NREL
NATIONAL RENEWABLE ENERGY LABORATORY

WBS 4.1.2.32 Bioeconomy Scenario Analysis

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Analysis & Sustainability

March 4, 2019

Emily Newes

National Renewable Energy Laboratory

Goal Statement

Inform BETO, other stakeholders, and policy-makers of the implications of policy choices and market developments to **enable prioritization and evaluation** of various actions and enable researchers to design and analyze the impacts of additional biomass-to-bioenergy scenarios.

- *Outcomes:*
  - Elucidate the transition dynamics to a bioeconomy, using a suite of state-of-the-art tools and analyses
  - Generate plausible scenarios for prospective policies, incentives, investments, R&D impacts, and strategies
  - Enable and facilitate focused discussion among stakeholders.
- *Relevance:*
  - Explore different strategies to directly provide context and justification for decisions at all levels
  - Identify potential unintended consequences (and relevant feedbacks)
  - Provide a bridge for analytic collaboration between BETO and other bioenergy stakeholders.

Quad Chart Overview

Timeline

- Start: FY2018 (*See Note*)
- Merit review cycle: FY2018-2020
- 50% complete of review cycle

	Total Costs Pre FY17**	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	$700k *See Note*	$450k *See Note*	$450k	$900k

Note: This project was formerly part of WBS 4.1.2.1

This project directly supports Co-Optima.

Barriers Addressed

- Analysis to Inform Strategic Direction [MYP At-A]
- Analytical Tools and Capabilities for System-Level Analysis [MYP At-B]
- Identifying New Market Opportunities for Bioenergy and Bioproducts [MYP At-D]

Objective

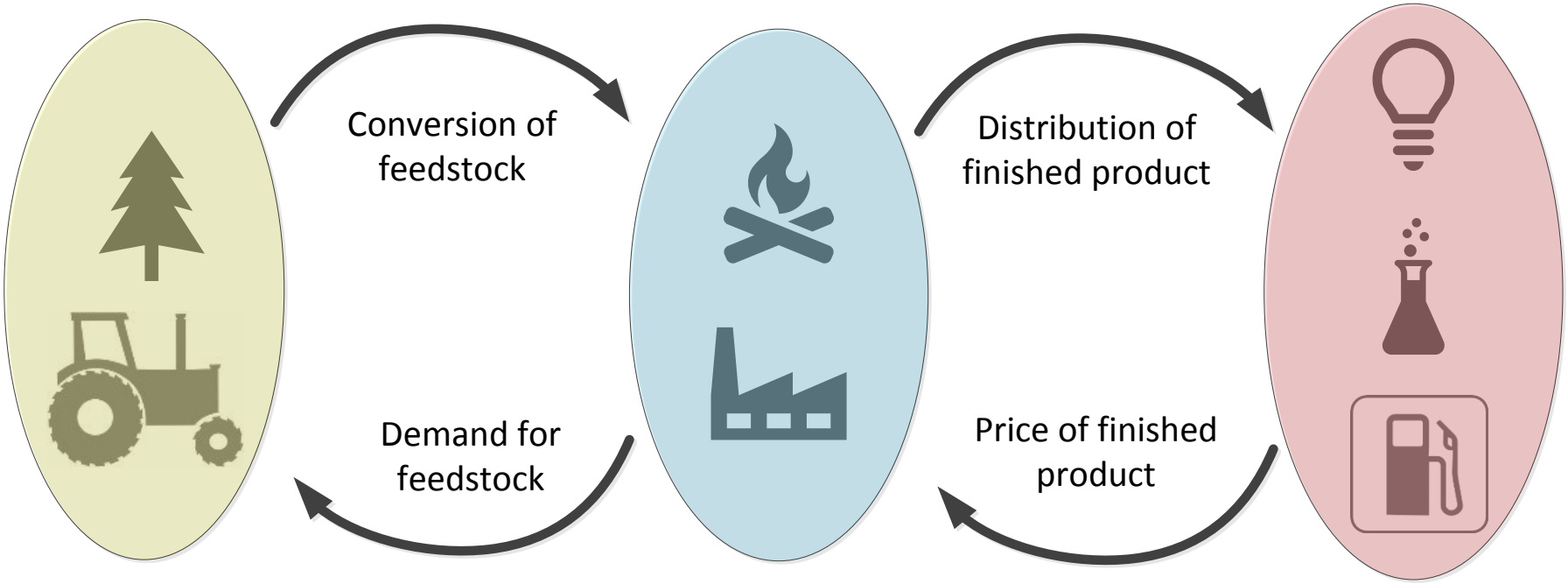
- **Provide bioeconomy scenarios analysis support** to BETO and the broader bioeconomy stakeholders
- Analysis informs **the creation of a bioenergy industry**

End of Project Goal

- Create a robust and nuanced understanding of **transition scenarios to a large-scale bioeconomy**, along with opportunities and barriers
- Increased recognition of BETO-funded models among key audiences, collaborations with a more diverse set of stakeholders, and citable publications.

System Dynamics Model of the Bioenergy Supply Chain

The Biomass Scenario Model (BSM) allows scenario exploration to support decision making highlighting **interactions across systems**, with nonlinearity, constant change, historical dependence, and evolving markets.

