

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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Rebecca J. Hanes, PhD

National Renewable Energy Laboratory

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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]

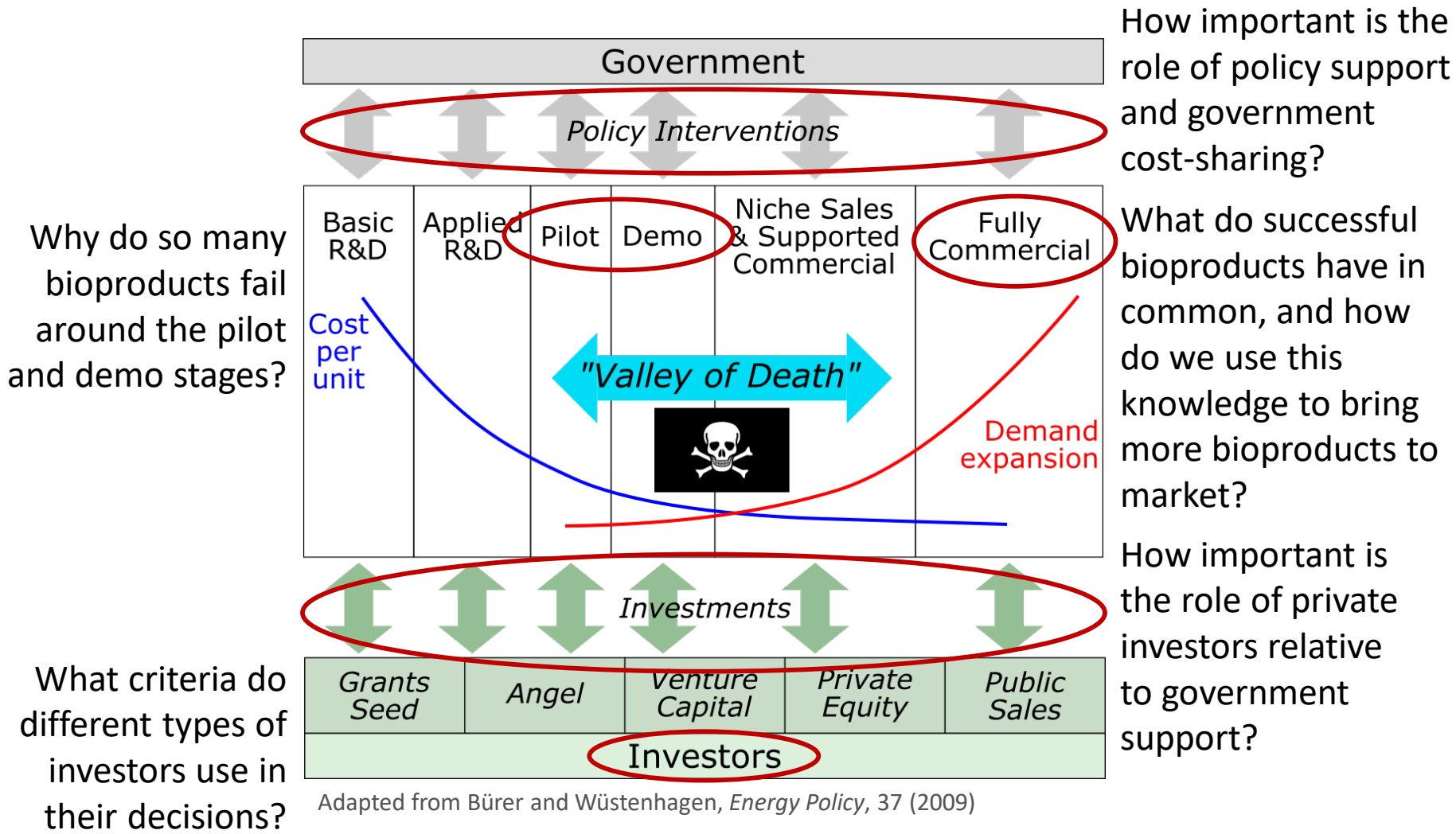
Objective

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



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

Project Overview

Project Objectives

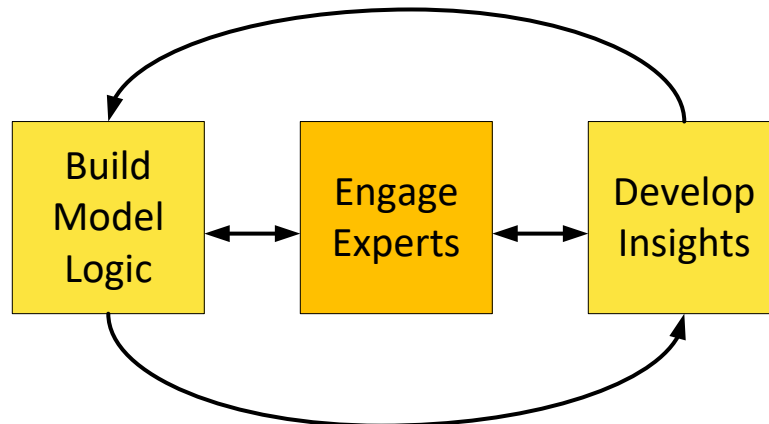
- Identify and understand factors that contribute to commercial success or failure for bioproducts and conversion processes
- Develop a decision support tool that can be used to lower the failure rate of bioproduct development projects and start-up firms, resulting in more bioproducts reaching commercial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

