



Bioproducts Transition System Dynamics

March 7, 2017

Bioenergy Technology Office (BETO) Analysis
Platform Review

Emily Newes

National Renewable Energy Laboratory

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Goal Statement

Relevance: BETO has been developing a broad understanding of different conversion processes that produce bioproducts and the associated market attributes. However, there is not much understanding around **how investment decisions are made** and the possible successful scenarios for **advancing the bioproducts and biofuels industries**.

Goal: To develop an analysis capability to achieve deeper understanding of the **environment and drivers** that impact the growth of the bioproducts industry in order to support BETO bioenergy strategy development.

Outcomes:

- Transparent, accessible system dynamics model
- Method for exploring **early-market transition dynamics** as a function of investor decision-making, techno-economics, and market factors.

Quad Chart Overview

- **Timeline**

- Brief, exploratory project
- Started October 2016
- Complete September 2017
- Continuation subject to annual DOE approval

	Total Costs FY 12 –FY 14	FY 15 Costs	FY 16 Costs	Total Planned Funding (FY 17)
DOE Funded	0	0	0	\$200k
Project Cost Share (Comp.)	0	0	0	0

- **Barriers**

- Comparable, Transparent, and Reproducible Analysis [MYPP At-A]
- Analytical Tools and Capabilities for System-Level Analysis [MYPP At-B]
- Data Availability [MYPP At-C]

- **Partners**

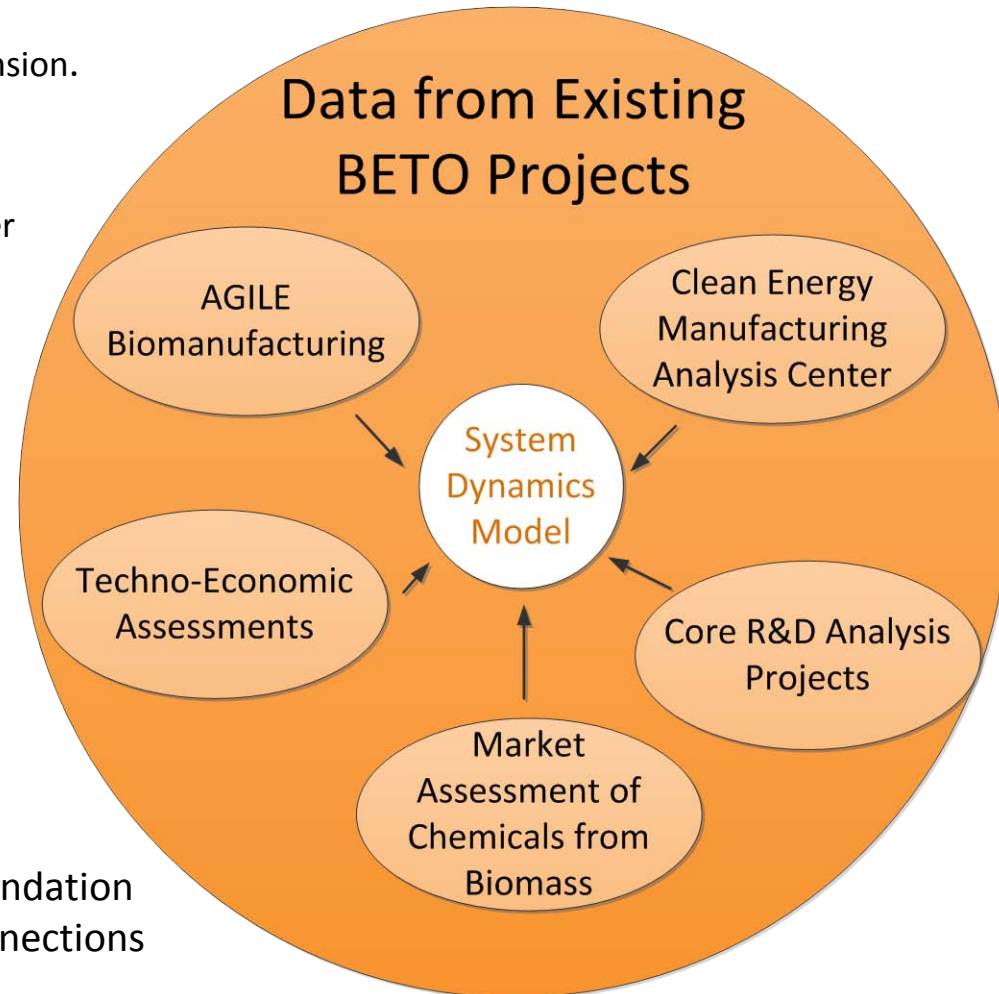
- Project Lead: Strategic Platform, National Bioenergy Center
- Subject-Matter Expertise:
 - National Bioenergy Center
 - Stakeholder engagement

