review)

Stover moisture after field drying	Fraction of stover in US
Dry	37%
Intermediate	37%
Wet	26%

Field drying is a challenge in many corn-producing regions.

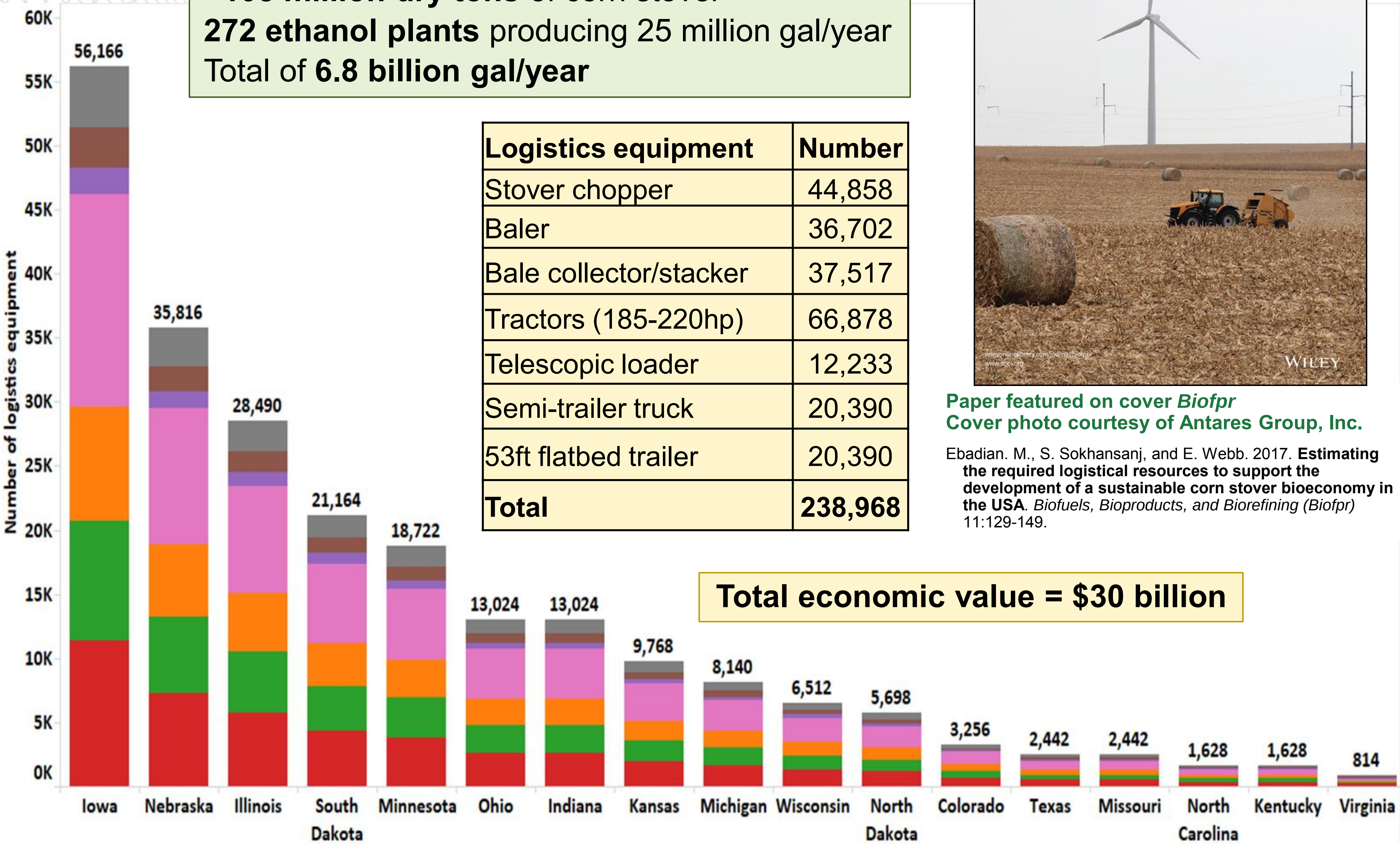
- High-moisture harvest, storage strategies needed
- Cost estimates in resource assessments should account for moisture challenges

3 – Technical Accomplishments/ Progress/Results

Equipment required to utilize available corn stover

We considered **17 major corn-growing states**
~108 million dry tons of corn stover
272 ethanol plants producing 25 million gal/year
Total of **6.8 billion gal/year**

Logistics equipment	Number
Stover chopper	44,858
Baler	36,702
Bale collector/stacker	37,517
Tractors (185-220hp)	66,878
Telescopic loader	12,233
Semi-trailer truck	20,390
53ft flatbed trailer	20,390
Total	**238,968**



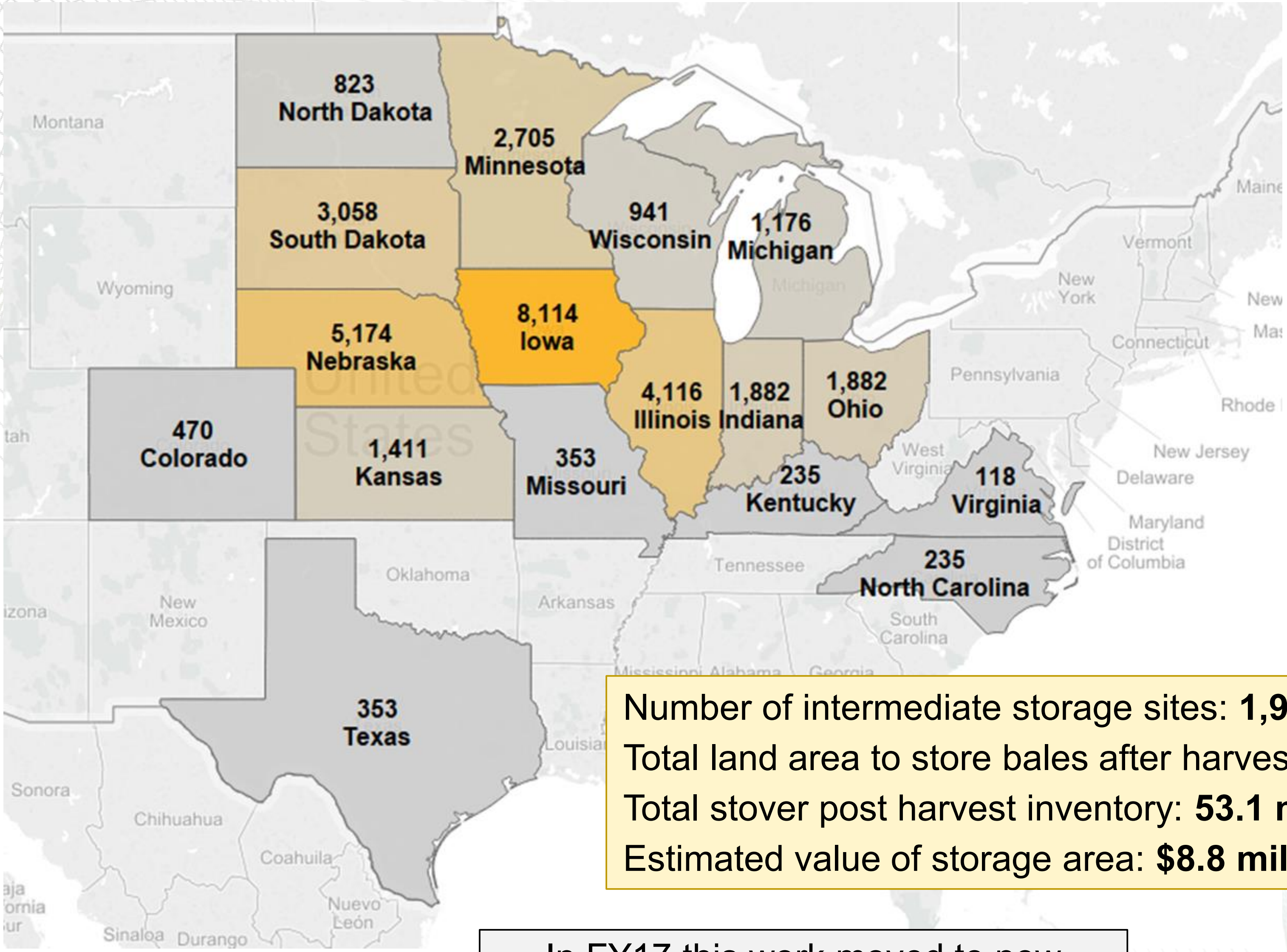
Total economic value = $30 billion

Paper featured on cover *Biofpr*
Cover photo courtesy of Antares Group, Inc.

