# WBS 4.1.2.31 Bioproduct Transition System Dynamics

## DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Analysis and Sustainability

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# Goal Statement

**Relevance**: Growing the bioproducts (chemicals from biomass) industry could support the biofuels industry, reduce carbon and other emissions associated with the U.S. chemical sector, and increase price stability in the chemical market.

- Bioproducts have historically been difficult to bring to market
- Currently there is a lack of knowledge around the factors that prevent or enable bioproducts to reach the commercial market

**Goal:** To develop a model of **early bioproduct technology development and market growth** that will be used by investors, technology developers, and government agencies to **accelerate market penetration** of bioproducts

**Outcomes**

- Publicly released, open-source decision support tool that will inform decisions around bioproduct development and investments
- Published and reproducible analyses around early-market growth dynamics that identify factors critical to bioproducts reaching the market

# Quad Chart Overview

## Timeline

- Start: October 2016 (seed project)
- Merit review cycle: FY2017-2019
- 75% complete of review cycle

| | Total Costs Pre FY17** | FY 17 Costs | FY 18 Costs | Total Planned Funding (FY 19-Project End Date) |
|---|---|---|---|---|
| **DOE Funded** | 0 | $200K | $146K | $400K |

## Barriers Addressed

- Analysis to Inform Strategic Direction [MYP At-A]
- Analytical Tools and Capabilities for System-Level Analysis [MYP At-B]

## Objective

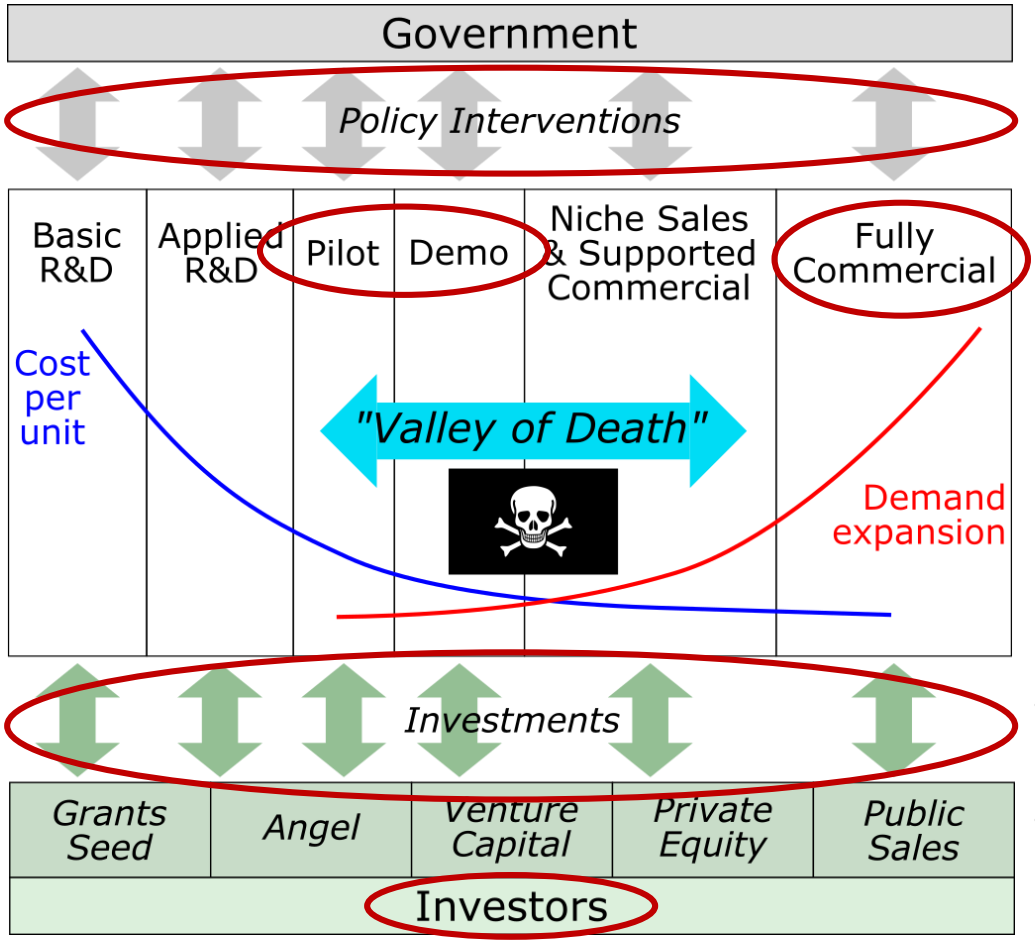
Develop a model of early bioproduct technology development and market growth that will be used by investors, technology developers, and government agencies to accelerate market penetration of bioproducts

## End of Project Goal

Publicly release the Bioproduct Transition Dynamics model as a decision support tool that will promote the growth of the bioproducts and biofuels industries

# Project Overview

Why do so many bioproducts fail around the pilot and demo stages?