1 – Project Overview - Background

This project builds upon existing work that has been funded by BETO:

- Market assessment of chemicals from biomass
 - laid out the existing market for chemicals from biomass and potential for expansion.
- Techno-economic assessment
 - The Clean Energy Manufacturing Analysis Center (CEMAC) bioproducts task
 - Current BETO-funded work considers coproduction of biofuels and chemicals from biomass.
- Research & Development (R&D) projects
 - Current BETO-funded analysis work considers coproduction of biofuels and chemicals from biomass.
 - On-going efforts in the AGILE biomanufacturing project

These projects are information-rich and lay the foundation for exploring possible future scenarios and the connections between bioproducts and biofuels.



Explore Bioproducts' Market Structures and Decision-Making Processes

Project Objectives

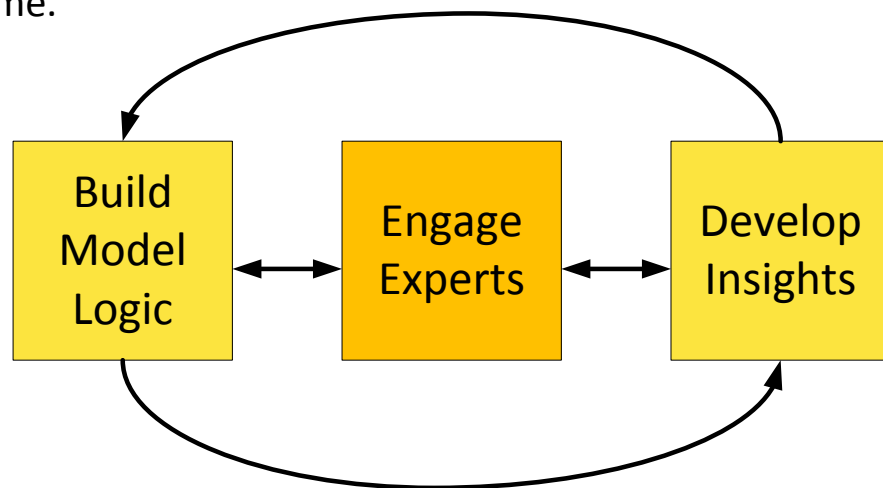
- **Support BETO** and the bioenergy community
- Achieve deeper understanding of the environment and drivers that impact the growth of the bioproducts industry
- Understand **early-market transition** dynamics as a function of investor decision-making, techno-economics, and market factors
- Explore **synergies between bioproducts and biofuels**

Benefits

- Provides critical insights and deep **understanding of the myriad factors** (e.g., techno-economics, shared learning, and demand-pull factors)
- Informs **targeted strategies and policies**
- Enables **crosscutting analysis** and to identify improvements in program plans.

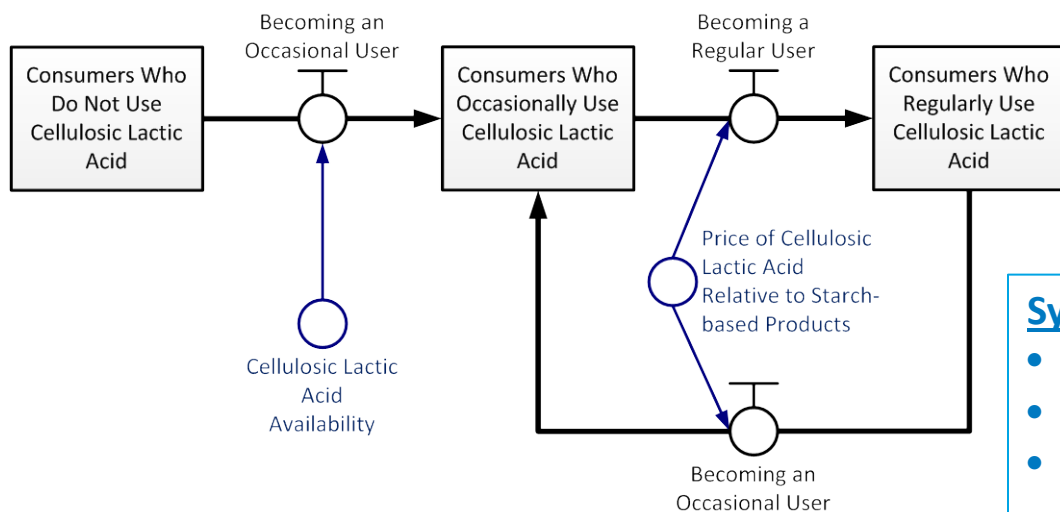
Engage Experts to Inform Project Content and Direction