Ebadian. M., S. Sokhansanj, and E. Webb. 2017. **Estimating the required logistical resources to support the development of a sustainable corn stover bioeconomy in the USA**. *Biofuels, Bioproducts, and Biorefining (Biofpr)* 11:129-149.

3 – Technical Accomplishments/ Progress/Results

Storage area (acres) required to utilize available corn stover



Ebadian et al (2017)

Number of intermediate storage sites: **1,903**
Total land area to store bales after harvest: **35,320 acres**
Total stover post harvest inventory: **53.1 million dry tons**
Estimated value of storage area: **$8.8 million**

In FY17 this work moved to new CEMAC project (6.3.0.9)

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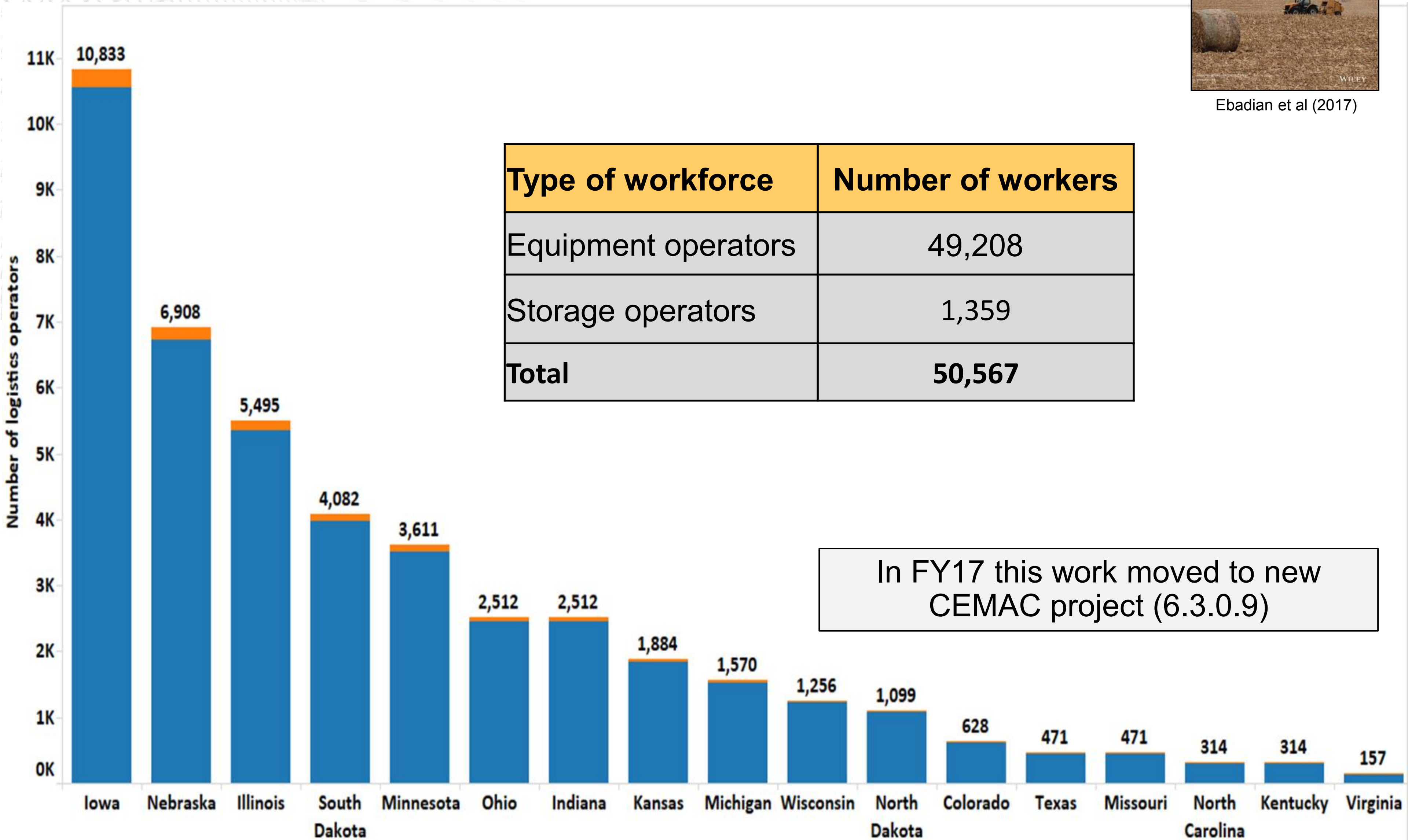
3 – Technical Accomplishments/ Progress/Results

Number of logistics operators

Ebadian et al (2017)



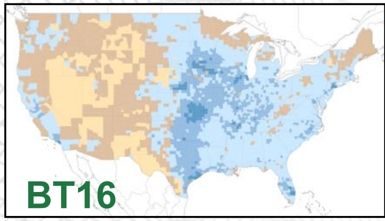
Type of workforce	Number of workers
Equipment operators	49,208
Storage operators	1,359
Total	**50,567**

In FY17 this work moved to new CEMAC project (6.3.0.9)

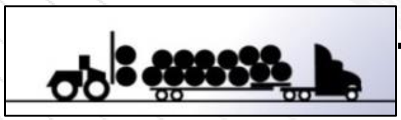
3 – Technical Accomplishments/ Progress/Results

BT16 Chapter 6: To the Biorefinery

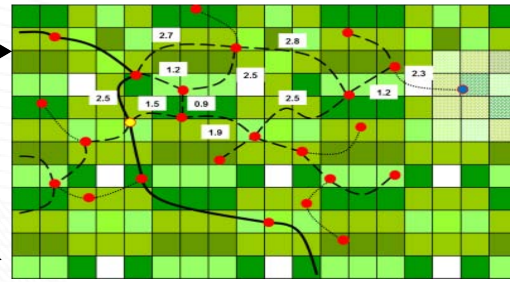
Roadside cost & quantity



Storage, handling, preprocessing costs

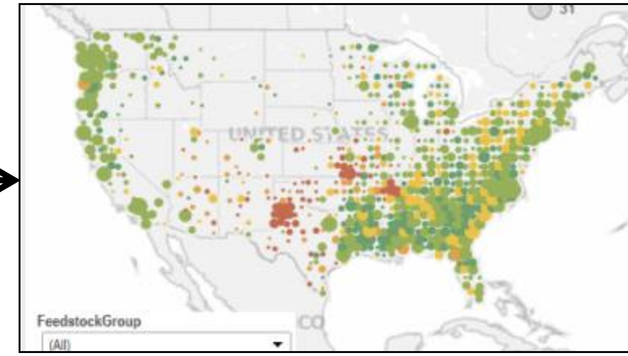


Transportation and spatial analysis



Supply Characterization Model (SCM)

Advanced visualization



DATA SOURCES

Roadside costs and quantities

- From BT16
  - By county, by feedstock
  - Supplies ≤$60/dry ton
  - Located at county centroid
  - Base case and high-yield scenario

Logistics costs

- From 2017 Logistics Design Cases (INL, 2013)