Adapted from Bürer and Wüstenhagen, *Energy Policy*, 37 (2009)

What criteria do different types of investors use in their decisions?

How important is the role of policy support and government cost-sharing?

What do successful bioproducts have in common, and how do we use this knowledge to bring more bioproducts to market?

How important is the role of private investors relative to government support?

**To what extent are the answers to these questions dependent on the type of bioproduct and market?**

# Project Overview

## Project Objectives

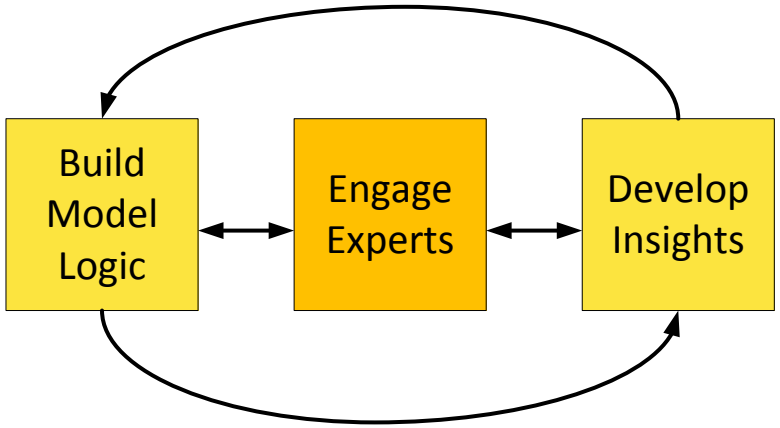
- Identify and understand factors that contribute to commercial success or failure for bioproducts and conversion processes
- Develop a decision support tool that can be used to lower the failure rate of bioproduct development projects and start-up firms, resulting in more bioproducts reaching commercial scale and capturing market share

## Key Project Takeaways

- Provides stakeholders with insight into how their decisions impact the nascent bioproducts industry:
  - Venture capitalists, interested firms, other investors
  - Technology developers
  - BETO, other government agencies
- Supports development of targeted, impactful strategies and policies that can promote the bioproducts industry

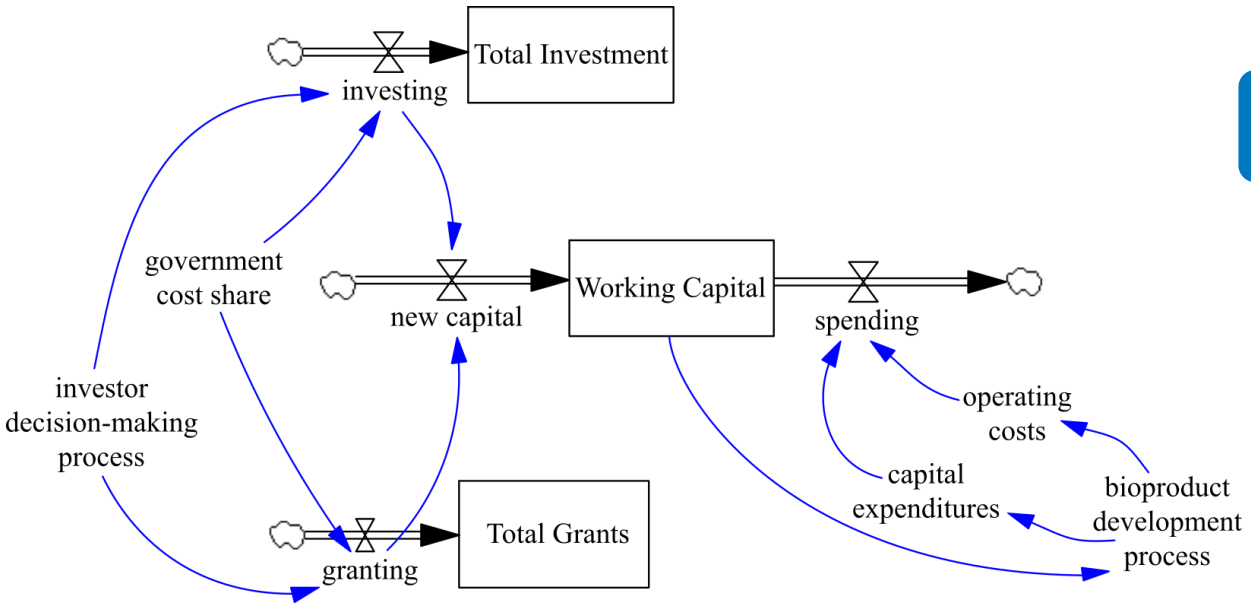
# Management Approach

- Multi-disciplinary project team
  - Rebecca Hanes *(PI, modeler, analyst)*, Brian Bush *(Modeler, analyst)*, Emily Newes *(Management support)*
  - Collective expertise in system dynamics modeling, biofuels and bioproducts, and energy and life cycle analysis
- Emphasis on collaboration and relationship-building with subject-matter experts in the bioproducts industry, in investment firms, at national labs and at BETO
  - Continued engagement during model development and preliminary analysis tasks