- Frequent communication and reporting to BETO
 - Collaboration on scoping, designing choice of bioproducts, and focus of analyses
 - Quarterly briefings
- Emphasis on a flexible development process
 - Involvement of team members with specialized areas of expertise
 - Collaboration with subject matter experts at BETO, national labs, and industry
 - Integration of data from ongoing projects
- Reliance on appropriate and well established modeling techniques
 - The system-dynamics modeling framework is a robust methodology for analyzing the behavior of complex real-world feedback systems over time.
- Careful consideration of level of detail
 - Broad, high level approach that captures key elements of bioproducts' early market transitions
- Completion of milestones.



Use System Dynamics to Explore Short-Term Transitions

We are developing a transparent, analytic system dynamics (SD) model that tracks the dynamics of production capacity addition, the influences of the various disruption types, the shifts in techno-economics, and the viability of the domestic and overseas industries, and other major metrics of interest to stakeholders.



System Dynamics

- Long-established methodology
- Powerful tool for scenario casting
- Key features of the technique
 - Behavioral focus
 - Endogenous viewpoint
 - Visual language for representing accumulation, flow, feedback, nonlinearities, scenario inputs
 - Simulation capabilities.

Potential Hypotheses to Test in SD Model

Model formulation and supporting research will focus on developing the capability for testing hypotheses:

- **Bioproduct Resilience**: The cellulosic bioproduct would be robust to competitive responses to its market entry.
- **First-mover advantage**: The first bioproduct for a particular function will lock out competing bioproducts, even if those have better long-term techno-economic potential.
- **Improved feedstock handling**: The development of the bioproduct will further industrial learning for biofuel-related feedstock supply, logistics, and/or handling significantly beyond the velocity of such learning without the bioproduct.
- **Improved biochemical processing**: The development of the bioproduct will further industrial learning for biofuel-related biochemical processes significantly beyond the velocity of such learning without the bioproduct.
- **Hedged intermediates**: Bioproduct processes that produce an intermediate for multiple potential products show greater market viability and are more robust with respect to market shocks.
- **Stable domestic market**: Bioproducts initially developed and proven in the domestic market will remain domestically produced in the longer term and insulated from foreign competition due to a domestic first-mover advantage.

Potential Hypotheses to Test in SD Model

Model formulation and supporting research will focus on developing the capability for testing hypotheses:

- **Resilience to operating costs**: Bioproduct processes with lower operating-to-capital cost ratios—including when this is due to lower feedstock costs—can weather market shocks better than ones with higher such ratios.
- **Prima-facie viability**: Bioproduct processes that appear at first sight to be viable in the marketplace are indeed viable when transitional and dynamic factors are also analyzed.
- **Parity with fossil**: Some bioproducts will have robust enough techno-economic and logistical attributes to effectively compete against their fossil-, sugar- or corn-derived counterparts under the full range of market conditions.
- **Drop-in vs functional**: Functional replacements generally are as viable as drop-in replacements.
- **Brief policy support**: Some bioproducts only require brief (R&D) policy, grant, or incentive support in order to soon play on an even field with the incumbent products.
- **Green premium**: Some bioproducts will only attain market viability when end users value them including a “green premium”.