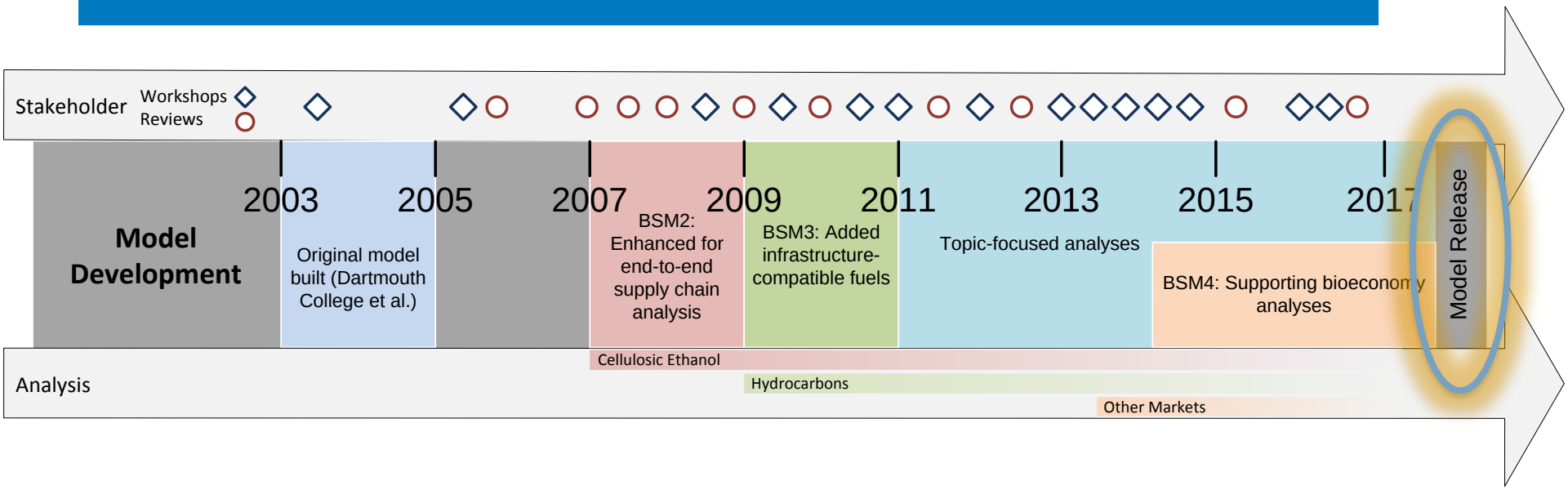


Simplistic representation of basic feedback between supply chain sectors

- Reliance on appropriate and well established modeling techniques
- Careful consideration of level of detail
- Solve coupled ordinary differential equations
- Perform analyses using new tools and data when relevant.

Project Overview

System Dynamics Model of the Bioenergy Supply Chain



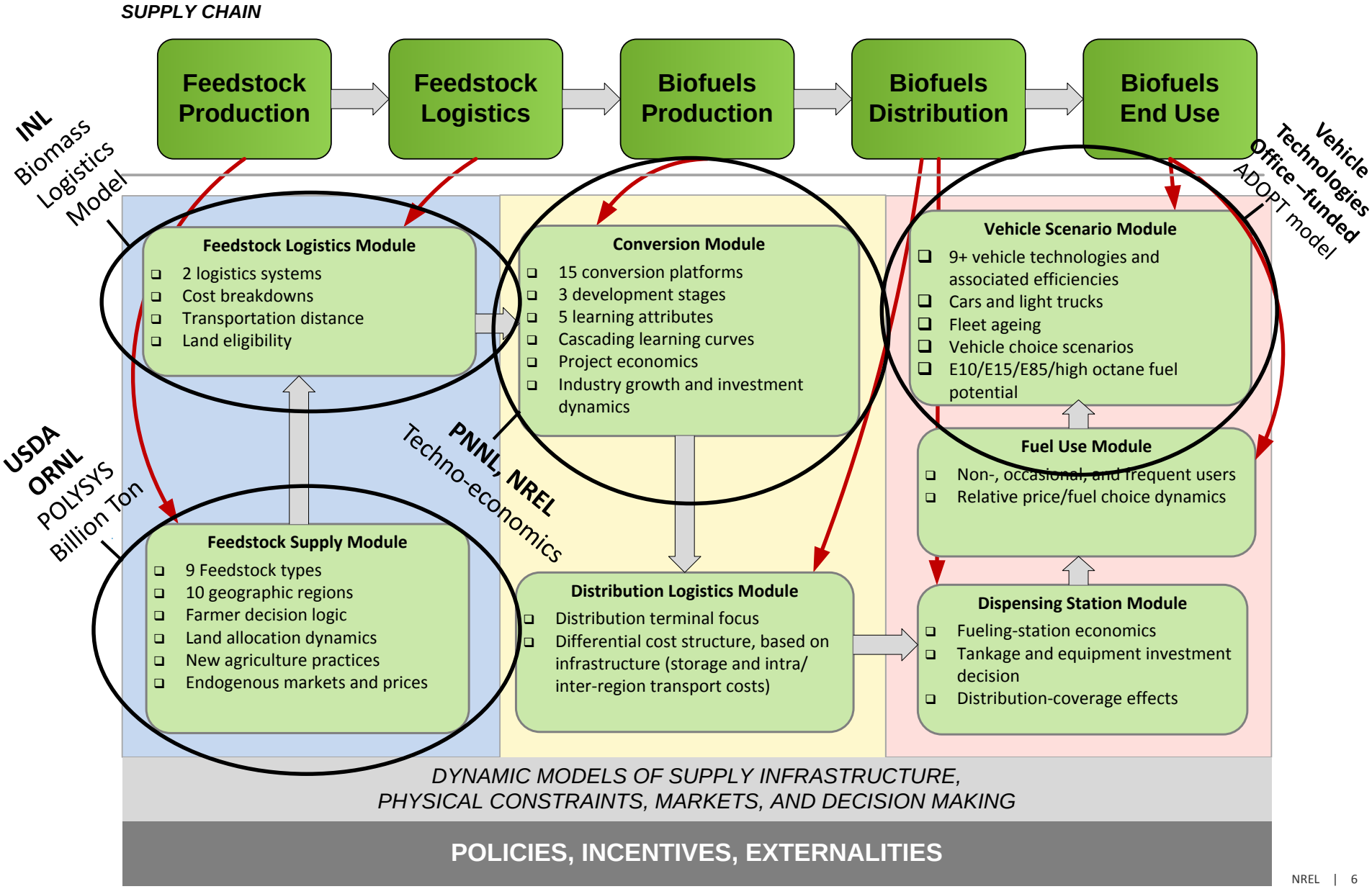
The BSM has been in development for 15 years and has undergone multiple technical reviews along with content workshops.

It was publicly released in 2017!