FEEDSTOCKS	
Herbaceous *Biochemical Pathway*	Woody *Thermochemical Pathway*
Biomass sorghum Corn stover Miscanthus Switchgrass Yard trimmings	Residues Whole tree C&D wastes Urban wood wastes Woody energy crops

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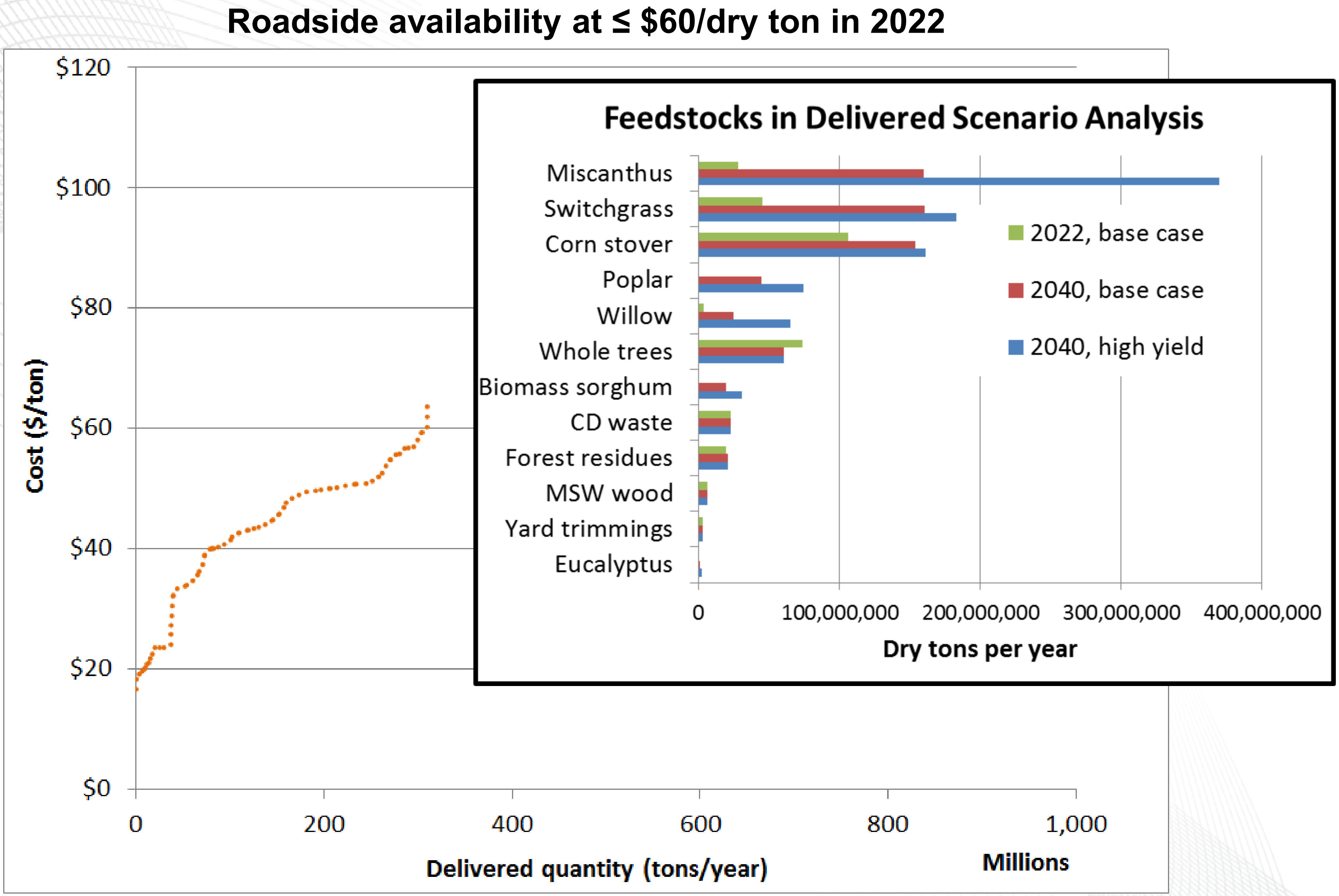
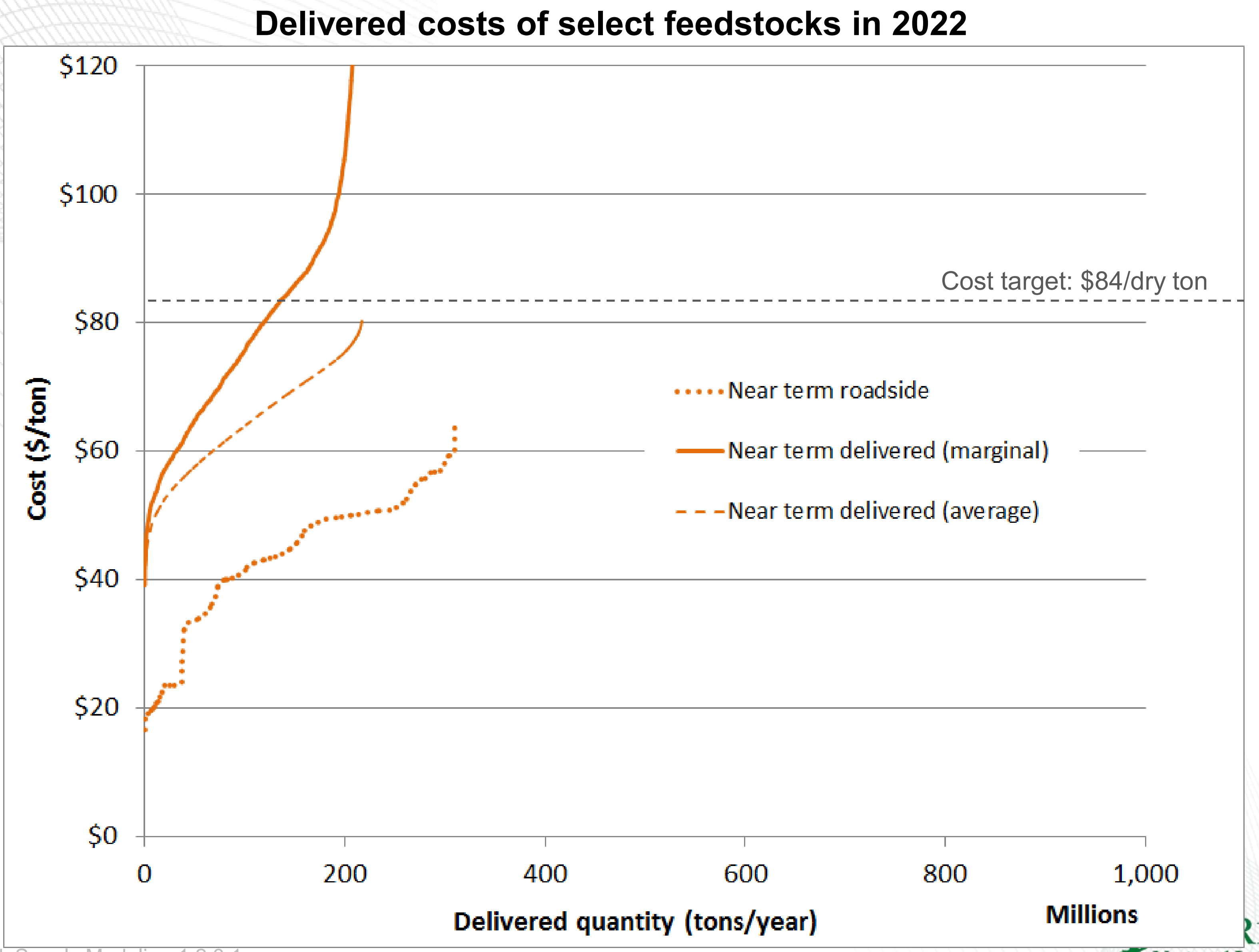
3 – Technical Accomplishments/ Progress/Results