Down-select of Chemicals from Biomass to Explore in Model

Chemical Name	Com-mercial Scale?	Market Size		Value Proposition	Feedstock
		United States	Global		
1,4-butanediol	Yes	301	1,868	Better economics and greater sustainability than butanediol made from conventional feedstocks and processes	Commodity sugars (lignocellulosic is under development)
1,3-butadiene	Yes	1,692	10,775	Fossil-based production decreased with ethylene production shifting to shale gas, creating price increase	Sugars, starch or lignocellulosic biomass
succinic acid	Yes	1	40	Potential market as a precursor is very large; Costs and profit potential are similar to fossil succinic acid	Glucose (currently from corn, lignocellulosic is under development) Glycerin (biodiesel)
lactic acid	Yes	215	477	Large growth potential due to increased polylactic acid demand	Carbohydrates from starch (lignocellulosic is under development)
para-xylene	No	3,426	33,372	Instability in prices for purified terephthalic acid (PTA) and para-xylene drive interest by downstream consumers to find alternative sources for PTA	Various - biological and thermochemical routes both possible
isoprene	No	175	870	Fossil-based production decreased with ethylene production shifting to shale gas, creating price increase	Sugars from starch or lignocellulosic biomass

- Approximately two dozen bioproducts were considered initially, relying on published reports.
- We chose six biomass-based chemicals that could be explored based on their diversity of market characteristics.
- A final selection is made in consultation with BETO.



Critical Success Factors

1. Building a dynamic model that advances stakeholder's thinking, hypotheses, and conjectures in the bioproducts sphere
2. Pinpointing key leverage points, market structure, and investment decision-making that would emphasize synergies between bioproducts and biofuels
3. Releasing an easy-to-use and transparent model to the analysis community.

Potential Challenges

1. Lack of available data, especially investor decision-making and market data
 - *Data availability partially dictates choice of bioproduct pathways for analysis.*

2. Avoiding “scope creep”
 - *Focus on a few core issues relevant to the transition to bioproducts.*

3. Difficulty in modeling investor and market behavior
 - *Tailor the modeling and analysis approach to be as robust as possible with respect to assumptions regarding investor and market behavior, also using sensitivity analyses of such assumptions.*

3 – Summary of Accomplishments (October 2016-February 2017)

- Down-select of chemicals from biomass
 - Focus on diversity of market factors and data availability
- Focus on possible hypotheses to test using the model
 - Documents issues of key importance to BETO and other stakeholders
- Exploration of potential model logic to test hypotheses
 - Reviewed modeling literature and key aspects of other models such as the Biomass Scenario Model.

System Dynamics Model Will Support Strategic Plan

“Technological developments in **renewable chemicals** can accelerate the commercial development of advanced biofuels by improving economics and diversifying market risks.” (BETO MYPP, pg 2-141, March 2016)