The BSM is characterized as…

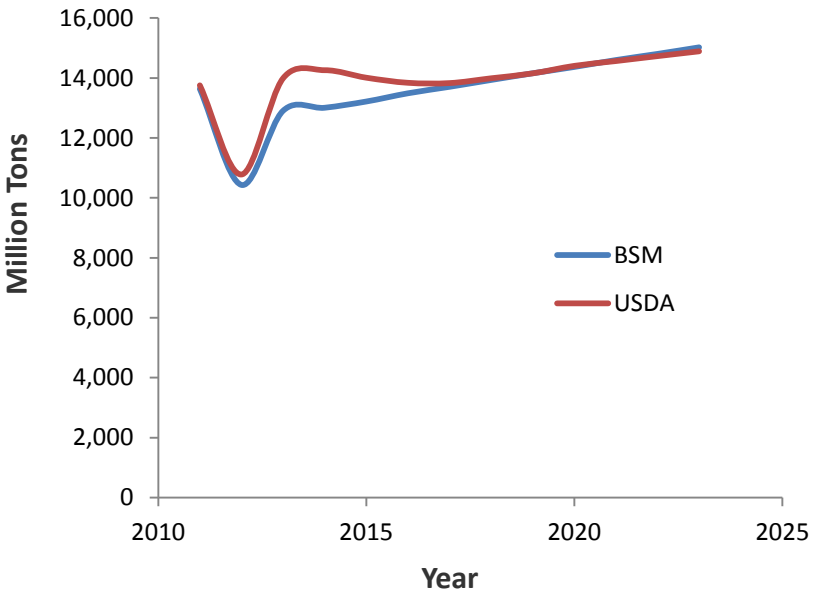
- Unique
- Validated
- State-of-the-art
- Fourth-generation

Key Characteristics of BSM Modules



Model Calibration and Validation

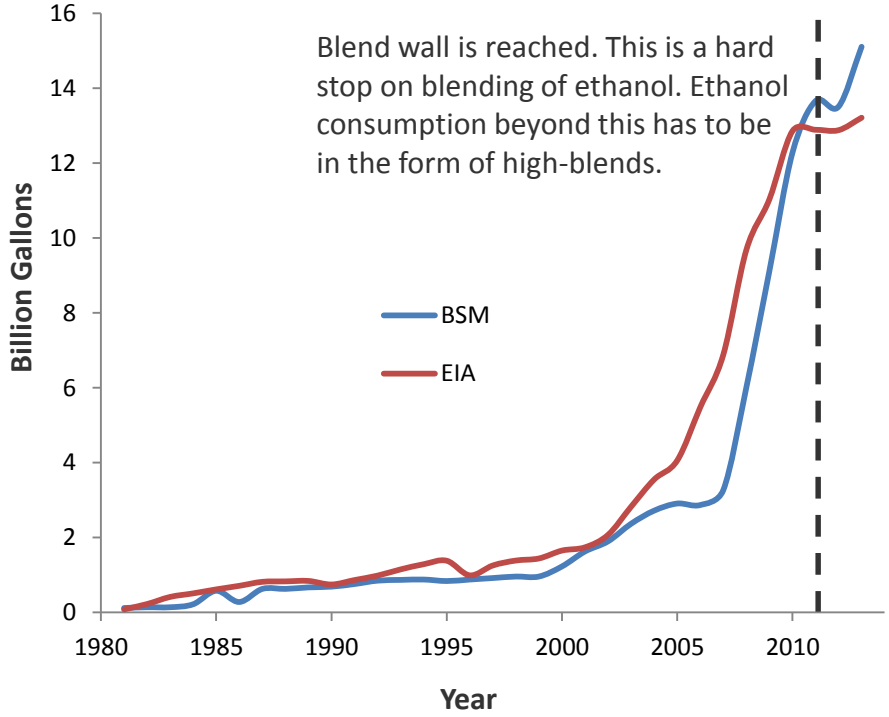
Calibration example: BSM simulated corn production vs. USDA long-term forecast (2014)



- Calibration is an ongoing process and involves many aspects of the BSM.
- We perform calibration to build confidence in our modeling assumptions.
- For example, we calibrate crop production in the BSM against the USDA long-term forecast each year.