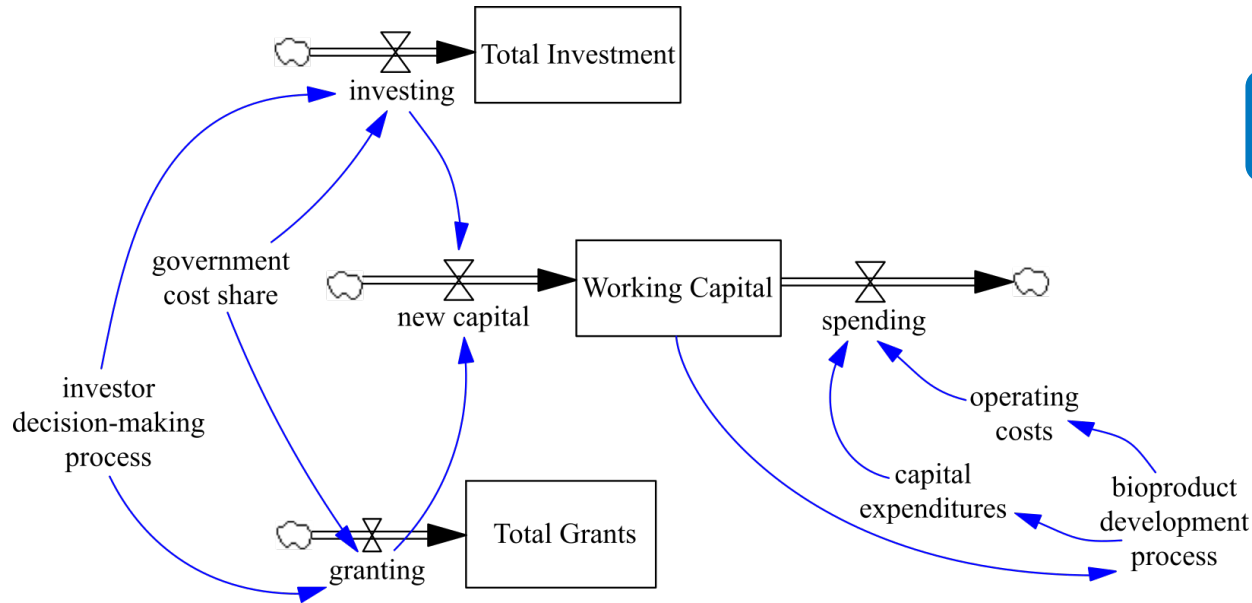
Management Approach

- 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

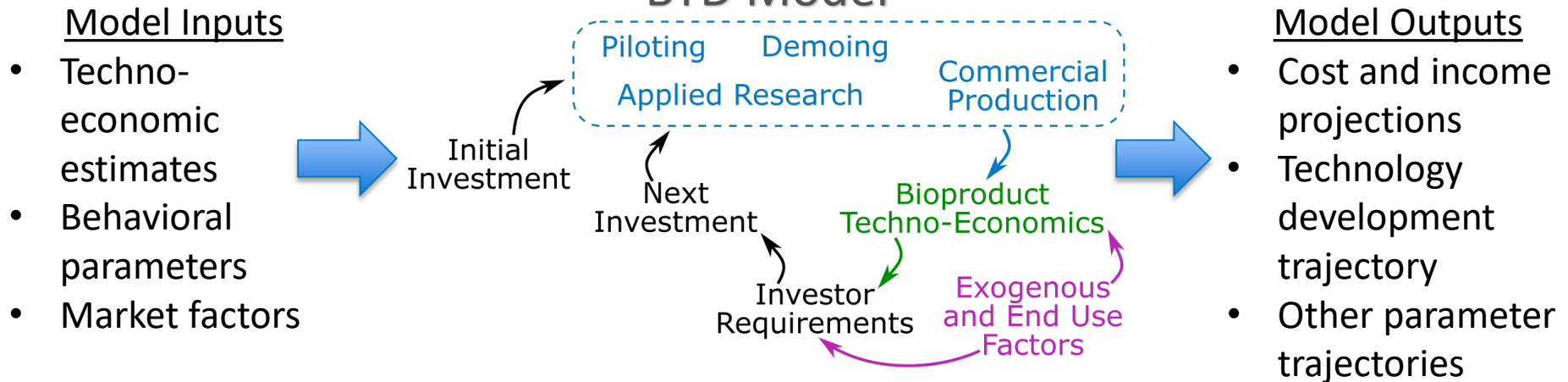
Key Features of System Dynamics Modeling

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 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 BTM 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 