BETO’s Strategic Plan

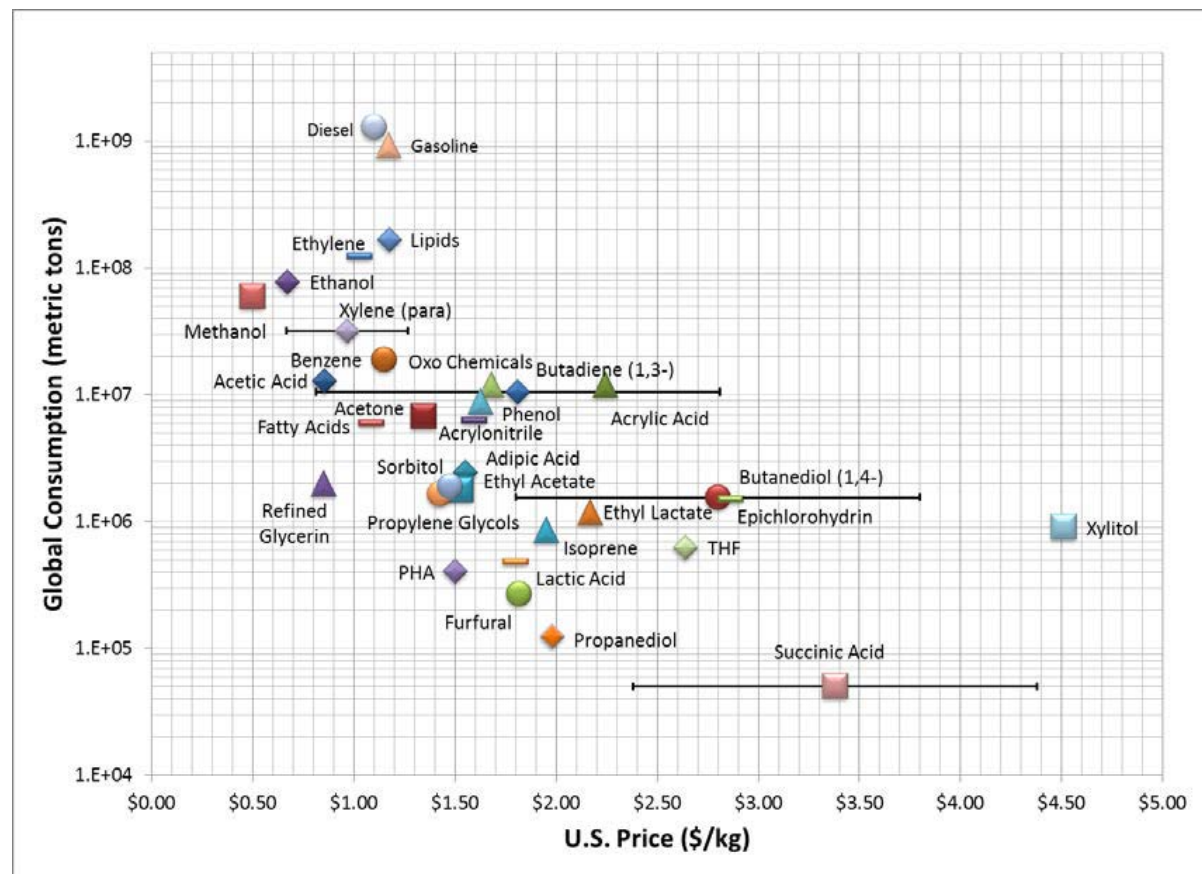
- The 2016 Strategic Plan expands BETO’s mission beyond the cellulosic ethanol market for renewable drop-in fuels (including diesel and jet fuels), **biobased chemicals**, and **bioproducts**.
- *Enhancing Bioenergy Value Proposition*
 - Develop and demonstrate innovative and integrated value chains for biofuels, **bioproducts**, and biopower that can respond with agility to market factors
- *Cultivating End Use Markets and Customers*
 - Conduct detailed market analysis for biofuels and **bioproducts**
 - Inform supportive policies for biofuels and **bioproducts**
- *Success Indicators / Milestones*
 - By 2020, provide an analytical framework for **bioproducts** research.

System Dynamics Model will Help BETO Attain Goals and Objectives

Element	MYPP Goal	Model Contribution
Strategic Analysis	provide context and justification for decisions at all levels [p. 2-130]	<ul style="list-style-type: none"> • Improve understanding of prospects for bioproducts and their synergies with biofuels. • Test hypotheses related to early market transition for bioproducts.
Feedstock Supply	develop technologies to enable the sustainable, secure, reliable, affordable supply of acceptable-quality terrestrial feedstock for the U.S. bioenergy industry [p. 2-17]	<ul style="list-style-type: none"> • Analyze how bioproduct market development could impact feedstock supply chain development and maturity.
Conversion R&D	develop commercially viable technologies for converting biomass feedstocks...into...liquid transportation fuels..., as well as bioproducts or chemical intermediates and biopower. [p. 2-65]	<ul style="list-style-type: none"> • Map how learning-by-doing for bioproduct pathways interacts among the bioproduct pathways and between bioproduct pathways and biofuel pathways. • Estimate role of intermediates in the viability of pathways.
Deployment and Market Transformation	develop commercially viable biomass utilization technologies through public-private partnerships that build and validate...integrated biorefineries; and develop supporting infrastructure [p. 2-99]	<ul style="list-style-type: none"> • Understand how market forces and external conditions affect the viability and robustness of the early market transition to bioproducts.

System Dynamics Model Will Educate on Bioproducts Market Dynamics

- Many bioproducts already exist, but are largely produced using conventional fossil and/or corn-, sugar-based feedstocks.
- Coproducts are needed to enable biofuels; this model helps to identify market drivers to scale-up and help to support products that have lower market risk.
- Market demand and price vary greatly for existing markets; bioproducts can have different factors driving their demand pull.