Validation example: BSM simulated starch ethanol production vs. historic data

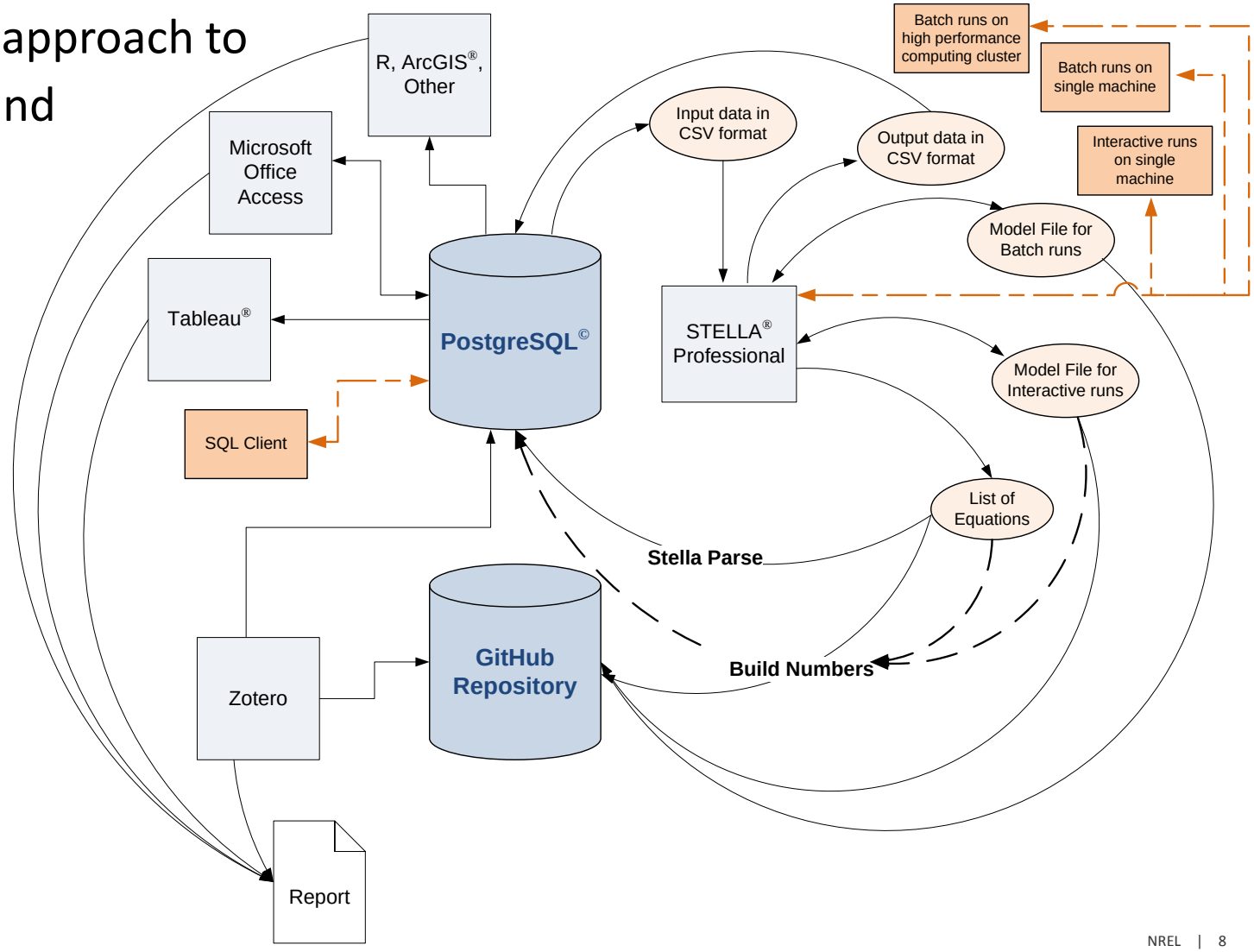
- Production levels, installed capacity, and timing of simulated results match with that which was observed.
- With existing logic and structure, the BSM can adequately reproduce the historical development of the starch ethanol industry in the US.



Quick and dirty goodness-of-fit: Regressing BSM simulated production values on observed industry values, we get an R^2 of 0.94, $p < 0.001$

Comparable, Transparent, and Reproducible Analysis

- Emphasis on a flexible development process with stakeholder feedback
- State-of-the-art approach to reproducibility and quality
- Sophisticated information architecture to enable inventorying and mining of results.



Success Factors and Challenges

Inform BETO, other stakeholders, management, and policy-makers of the implications of policy choices and market developments to **enable prioritization and evaluation** of various actions and enable researchers to design and analyze the impacts of additional biomass-to-bioenergy scenarios.

Critical Success Factors

- Ensuring that modeling represents best available information
- Establishing collaboration with meaningful information exchange
- Ensuring mathematics is appropriate to represent the system

Potential Challenges

- Lacking available data or experts willing to share knowledge/time
- Ensuring that collaborators are engaged
- Avoiding scope creep, answering questions appropriate to methodology

Multi-disciplinary Team

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.

State-of-the-art approach to reproducibility and quality

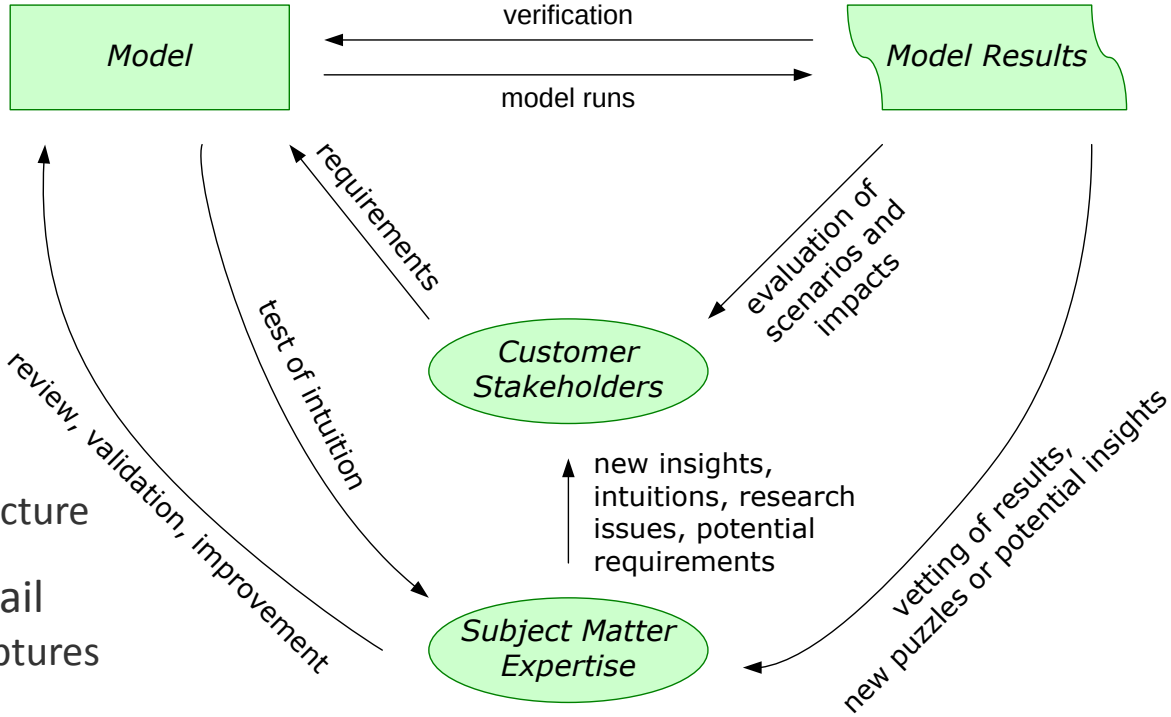
- **Defensible and traceable** inputs, with metadata
- Full archives of analysis results, from the inception of the project
- Configuration management and issue tracking systems
- Explicit quality assurance, quality control, verification, and validation