BTM 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

Initial
research

Model
development

Sensitivity
analysis

Workshop

Technical
report draft

Completed during FY18

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

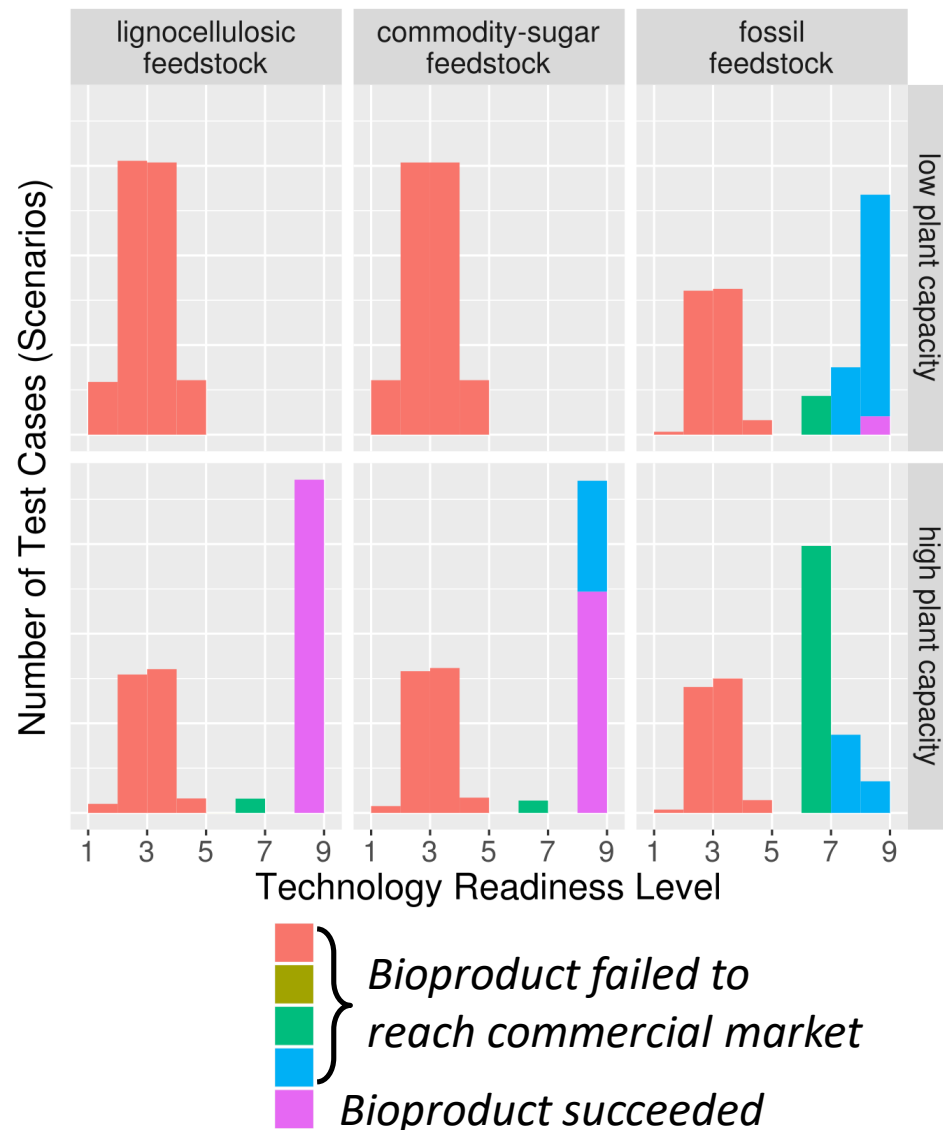
Objective: Explore analysis questions that could be answered with the BTD and assess model outcomes