- Frequent reporting to and collaboration with BETO

# Technical Approach: System Dynamics 101




## System Dynamics Model

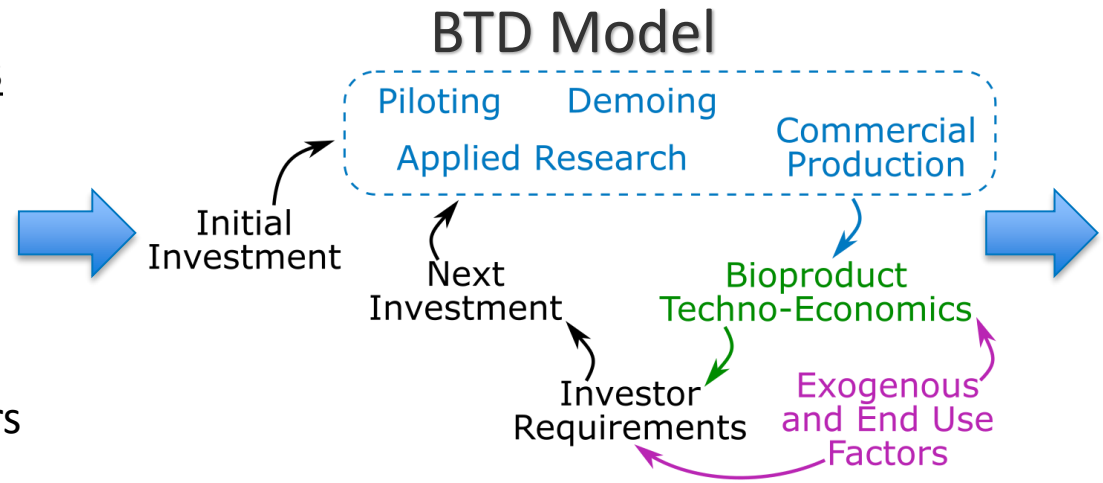
- A system of coupled, nonlinear, first-order differential or integral equations

| | |
|---|---|
| **Key Features of System Dynamics Modeling** | Visual language can aid communication |
| | Represents physical and non-physical flows, endogenous feedbacks, non-linearities |
| | Emphasis on scenario analysis and simulation |

# Technical Approach: Model Development

**Model Inputs**

- Techno-economic estimates
- Behavioral parameters
- Market factors




**Model Outputs**

- Cost and income projections
- Technology development trajectory
- Other parameter trajectories

Model structure was derived from…

- Interviews with bioproduct industry experts
- Research on investor decision-making and innovation processes in bioproduct and analogous industries including biofuels and pharmaceuticals
- Data and information generated during previous BETO-funded projects
- Shared learning models developed within BETO

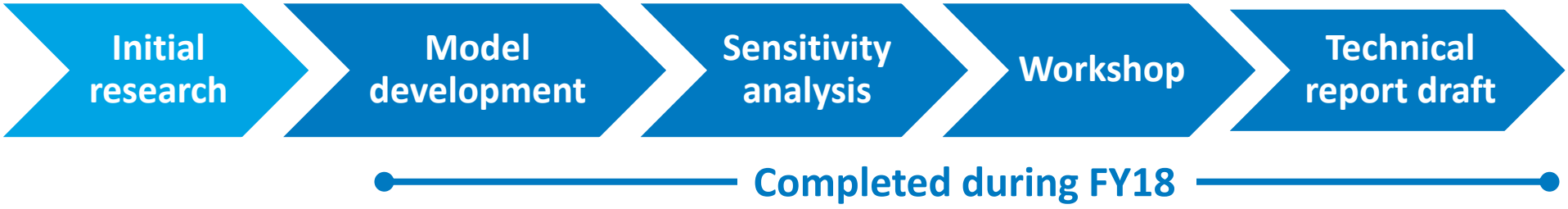
Unique aspects of the approach…

- Capturing technical development (quantitative) and the related decision-making processes (semi-quantitative, qualitative) in a **single model**
- Use of **technology readiness level** to track technical progress

# Technical Approach

| Challenges | Approach to Overcoming | Success Factors |
|---|---|---|
| General lack of quantitative and qualitative information | Use system dynamics modeling to allow for wide-ranging scenario and sensitivity analyses | Accurately and flexibly representing a wide range of decision-making processes |
| Model validation and verification | Engage prospective BTD users early and often; repeatedly solicit and incorporate feedback | Getting buy-in from prospective users and bioproducts industry stakeholders |
| Ensuring model users can extract actionable knowledge from the BTD model | Balance model utility with usability by focusing on processes most of interest to prospective users | Creating a model that represents the real world but is not so complex as to deter use |

# Accomplishments




## Completed initial model development by capturing…

- Investor decision-making processes
- **Technological development** as a result of **successes and failures** during applied research, piloting and demoing
- Bioproduct **techno-economics** as a function of technological development
- Bioproduct developer cash flow models
- Stochastic models for **feedstock prices**

**Outcome**: We were able to explore analysis questions answerable with the BTD via a **sensitivity analysis** and review model logic with subject-matter experts during the **BTD workshop**.