Frequent communication and reporting to BETO

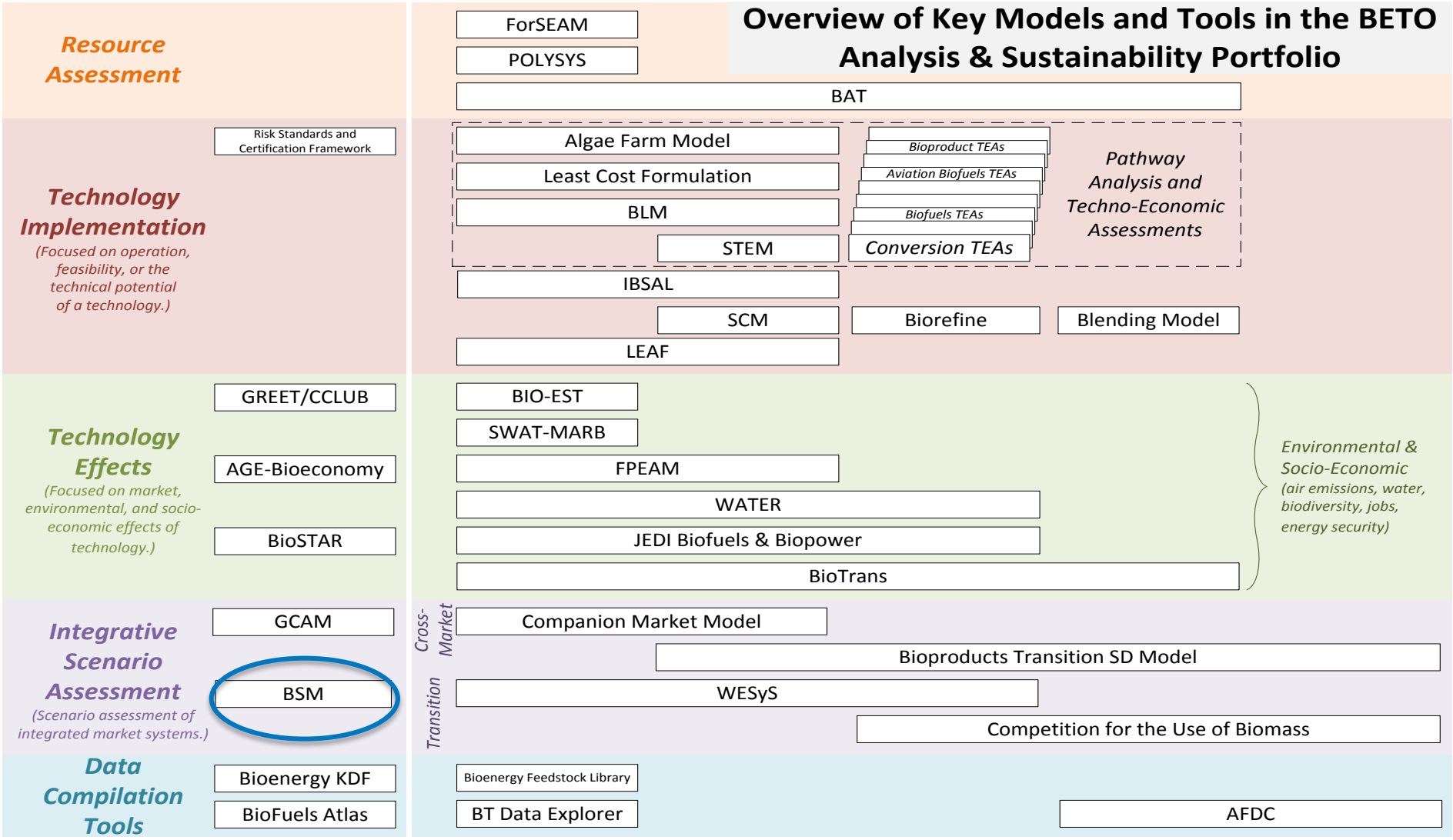
- Involvement of **team members with specialized areas of expertise**
- Collaboration with **external subject-matter experts**
- Adaptive adjustment of analysis plans
- Flexible, modular modeling architecture