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

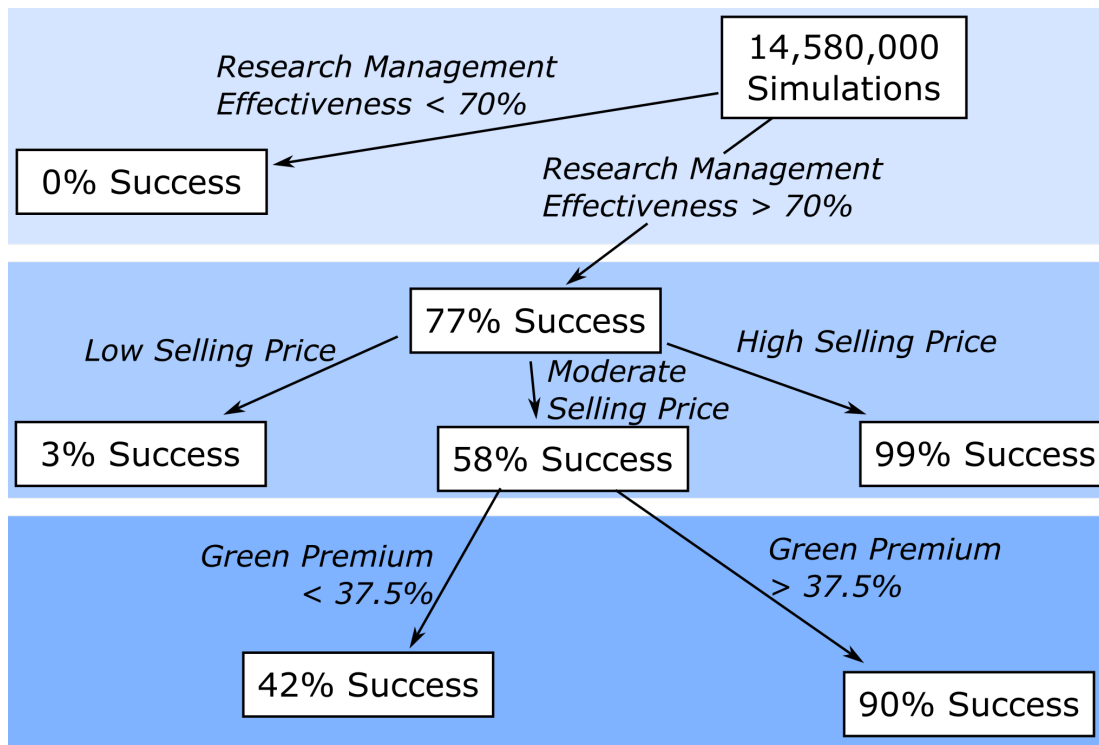


Accomplishments: Sensitivity Analysis

Objective: Explore analysis questions that could be answered with the BTM 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 BTM 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.