# Accomplishments: Sensitivity Analysis

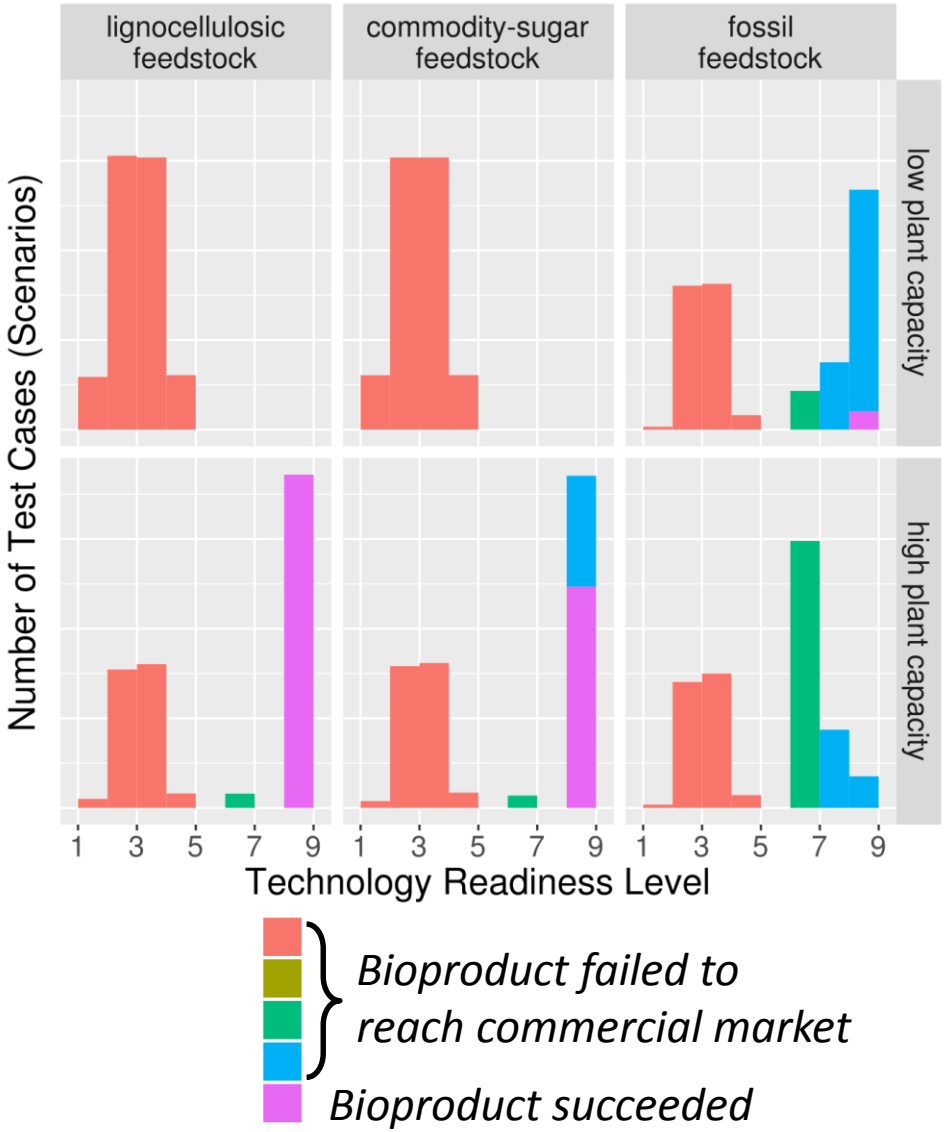
**Objective**: Explore analysis questions that could be answered with the BTD and assess model outcomes

**Question**

How does plant scale and feedstock influence bioproduct development?

**Insights** *(for succinic acid)*:

- Larger plants are necessary for lignocellulosic and commodity sugar processes to compete with fossil process
  - ➢ Economies of scale
- At a large scale, lignocellulosic process is marginally more competitive than commodity sugar process
  - ➢ Feedstock cost trends over time