Careful consideration of level of detail

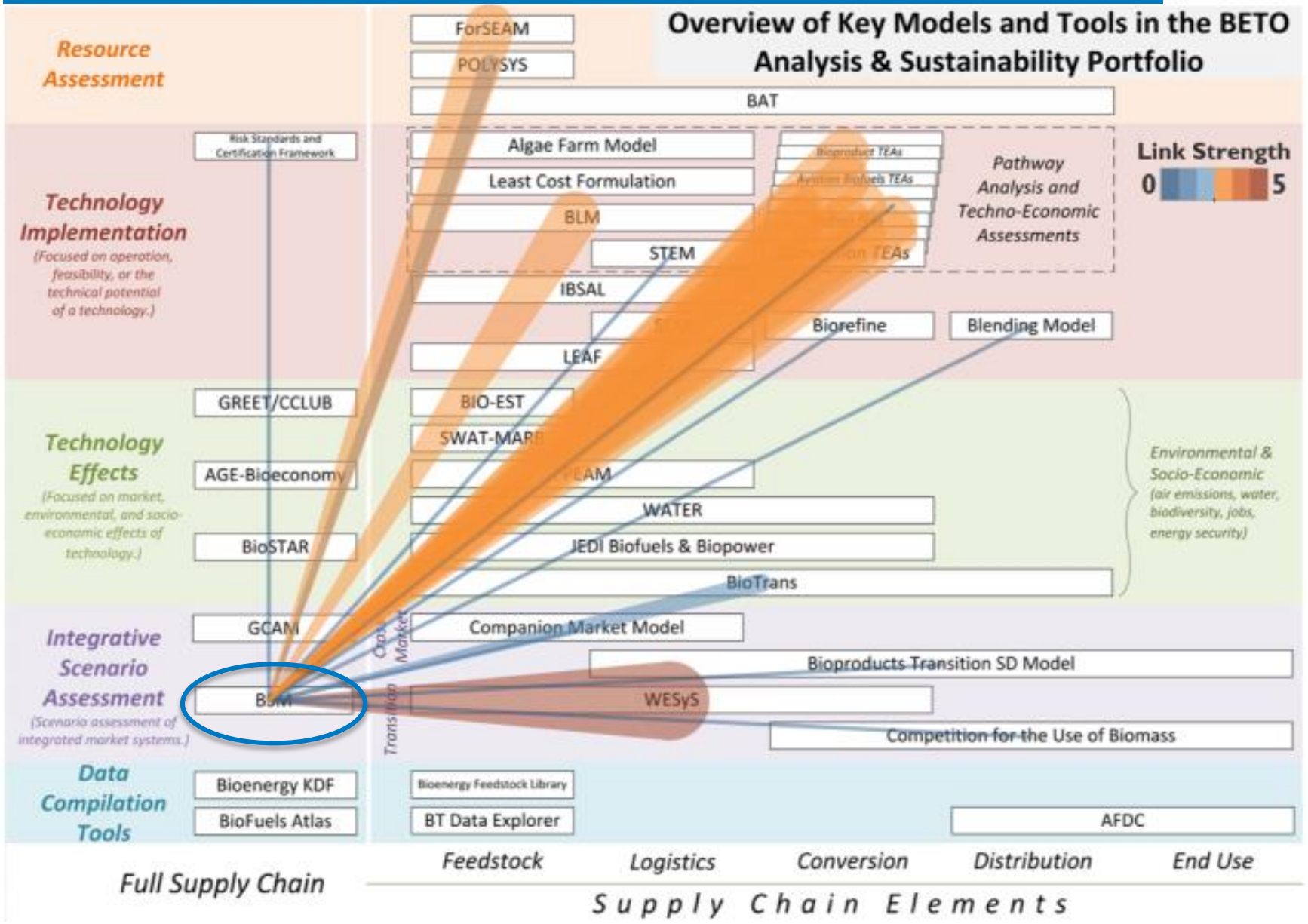
- Broad, high level approach that captures **entire supply chain**.



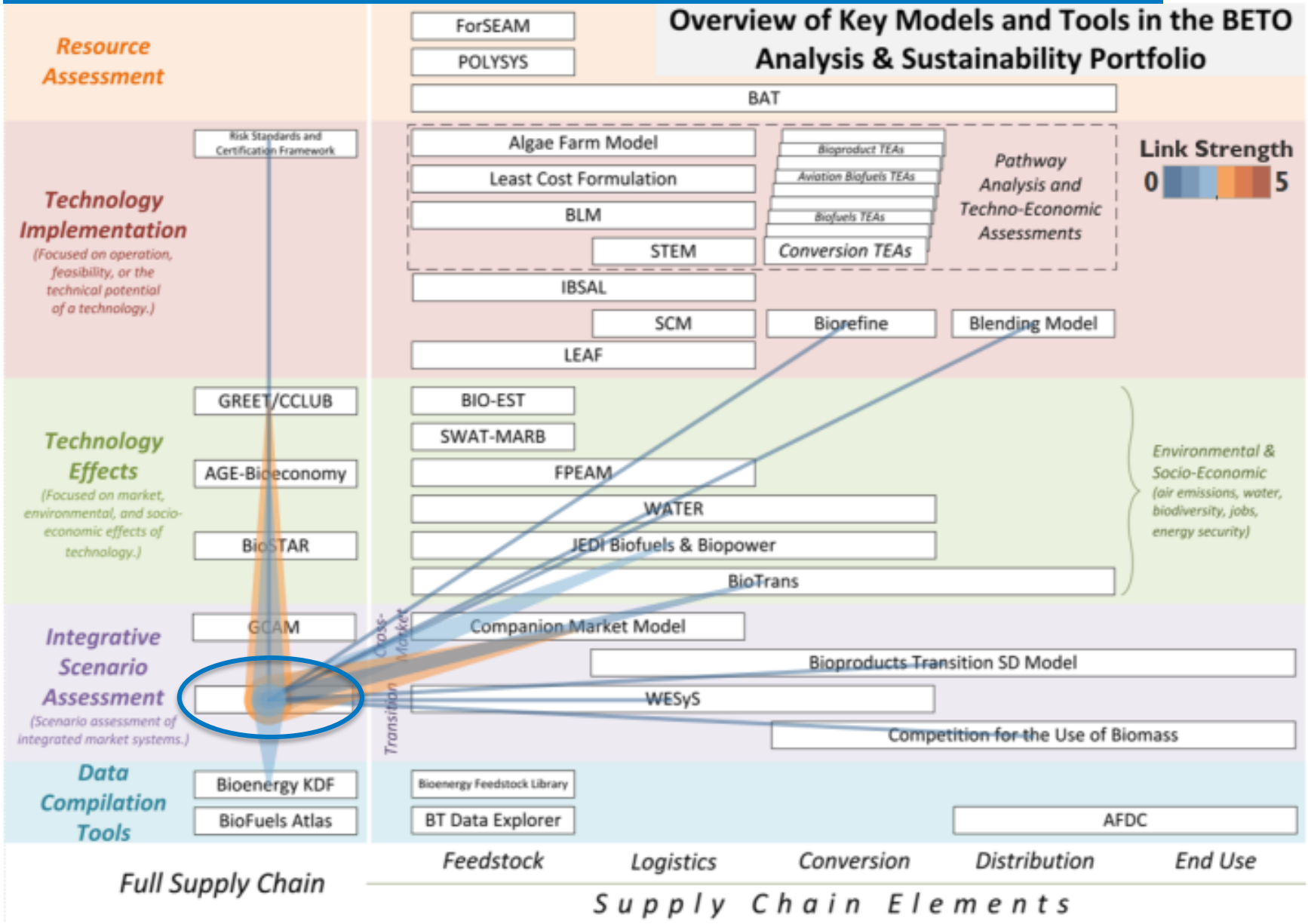
Deep Connections with BETO Models



Deep Connections with BETO Models (Inputs)