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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 BTM 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 BTM 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 BTM 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 BTM; Publicly release BTM model

Thank You

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rebecca.hanes@nrel.gov

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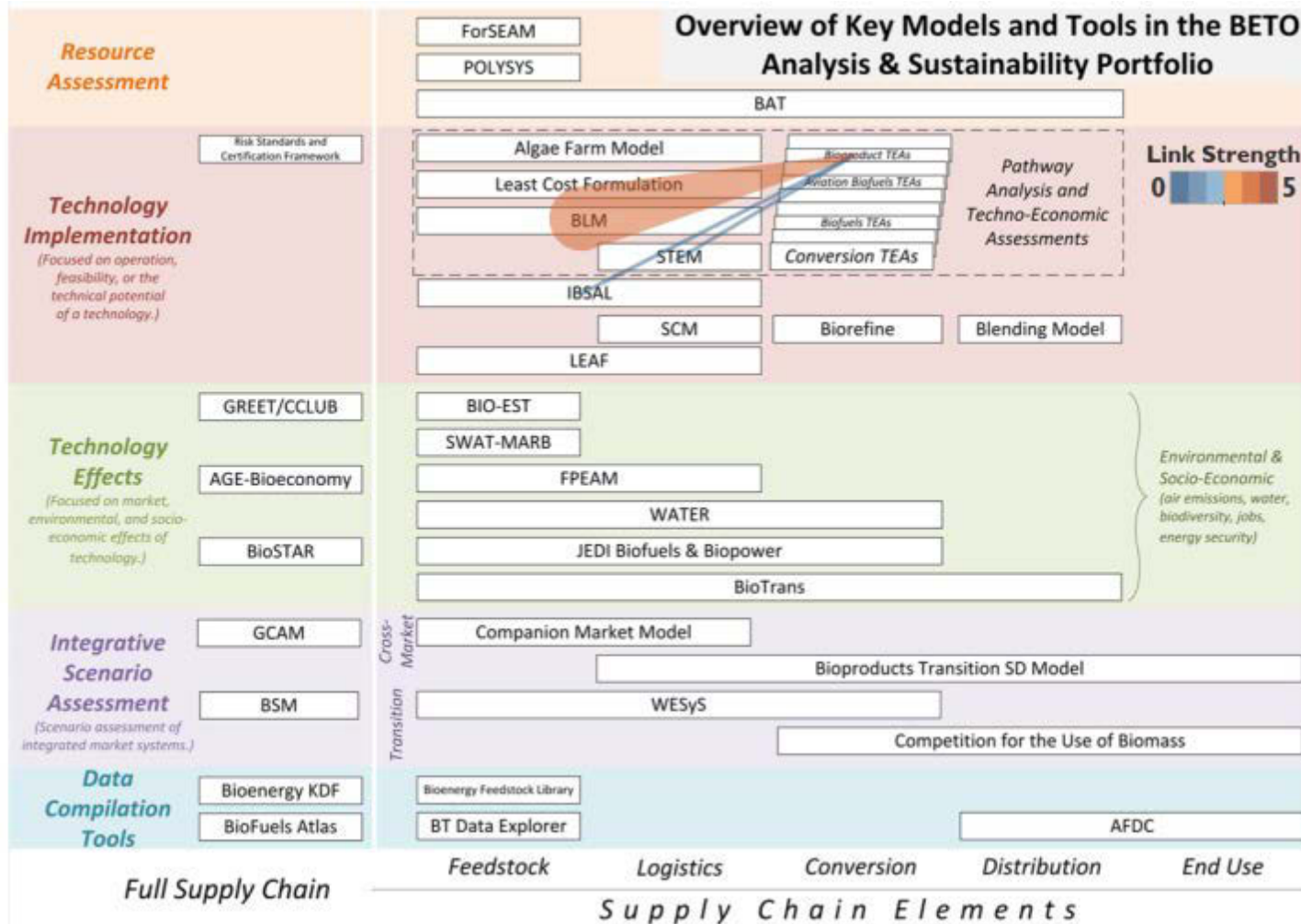
Response to Reviewers' Comments 2017

- “... 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 Bidy. “Bioproduct Transition Dynamics.” September 2018. Report draft.

BTD – Inputs



BTD – Outputs