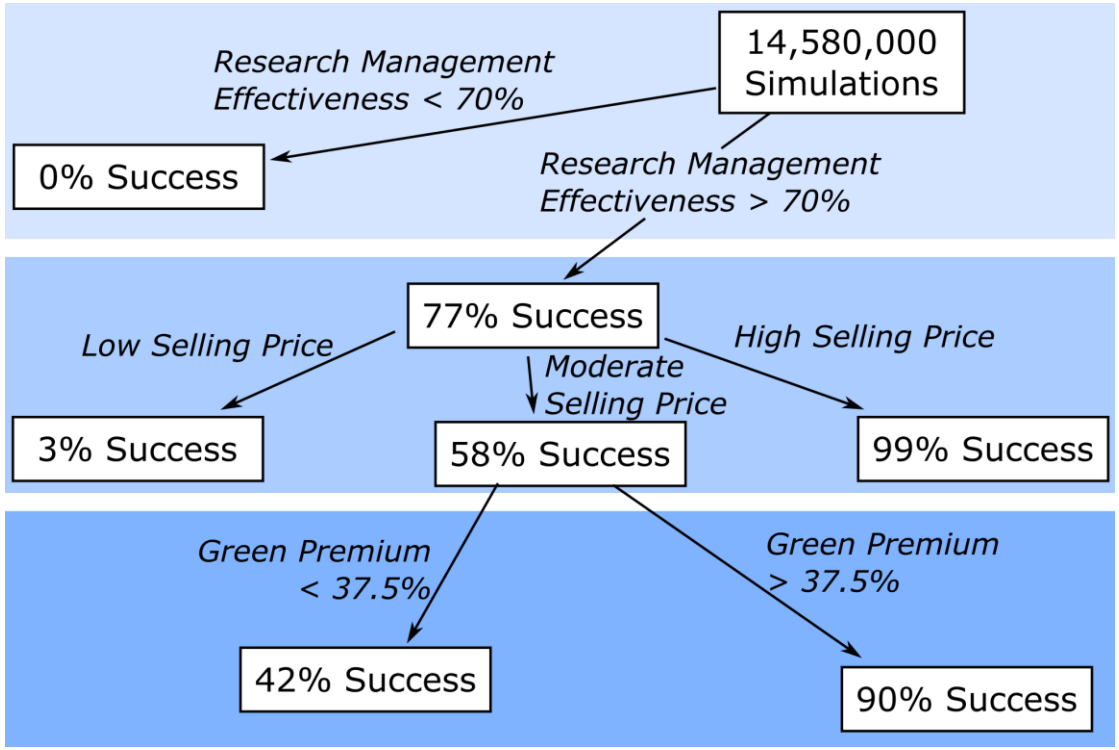


# Accomplishments: Sensitivity Analysis

**Objective**: Explore analysis questions that could be answered with the BTD and assess model outcomes

## Question

Which factors of those studied have the greatest influence on bioproduct success?




## Insights *(for succinic acid)*:

1. Research management effectiveness
   - Money must be spent efficiently from the start for a bioproduct to reach the market
2. Bioproduct selling price
   - Determines potential revenue and profitability
3. Size of green premium
   - Increases selling price

# Accomplishments: BTD Workshop

| Attendees |
| --- |
| 3 industry representatives |
| 5 investors or venture capitalists |
| 3 DOE representatives |
| 1 national laboratory representative |

**Objective**: Review BTD model development and prospective analyses with stakeholders and subject matter experts

- Attendees included representatives from all bioproduct industry-related areas covered by the BTD model
- Workshop discussions covered BTD model logic, assumptions and simplifications, model inputs, and sensitivity analysis results

**Outcome:** We compiled and prioritized a list of recommended model development tasks including…

- Focus the model scope on piloting and demoing
- Perform additional sensitivity analyses and stochastic analyses
- Rewrite some of the model logic around investor decision-making

# Accomplishments: Technical Report Draft

- Report draft contained…
  - A summary of the initial research done prior to model development
  - A detailed presentation of BTD model logic, assumptions, inputs, and sensitivity analysis results
- Draft was revised in FY18 Q4 to incorporate model development and analysis tasks to undertake in FY19-20 based on feedback and suggestions from workshop attendees

**Outcome:** We submitted the report draft to BETO for review as the FY18 Q4 deliverable.

## Table of Contents

# Accomplishments: Milestones Overview

- All project milestones to date have been completed and submitted to BETO on time

| Date | Title / Topic | Status |
|---|---|---|
| FY17 Q1 | Provide memo that outlines bioproducts the model will incorporate and rationale behind the choices | Completed on time |
| FY17 Q2 | Present status report on model design and development; outline data gaps/uncertainties and discuss plans to overcome | Completed on time |
| FY17 Q3 | Complete SD model with basic industry structure for two to four chemicals from biomass; brief BETO in quarterly check-in | Completed on time |
| FY17 Q4 | Deliver briefing to BETO on utilization of developed SD model to evaluate at least two chemicals from biomass | Completed on time |
| FY18 Q1 | Provide briefing on proposed workshop agenda and technical report topics | Completed on time |
| FY18 Q2 | Deliver briefing on current model progress to support technical report | Completed on time |
| FY18 Q3 | Completed draft technical report for review in advance of BTD workshop | Completed on time |
| FY18 Q4 | Deliver draft technical report covering the BTD model and incorporating insights from the BTD workshop | Completed on time |
| FY19 Q1 | Complete one internal and one external review of the technical report | Completed on time |
| FY19 Q2 | Complete model development tasks from workshop; complete and document model validation using at least two chemicals | In progress |

# Relevance

Growing the bioproducts industry has the potential to

- Support the biofuels industry by contributing to feedstock supply chain development and increasing biorefinery revenue when bioproducts are produced as coproducts
- Reduce carbon and other emissions associated with the U.S. chemical sector
- Increase price stability in some areas of the chemical market

These benefits cannot be realized unless **more bioproducts are successfully brought to market**.