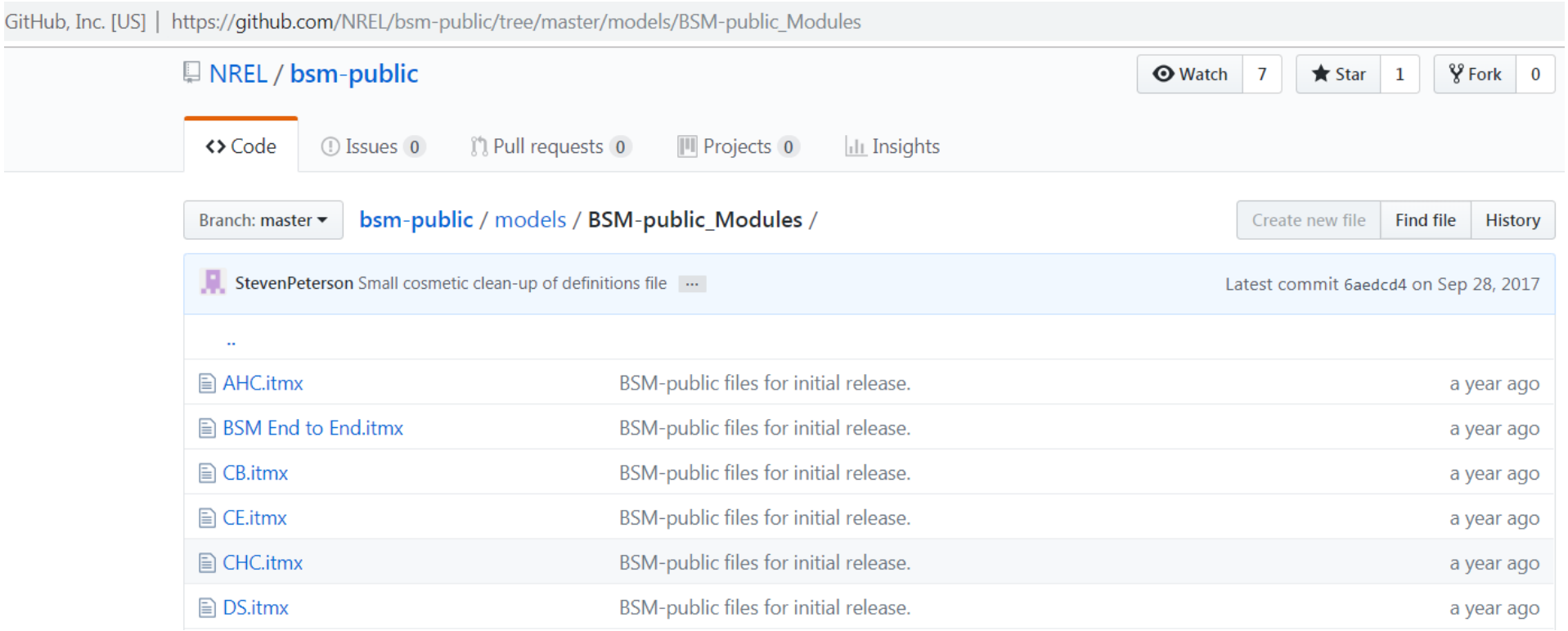


Deep Connections with BETO Models (Outputs)



Accomplishments

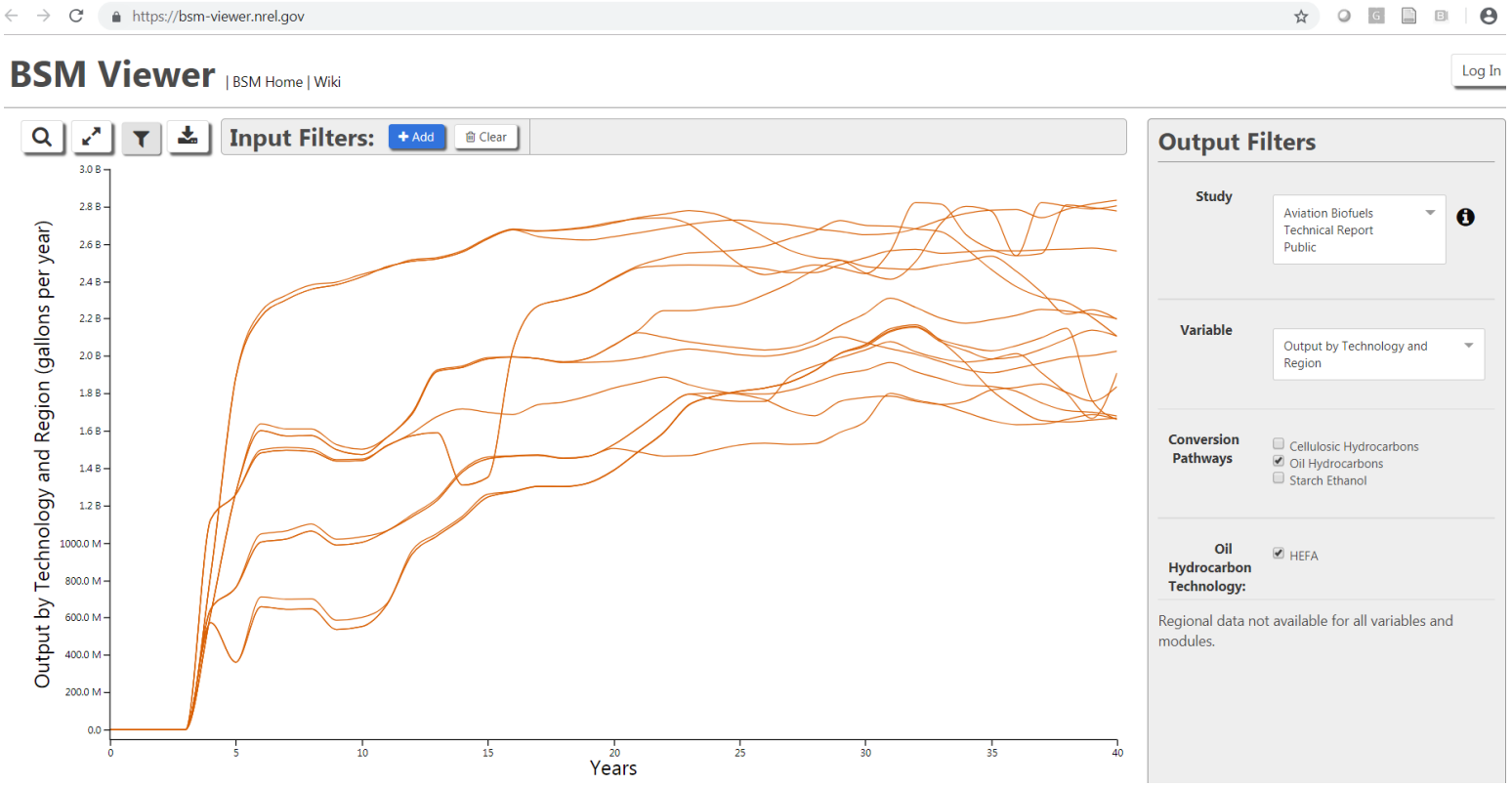
The BSM is Publicly Released!