BT16 Chapter 6: To the Biorefinery

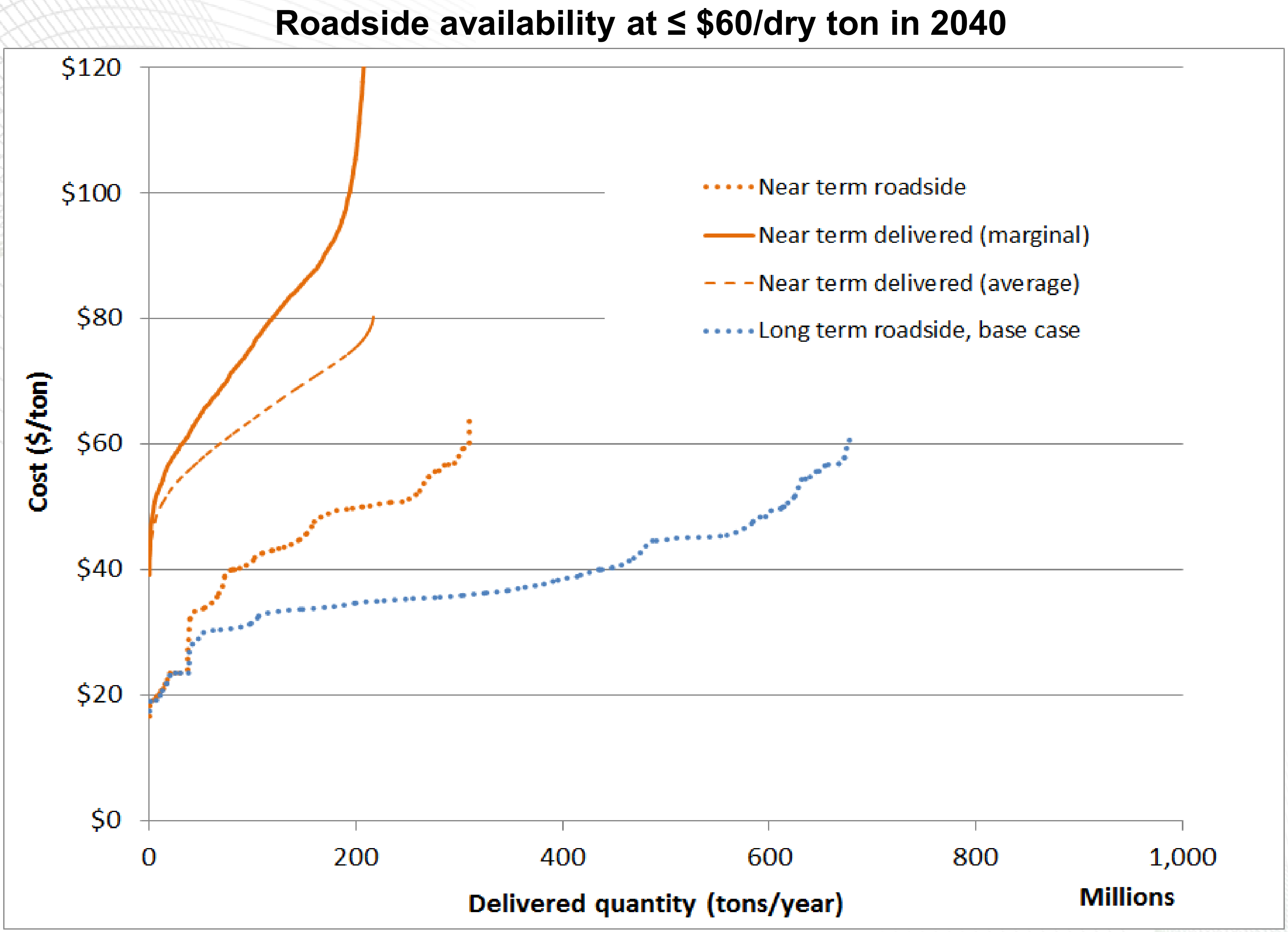


3 – Technical Accomplishments/ Progress/Results

BT16 Chapter 6: To the Biorefinery



3 – Technical Accomplishments/ Progress/Results
BT16 Chapter 6: To the Biorefinery



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3 – Technical Accomplishments/ Progress/Results

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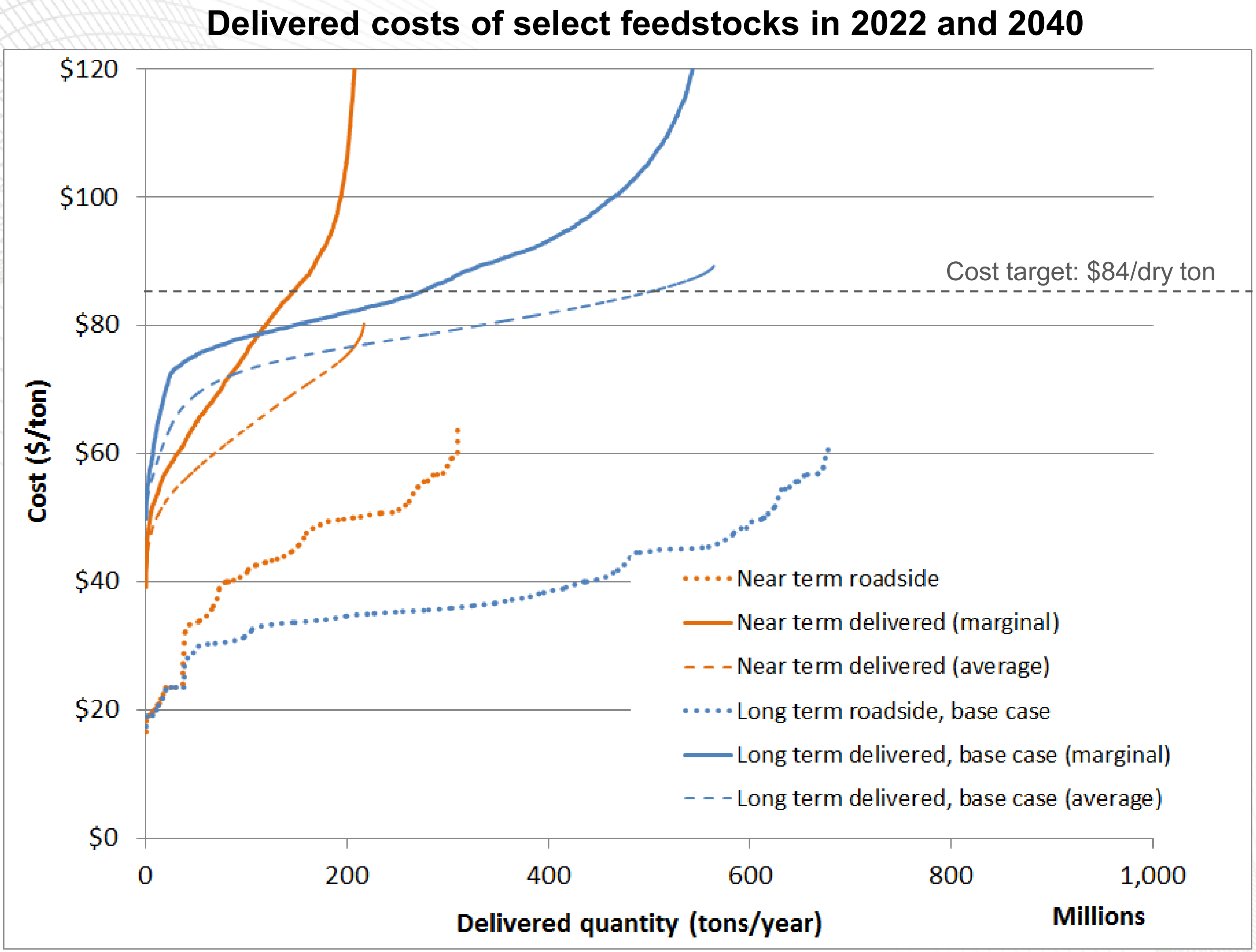