This project will identify **factors that contribute to commercial success** for bioproducts and **inform decisions** around investments, development and government support across the bioproducts industry.

Currently no decision-support tool similar to the BTD model exists. This project is filling a substantial analytic and educational gap.

# Relevance to BETO

The Bioproduct Transition Dynamics project supports the following Key Opportunities from BETO's 2016 Strategic Plan:

- Develop and demonstrate innovative and integrated value chains for … bioproducts … that can **respond with agility to market factors** [*Enhancing Bioenergy Value Proposition]*
- Inform **supportive policies** for biofuels and bioproducts [*Cultivating End Use Markets and Customers]*

From BETO's 2019 draft MYP, the Analysis and Sustainability program strategic goal is to "… provide context and justification for decisions at all levels by … tracking progress toward goals, and informing portfolio planning and management" [p. 50].

- This project contributes by providing insight into how investor, developer and government decisions promote or hinder bioproducts industry growth over time

# Future Work: Key Milestones and Deliverables

## FY19 Q2

**Implement** workshop recommendations in the BTD model
**Validate** the model against historical data for at least two bioproducts

*On target*
*Validation is pending data availability (implicit go/no-go)*

## FY19 Q4

Complete **draft publication** on using the BTD model to address an **analysis question** of interest to BETO

*Pending feedback from BETO*

## FY20

Continue to engage **prospective users** and **BETO** for model vetting and review

## FY20 Q4

Publicly **release** the BTD model and supporting documentation

*Pending go/no-go decision from BETO*

# Near-Term Future Work

- **Model development** tasks compiled from workshop attendee recommendations
  - Focus model scope on piloting and subsequent tasks
  - Account for regulatory and permitting delays in the pre-commercial phases
  - Perform additional sensitivity analyses
- **Review** updated model logic, validation results and new sensitivity analysis results **with BETO**

# Long-Term Future Work

Use the BTD to address analysis questions developed in collaboration with BETO leadership.

Current analysis question to be addressed, pending BETO approval, is…

- What are the factors that cause a bioproduct to be successful or unsuccessful in moving from basic research to a pilot-scale facility?
- How do these factors change when the bioproduct is a performance advantaged product versus a drop-in replacement?
  - Performance advantaged product: Same or better functionality, different molecule
  - Drop-in replacement: Same functionality, same molecule

# Summary

**Objective**: Support bioproducts industry growth by codifying the environment and drivers that influence bioproducts industry growth in the Bioproduct Transition Dynamics model

**Approach**: Draw on previous BETO-funded projects and subject-matter experts to develop a system dynamics model of bioproduct development and market expansion

**Technical Accomplishments**: Initial model and exploratory sensitivity analysis was completed and reviewed by stakeholders, leading to future model development and analysis tasks

**Relevance**: Supports bioproducts and biofuels industry growth by developing understanding around how bioproducts can be successfully brought to market

**Future work**: Continue model development and vetting; Complete draft publication on analysis using BTD; Publicly release BTD model

# Thank You

**www.nrel.gov**

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**NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.**