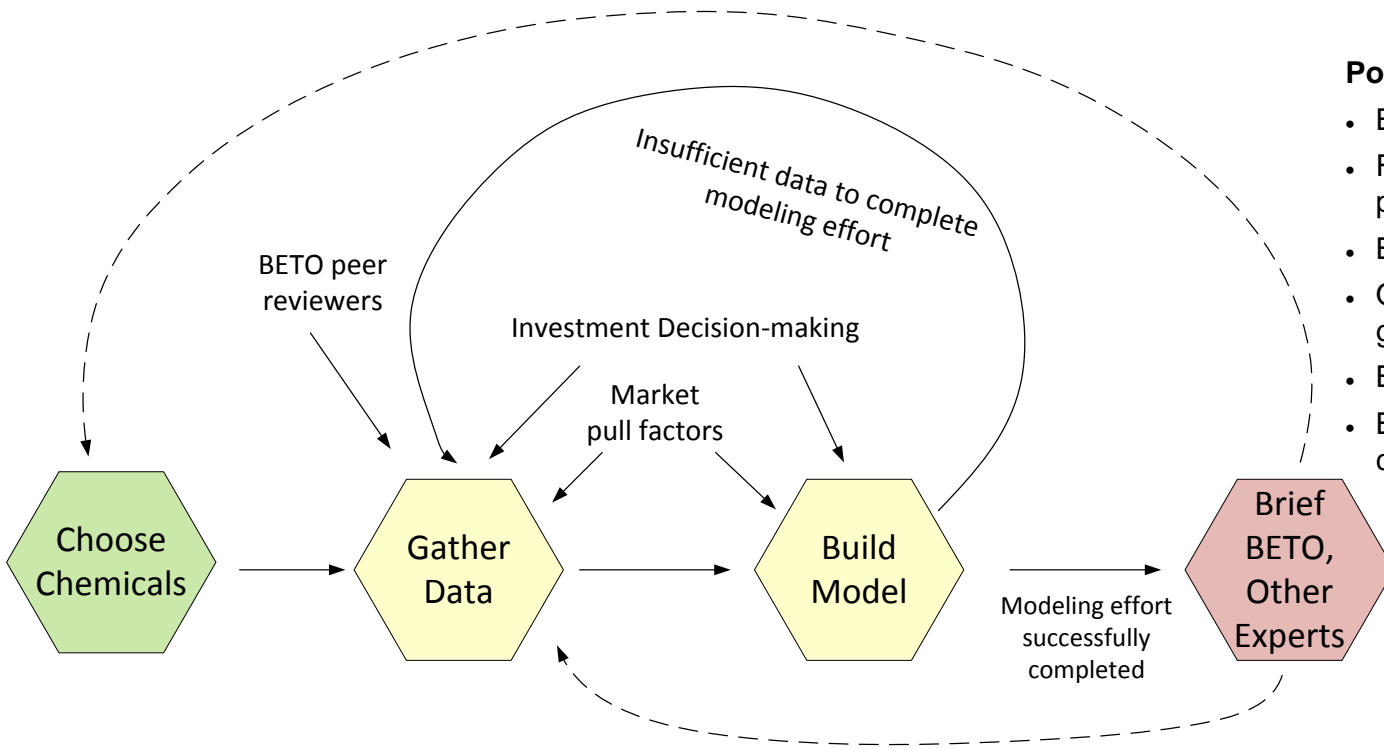
Source: Bidy et al. (2016)

5 – Future Work: Milestone/Deliverable Status

- **Q1 QPM:** Provide memorandum or briefing that outlines the two to four bioproducts the model will incorporate and rationale behind the choices. • Completed
- **Q2 QPM:** Present status report (memorandum or briefing) on model design and development. Outline any data gaps/uncertainties and discuss plans to overcome these barriers. • On Target
- **Q3 QPM:** Complete SD model with basic industry structure for two to four chemicals from biomass. Brief BETO in quarterly check-in on project status. • On Target
- **Q4 Milestone:** Deliver briefing to BETO on utilization of the developed SD model to evaluate at least two chemicals from biomass. This effort will focus on addressing key questions on early transitions in the bioproducts industry including
 - how investor decision-making interacts with techno-economic and market factors to impact the development of the bioproducts industry,
 - the extent to which such factors and development are predictable, and
 - how data gaps in techno-economics, markets, and investor decisions impact the results.• On Target

Our goal is to demonstrate the analysis approach, provide insight into the bioproducts industry, and identify gaps in understanding.