3 – Technical Accomplishments/ Progress/Results
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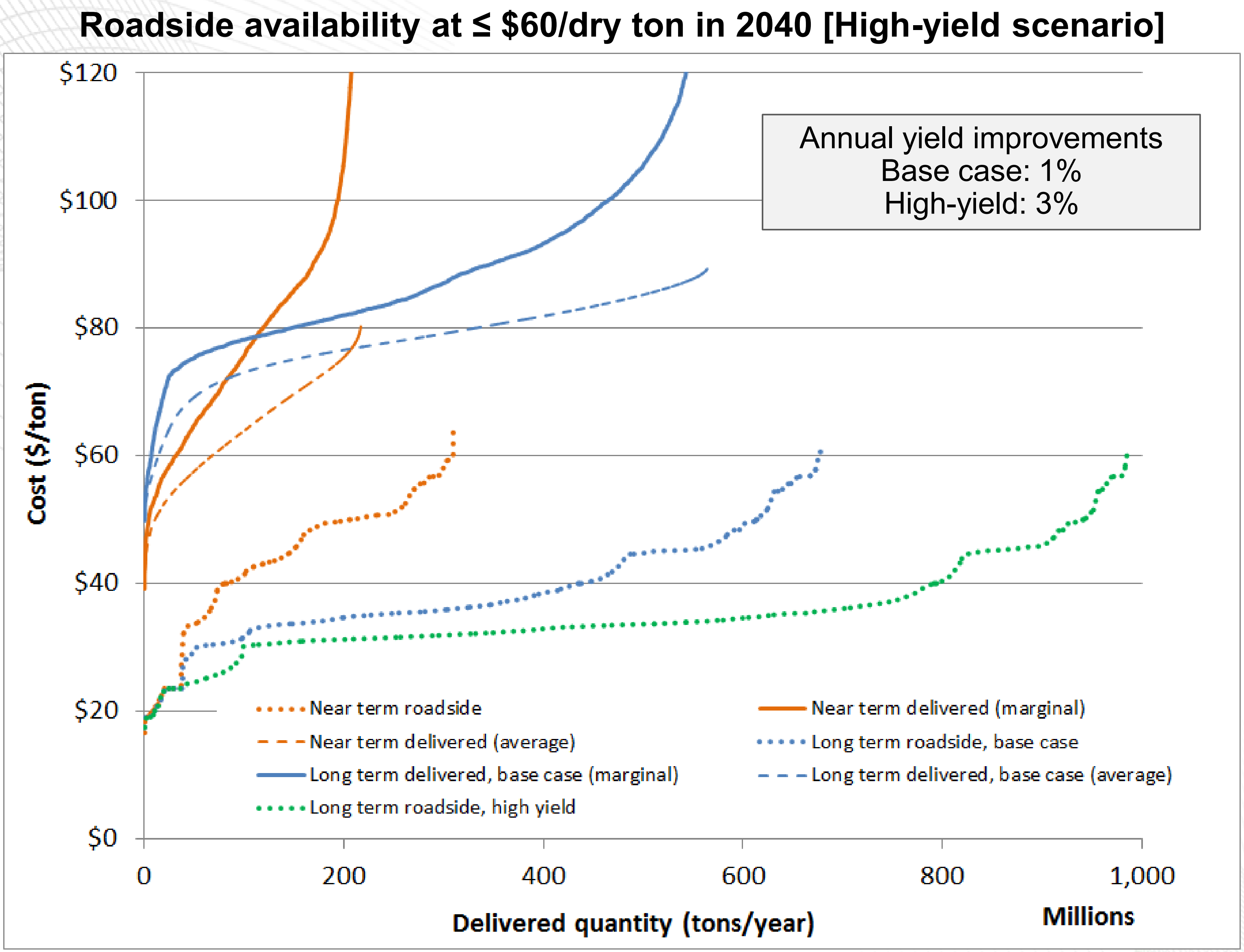

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3 – Technical Accomplishments/ Progress/Results

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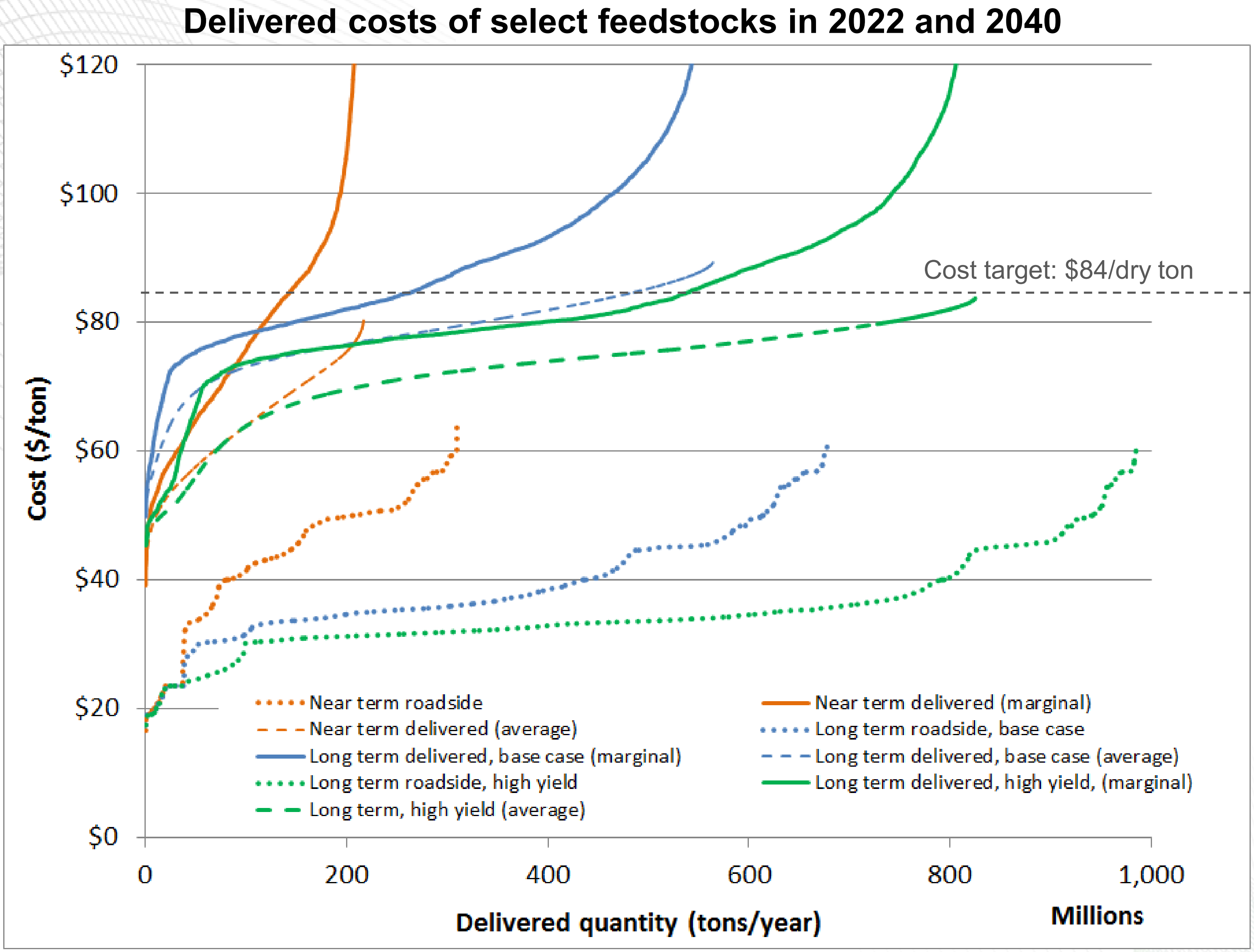