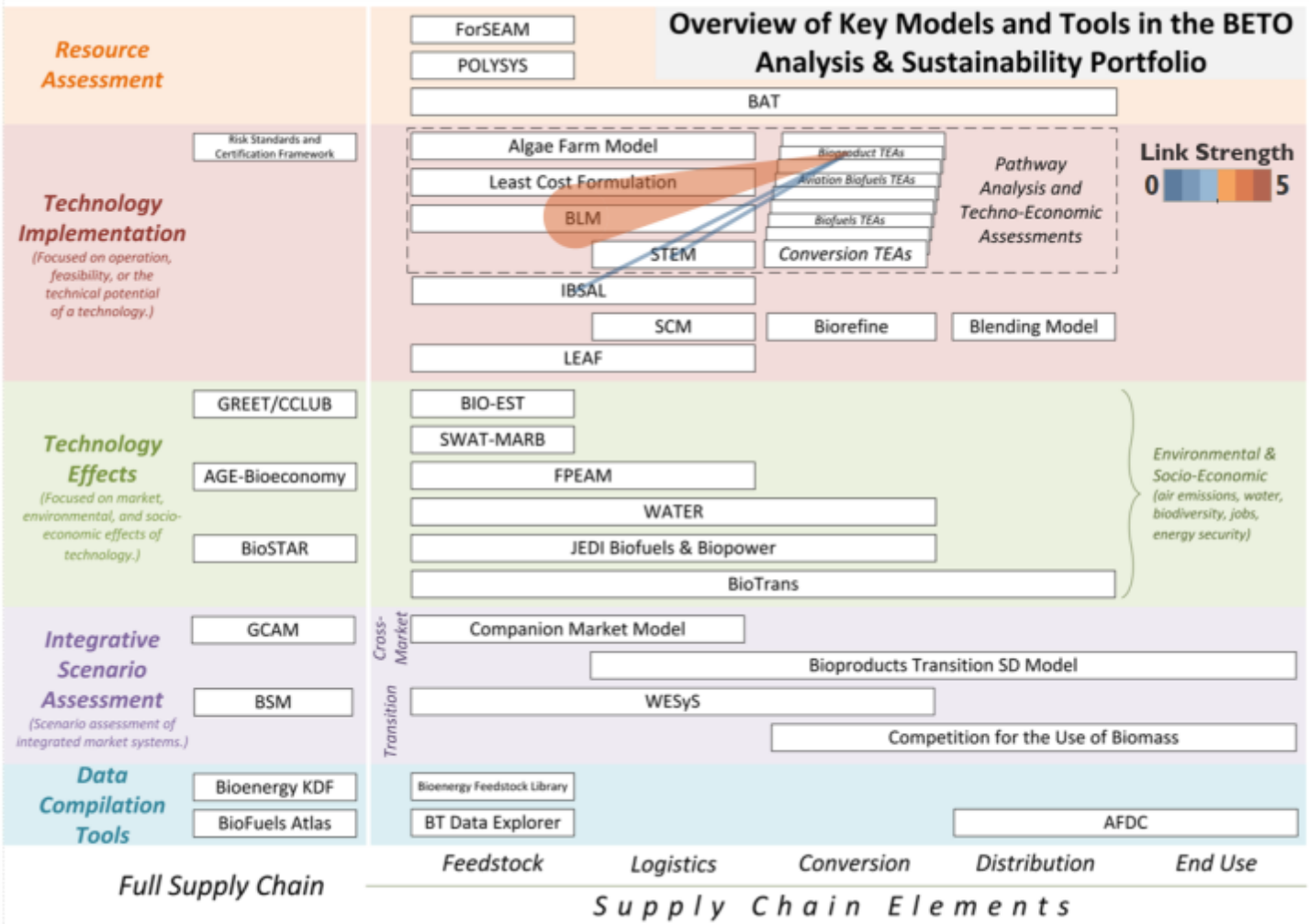
# Response to Reviewers' Comments 2017

- "… there are several projects working in closely related aspects of this work. Care should be taken not to duplicate efforts."
  - "This project strives to fill a current gap in the BETO modeling portfolio that is not being addressed in other projects. Specifically, the model seeks to develop a more thorough understanding of the investment decision-making process for early-stage bioproducts. … This tool will help BETO better understand commercialization potential of products and could help alignment of R&D strategies and funds by BETO to support technologies with a higher probability to move to the market faster and grow the bioeconomy at a greater rate."
- "My concerns with the project have largely to do with the limitations of SD as a method. … One must be careful not to extrapolate relationships which are reasonable approximations to local dynamics to the point where they generate a reduction ad absurdum. It is not clear to me how the calibration of the modeling effort here will avoid such a possibility."
  - "The SD modeling framework has proven its value over the last decade of its application to scenario analysis of the biomass-to-biofuel supply chain. We are acutely aware of the dangers of extrapolation, so the project has undertaken a calibration and confidence-building effort to model a historic success and failure in the bioproducts industry, thus moving the future use of the model from the realm of extrapolation to that of safer interpolation. Additionally, the specification of SD equations and feedbacks will be reviewed by subject matter experts and modelers with expertise in SD and other frameworks.