Develop System Dynamics Model in Close Collaboration with Experts



Possible Stakeholders in the System:

- Bioproduct manufacturers
- Fossil/lignocellulosic/starch-based product manufacturers
- Biofuel manufacturers
- Other bioproduct investors, including government agencies
- Bioproduct purchasers
- Biomass-derived end product consumers

Remaining Tasks for FY2017:

Q2	Status report (memorandum or briefing) on model design and development.
Q3	Complete SD model with basic industry structure for two to four chemicals from biomass.
Q4	Briefing to BETO on utilization of the developed SD model to evaluate at least two chemicals from biomass.

Explore Pressing Questions to Arrive at System Insights

Assuming this modeling effort is successful (implicit Go/No Go)

Provide analysis using the model, highlighting key questions:

- Under what circumstances will the bioproducts industry (including non-food feedstocks) develop? How will it compete with fossil- and starch-based products?
- What impact on the bioeconomy do drop-in direct replacements have compared to functional replacements?
- What would be necessary to encourage the development of biofuels and bioproducts in tandem?
- What delays and/or areas for intervention are inherent in the system?

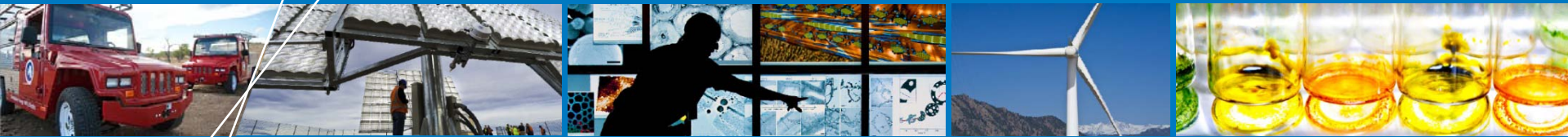
Refine Model, Sharpen Insights, Increase Accessibility

- **Model development**
 - Vet
 - Broaden slate of chemicals
 - Genericize pathways to increase utility to industry
- **Analysis**
 - Perform large-scale sensitivity analysis of model parameters
 - Inform R&D decisions from market perspective
- **Collaboration**
 - Engage with key stakeholders to define follow-on analysis
 - Connect with established models for sustainability considerations (e.g., GREET, JEDI) and use logic to inform other models (e.g., BSM)
- **Publicly release the model.**

Summary

The new system dynamics model will provide key insights into bioproduct transitions.

- Challenge/Objective
 - To develop an analytic platform to explore and understand short-term investment decision-making in the bioproducts industry.
- Relevance
 - Better understand bioproducts' market structures and decision making processes
 - Explore technical and market synergies with biofuels
- Future Work
 - Model vetting
 - Genericized model
 - Integration with other tools
 - Public release



Additional Slides

References

- Biddy, Mary, Christopher Scarlata, and Christopher Kinchin. "Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential." Golden, CO: National Renewable Energy Laboratory, 2016. <http://www.nrel.gov/docs/fy16osti/65509.pdf>.
- de Jong, Ed, Adrian Higson, Patrick Walsh, and Maria Wellisch. "Biobased Chemicals Report LR." The Netherlands: International Energy Agency, February 2012. http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/4/2/4/f579df5e-95fe-4bdb-8895-84b1297906a4_Biobased%20Chemicals%20Report%20LR%20February%202012.pdf.
- E4tech (UK) Ltd, Consorzio per la Ricerca e la Dimostrazione sulle Energie Rinnovabili, and Wageningen University and Research Centre. "From the Sugar Platform to Biofuels and Biochemicals." Brussels, Belgium: European Commission Directorate, April 2015. <http://www.e4tech.com/reports/from-the-sugar-platform-to-biofuels-and-biochemicals/>.
- Marifaith Hackett, Xiaomeng Ma, Kristin Squires, Squires and Kisondra, and Kisondra Waters. "Chemical Building Blocks from Renewables." London, United Kingdom: IHS Chemical, April 2014.
- Nexant Inc. "Renewable Chemicals & Materials Opportunity Assessment." Washington, DC: U.S. Department of Agriculture, January 2014. https://www.usda.gov/oce/reports/energy/USDA_RenewChems_Jan2014.pdf.
- Weastra, s.r.o. "WP 8.1. Determination of Market Potential for Selected Platform Chemicals." The Netherlands: 7th Framework Programme of the European Union, 2012. http://www.bioconcept.eu/wp-content/uploads/BioConSepT_Market-potential-for-selected-platform-chemicals_report1.pdf.