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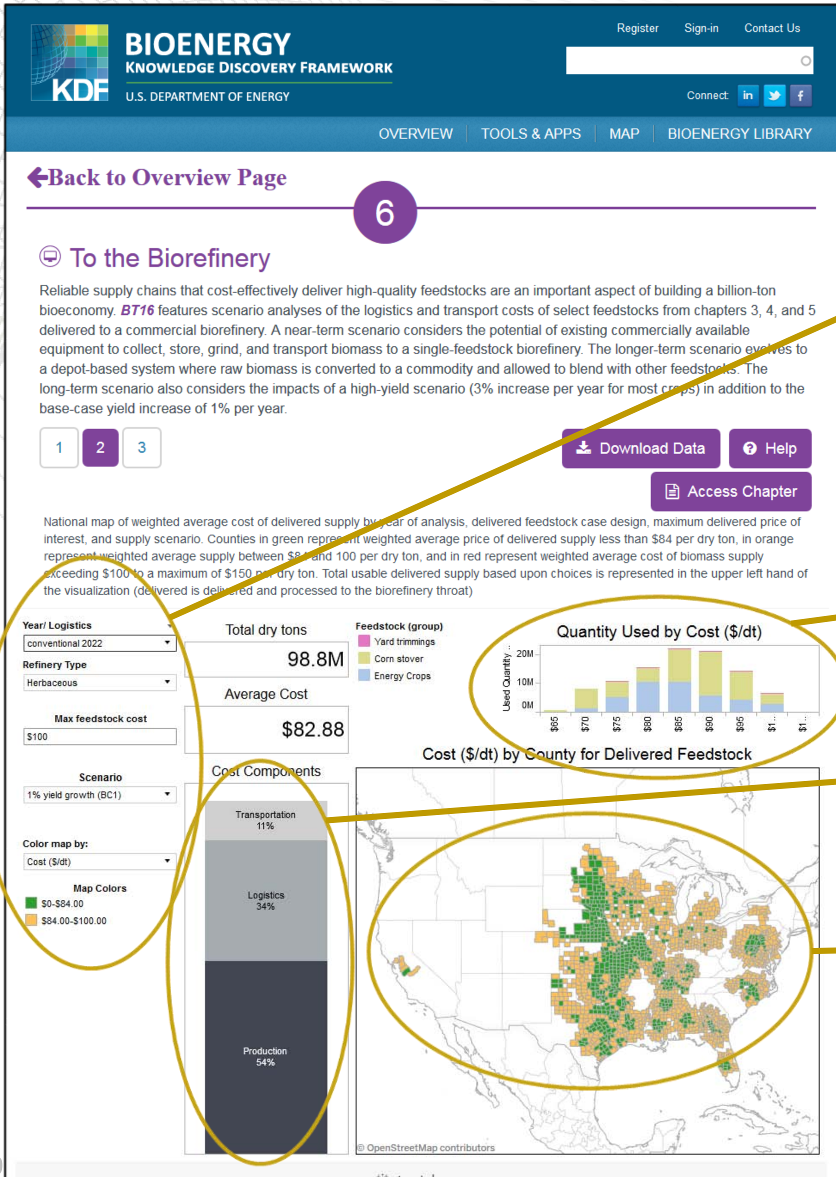
3 – Technical Accomplishments/ Progress/Results

BT16 Chapter 6: To the Biorefinery

Interactive version available at: https://bioenergykdf.net/billionton2016/6/2/tableau



Scenarios available:

- Herbaceous vs. Woody feedstocks
- Near-term (2022) vs Long-term (2040)
- Base case yield vs. High-yield

Quantity used by cost, by feedstock

Cost breakdown: transportation, logistics, and production

Quantity and average cost by county

3 – Technical Accomplishments/ Progress/Results

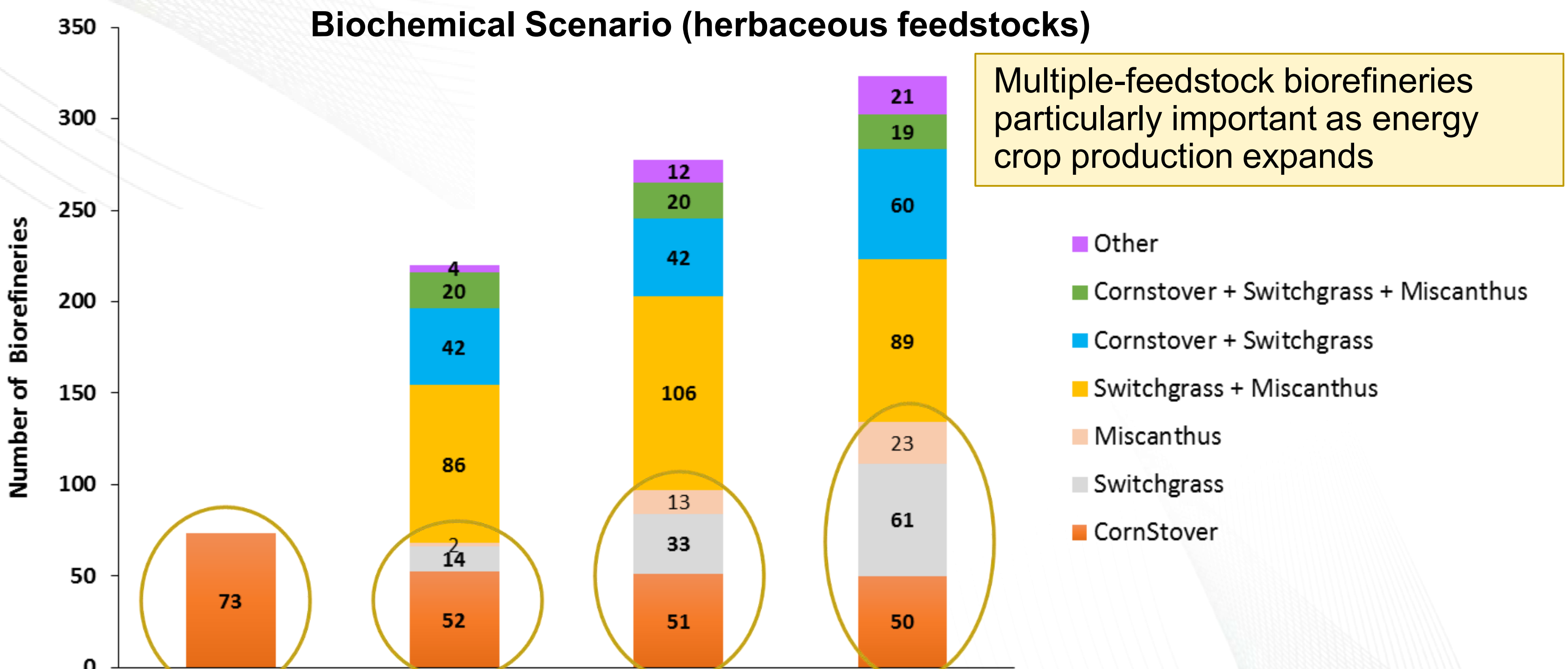
Assessing industrial relevance of feedstock combinations

Utilizing multiple feedstocks is important strategy for reducing costs and mitigating supply risk and variability

- What are most likely feedstock combinations?
- Where are multi-feedstock strategies most likely?