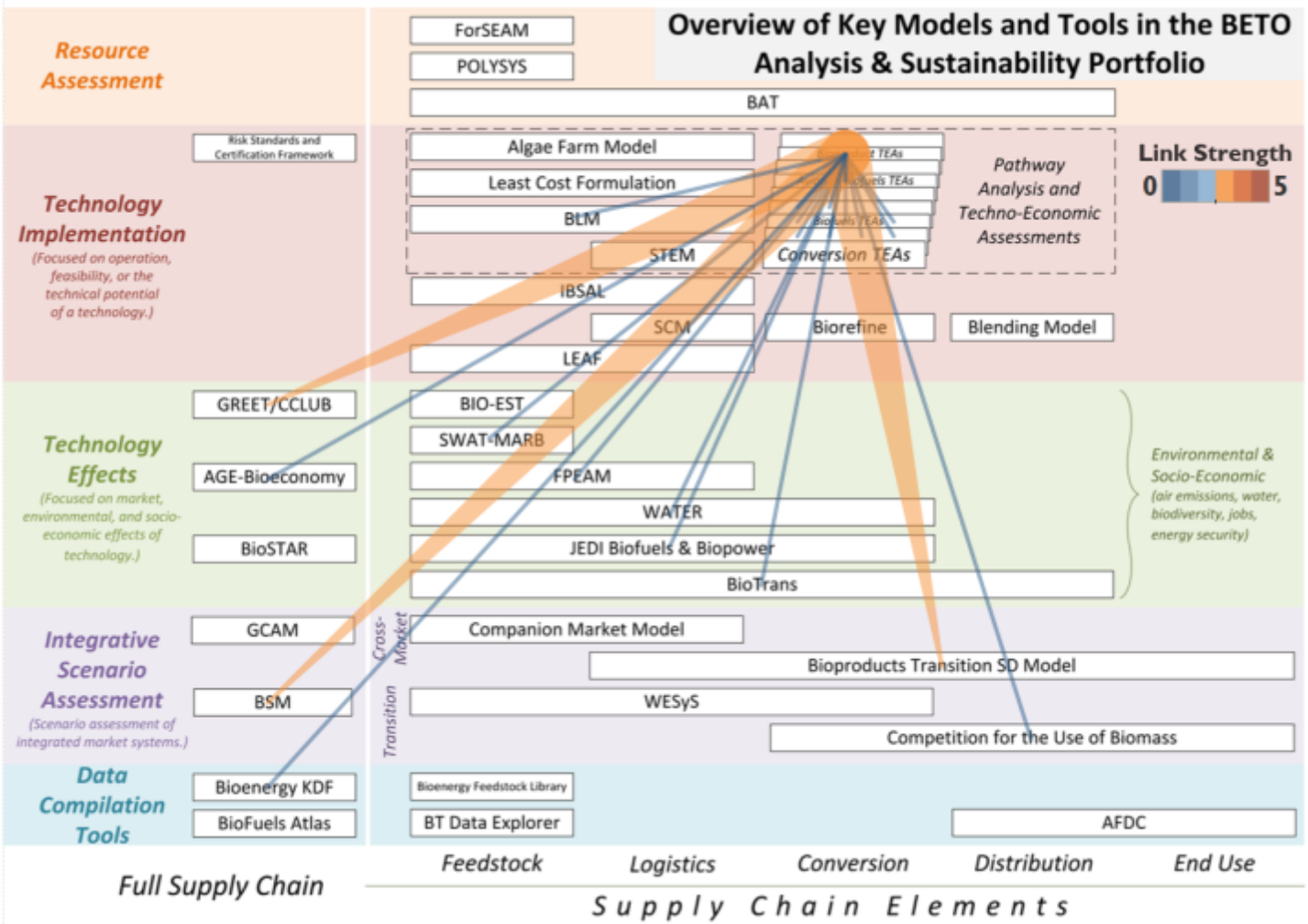
# Presentations and Publications

- Hanes, Rebecca, Brian Bush, and Emily Newes. “A system dynamics model of early-stage transition dynamics in the bioproducts industry.” Presented at International Symposium on Sustainable Systems and Technologies, Buffalo, NY, June 27, 2018. URL.
- Hanes, Rebecca, Brian Bush, Emily Newes, and Mary Biddy. “Bioproduct Transition Dynamics.” September 2018. Report draft.

# BTD – Inputs


Overview of Key Models and Tools in the BETO Analysis & Sustainability Portfolio
Resource Assessment
ForSEAM
POLYSYS
BAT
Technology Implementation
(Focused on operation, feasibility, or the technical potential of a technology.)
Risk Standards and Certification Framework
Algae Farm Model
Least Cost Formulation
BLM
STEM
IBSAL
SCM
LEAF
Bioproduct TEAs
Aviation Biofuels TEAs
Biofuels TEAs
Conversion TEAs
Biorefine
Blending Model
Pathway Analysis and Techno-Economic Assessments
Link Strength
0
5
Technology Effects
(Focused on market, environmental, and socio-economic effects of technology.)
GREET/CCLUB
AGE-Bioeconomy
BioSTAR
BIO-EST
SWAT-MARB
FPEAM
WATER
JEDI Biofuels & Biopower
BioTrans
Environmental & Socio-Economic
(air emissions, water, biodiversity, jobs, energy security)
Integrative Scenario Assessment
(Scenario assessment of integrated market systems.)
GCAM
BSM
Cross-Market
Transition
Companion Market Model
Bioproducts Transition SD Model
WESyS
Competition for the Use of Biomass
Data Compilation Tools
Bioenergy KDF
BioFuels Atlas
Bioenergy Feedstock Library
BT Data Explorer
AFDC
Full Supply Chain
Feedstock
Logistics
Conversion
Distribution
End Use
Supply Chain Elements

# BTD – Outputs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