Assumptions

- Approach similar to BT16 using SCM model
- Conventional supply chain design
- Biorefinery can accept any feedstock combination

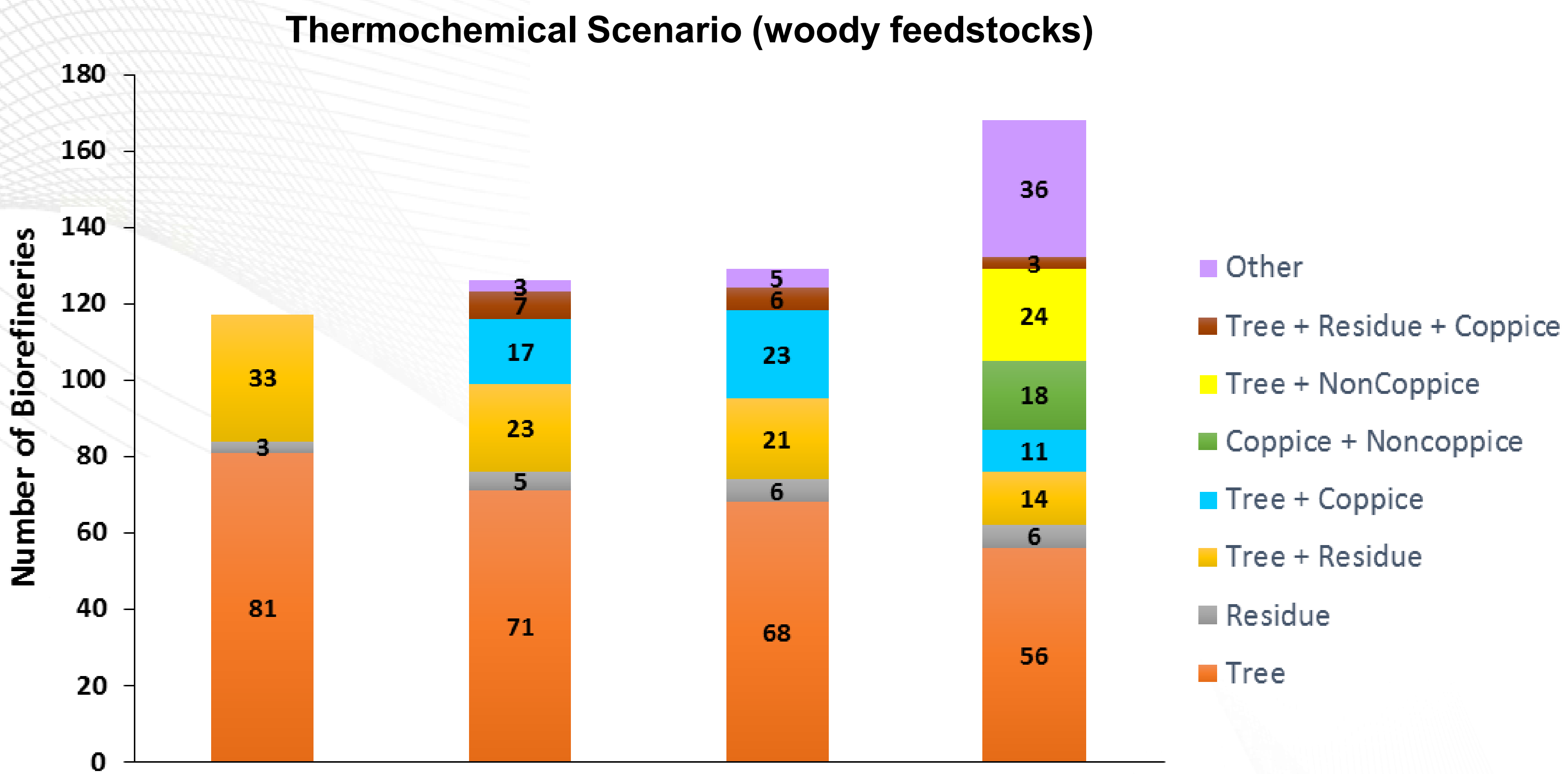


Year	2017	2022	2025	2030
Total Biorefineries	73	220	277	323
% Single feedstock	100	31	35	42
% Multiple feedstock	0	69	65	58

NOTE: Here multiple feedstocks could be blends, different receiving/processing lines, or seasonal use

3 – Technical Accomplishments/ Progress/Results

Assessing industrial relevance of feedstock combinations



Year	2017	2022	2025	2030
Total Biorefineries	117	126	129	168
% Single feedstock	72	61	60	42
% Multiple feedstock	28	39	40	58

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4 – Relevance

- **COST AND QUANTITY**
  - IBSAL Algae modeling analysis suggests that pelletizing algae has potential to reduce supply chain costs
  - Stover field drying analysis enables us to account for moisture-management in future resource assessment cost projections
  - New delivered cost analysis for BT16 makes it possible to move beyond case study cost analysis only and to evaluate BETO cost targets at a national scale
  - Spatial analysis of biomass supplies used to determine where using multiple feedstocks reduces biorefinery cost
- **QUALITY**
  - New stover field drying analysis improves accuracy of moisture tracking in IBSAL corn stover models
  - Spatial analysis of biomass supplies identifies promising candidate feedstock blends for experimental testing
- **INDUSTRY IMPACTS**
  - Corn stover bioeconomy has near-term potential to add $30 billion to ag harvest and transport equipment industries

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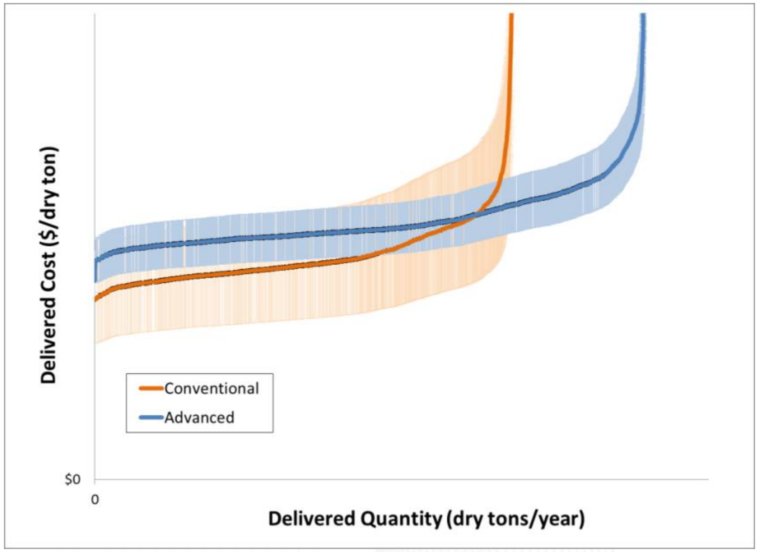
5 – Future Work

- Modeling biomass moisture management
  - Expand field drying analysis to other herbaceous feedstocks
  - Model stover ensilage supply chains (collaboration with INL)
  - Develop regional harvest costs for resource assessment modeling
- Equipment, infrastructure for bioeconomy
  - In FY17 this work moved to NEW project with Clean Energy Manufacturing Analysis Center (CEMAC) at NREL with INL
  - Evaluate new feedstocks, new supply systems
- Spatial analysis of biomass delivery
  - Expand and refine modeling to better represent biorefinery decisions
  - Explore feedback loop between industry expansion and biomass crop adoption
  - Add model constraints to achieve prescribed feedstock blends and test industrial relevance of promising blends

5 – Future Work

- Modeling operational disruptions
  - Build model to compare cost impacts of problematic bale-handling operations at a biorefinery vs. at an advanced preprocessing depot
  - Operational challenges to consider
    - Disruptions due to feedstock handling issues
    - Risk of fire in large biomass bale yards
- Modeling supply variability
  - Apply IBSAL and SCM to quantify benefits of commoditized feedstocks in reducing impacts of supply variability
    - Hypothesis: Biorefineries will be willing to pay higher average feedstock costs for a more reliable supply
    - Cost impacts (average and range) of converting raw biomass to pellets when facing variable year-to-year supplies



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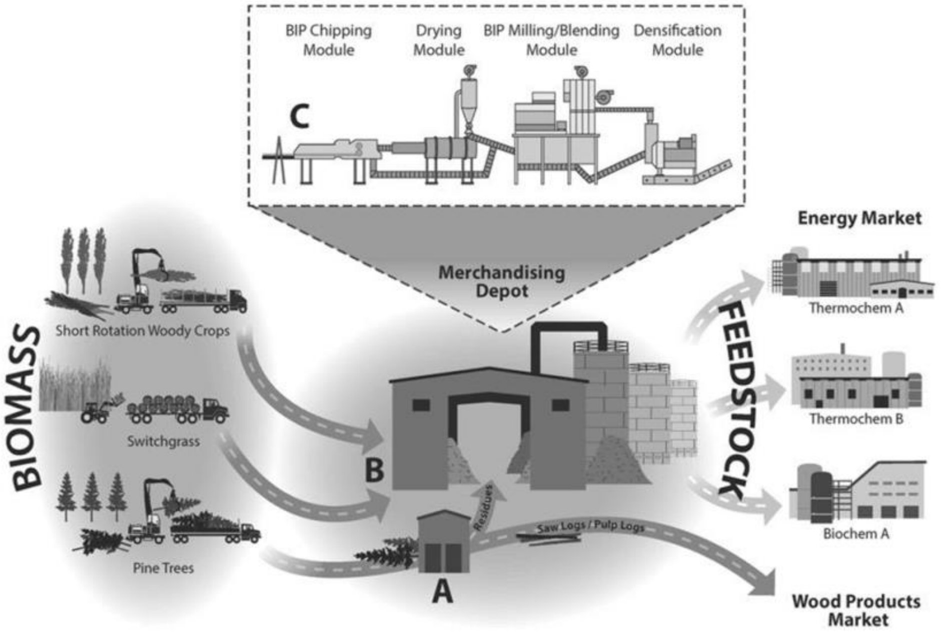
5 – Future Work

- Cost impacts of UT logistics demonstration project (LEAF)
  - Building on ORNL analysis of other logistics demonstration projects
  - Major goal will be to leverage field data from this project to inform INL and ORNL depot analysis
- Dynamics of multi-feedstock supply systems
  - Inventory management
  - Just-in-time delivery
  - Equipment utilization



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Summary

GOAL: Build and apply simulations of biomass supply chains to address questions on feedstock cost, quantity, and quality

APPROACH: Integrating biomass resource assessment, feedstock logistics models, transportation and siting model, and advanced visualization

IMPACTS: (a) Expanded Billion-Ton projections to reactor throat, (b) improved moisture modeling, (c) evaluate industrial relevance of feedstock blends

Additional Slides

Responses to Previous Reviewers' Comments

Overall Impressions

- Overall, the project is a useful integrating activity and should continue to focus on improving input data to represent realistic business scenarios.
- Overall, this is a good project. The team is responding to current needs and refining their analytical tools to reflect state-of-the-art.
- BETO has accomplished a lot with its modeling work and has led the way in many important aspects. This is a good time for BETO to commit itself to developing linked, verified, tested models that describe the economic and environmental performance of managed bioenergy systems all the way from the sub-field scale to the national scale. These models are needed also to bring along the rest of the society. We have to show how sustainably managed bioenergy systems can help achieve national economic and environmental goals.
- The structure and approach is quite solid, but this project is all about getting ground-truthed data. I see a major weakness around the data for the logistics portion that needs to be improved. As the presenter mentioned, models can be made around anything, but the relevance has everything to do with the data and assumptions informing the model.

PI Response to Reviewer Comments

- Thank you for the encouraging and constructive feedback from the reviewers. We appreciate that the reviewers recognized our efforts to construct high-quality, accurate simulation models for better understanding of the impact and challenges of biomass supply chains. We agree that a key factor to success of this project is to base analyses on commercial-scale data. To do this, we are continuing efforts to build and strengthen partnerships with feedstock suppliers and biorefineries for knowledge and data sharing.

Publications, Patents, Presentations, Awards, and Commercialization

Publications

1. U. S. Department of Energy. 2016. *2016 Billion-Ton Report Volume 1: Advancing Domestic Resources for a Thriving Bioeconomy*. {Lead author for Chapter 6 – To the Biorefinery: Delivered Forestland and Agricultural Resources}
2. Castillo-Villar, K. K, H. Minor-Popocatl, and E. Webb. 2016. Quantifying the Impact of Feedstock Quality on the Design of Bioenergy Supply Chain Networks. *Energies* 9(3):203.
3. Sokhansanj, S., E. G. Webb, and A. T. Turhollow. 2016. Evaluating industrial drying of cellulosic feedstock for bioenergy: a systems approach. *Biofuels, Bioproducts, and Biorefining* 10(1): 47-55.
4. *Oyedeji, O., S. Sokhansanj, and E. Webb. 2016. Spatial Analysis of Stover Moisture Content During Harvest Season in the United States. *Transactions of the ASABE* (in review).
5. Ebadian, M., S. Sokhansanj, and E. Webb. 2016. Estimating the required logistical resources to support the development of a sustainable corn stover bioeconomy in the USA. *Biofuels, Bioproducts, and Biorefining* 11:129-149
6. Wang, Y., M. Ebadian, E. Webb, and S. Sokhansanj. 2016. Impact of the biorefinery size on the logistics of corn stover supply - a scenario analysis. *Applied Energy* (in review)
7. Lautala, P. T., M. R. Hilliard, E. G. Webb, I. Busch, J. R. Hess, M. S. Roni, J. Hilbert, R. M. Handler, R. Bittencourt, A. Valente, and T. Laitinen. 2015. Opportunities and Challenges in the Design and Analysis of Biomass Supply Chains. *Environmental Management*.

Presentations

1. Fasina, O. and E. Webb. 2016. Answering Logistical Questions in the BT16 with data from the Supply Characterization Model. ASABE Annual Meeting, Orlando, FL, July 17-20, 2016.
2. Hilliard, M., E. Webb, C. Brandt, L. Eaton, G. Gresham, E. Searcy, and S. Sokhansanj. 2016. BT16: To the Biorefinery Estimating Delivered Costs. Bioenergy 2016, Washington, DC, July 12-13, 2016 (Invited).
3. McCullough-Amal, D., E. Webb, C. Brandt, T. Alland, L. Eaton. 2016. Modeling Bioenergy Industry Evolution. IBSS Annual Meeting, Oak Ridge, TN July 27-28, 2016.
4. Oyedeji, O., S. Sokhansanj, and E. Webb. 2016. Spatial Analysis of Stover Moisture Content During Harvest Season in the United States. ASABE Annual Meeting, Orlando, FL, July 17-20, 2016.
5. Ruggeri V., M. Hilliard, E. Webb. 2016. Illustrating Logistical Cost of BioEnergy Feedstocks using Tableau and the Supply Characterization Model. Modeling Bioenergy Industry Evolution. ASABE Annual Meeting, Orlando, FL, July 17-20, 2016.
6. Webb, E., M. Hilliard, C. Brandt, L. Eaton, G. Gresham, E. Searcy, and S. Sokhansanj. 2016. BT16: To the Biorefinery Delivered Cost Scenarios. ASABE Annual Meeting, Orlando, FL, July 17-20, 2016 (Invited).
7. Webb, E., M. Hilliard, A. Myers, L. Eaton, M. Langholtz. 2016. Interactive BT16 Bioenergy Knowledge Discovery Framework. ASABE Annual Meeting, Orlando, FL, July 17-20, 2016 (Invited).
8. Webb, E., M. Hilliard, C. Brandt, S. Sokhansanj, L. Eaton, and M. Martinez Gonzalez. 2015. American Society of Agricultural and Biological Engineers Annual International Meeting; July 2015, New Orleans, LA.
9. Webb, E., S. Sokhsansanj, K. Comer, and T. Clark. 2014. Simulation as a tool for evaluating bioenergy feedstock supply chains. Winter Simulation Conference; December 2014, Savannah, GA.