- Facilitated workshop in DC on planned model release
- Completed testing of BETA BSM, with 9 external reviewers
- Publicly released model in September 2017
- Collaborated with academics and hosted students to support theses.

Accomplishments

BSM Viewer and User Interface Complement Release

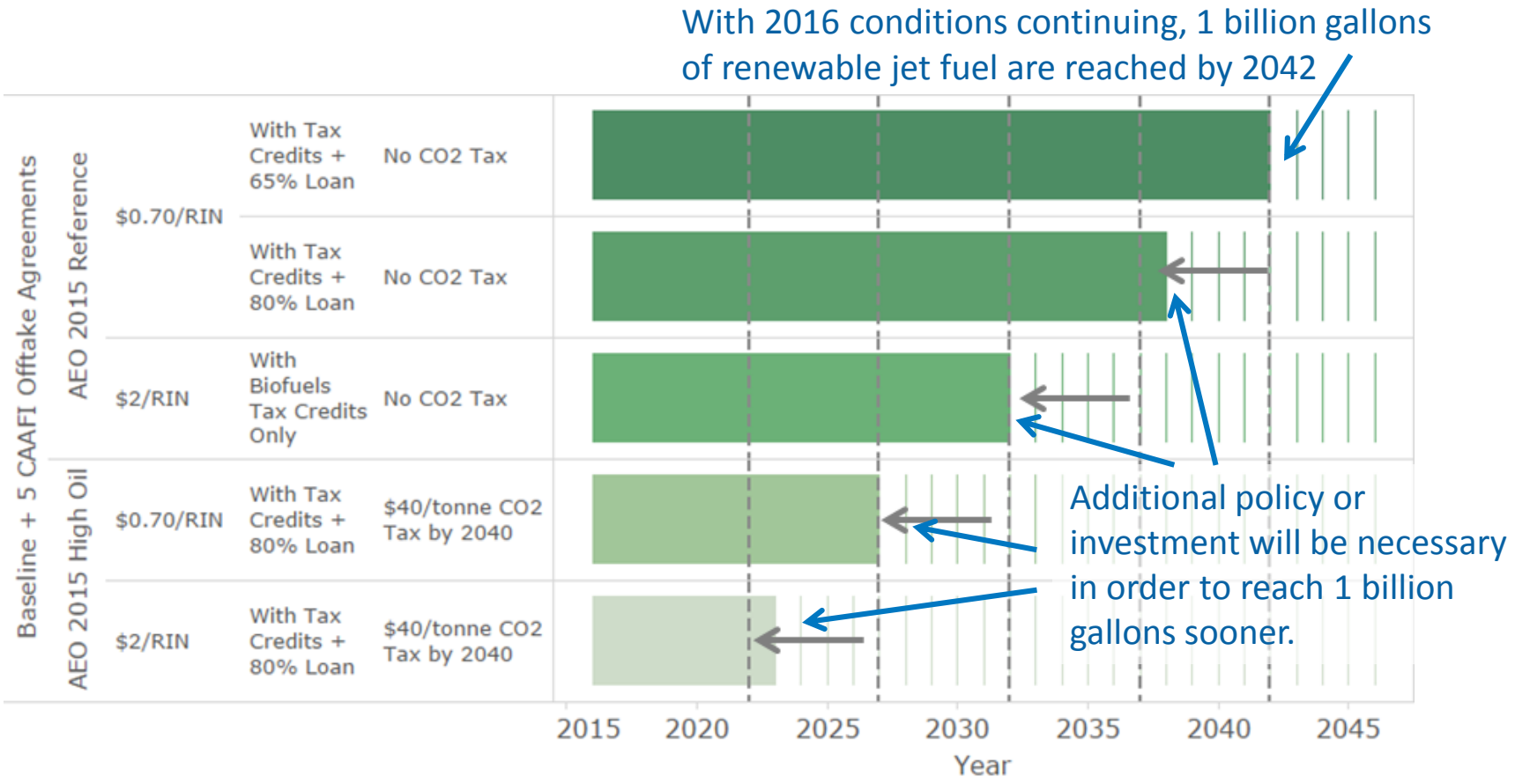


- Launched BSM Viewer, with interactive publicly-available results directly connected to the BSM database
- Completed BETA version of user interface for those who do not want to download the full BSM model
- Updated BSM-related website content (NREL, OpenEI, Github)

Interagency Study on Aviation Biofuel Potential

Analysis focused on two questions:

1) How much alternative jet fuel (AJF) can be produced and how soon?
2) What is the likely geospatial distribution of feedstock and fuel production and AJF delivery?



Authors from NREL, Volpe National Transportation Systems Center, U.S. Federal Aviation Administration, U.S. Department of Energy, Dartmouth College, Washington State University, University of Tennessee, and University of Idaho

Source = Lewis et al. (2018)

Sensitivity Analysis Characterizes Cost-effective Biofuels Industry Growth

1. Our analysis identified a "frontier" set of cost-effective scenarios.
2. We analyzed the complex variations in conditions for cost-effective growth in biofuels production.
3. **Simulated cellulosic biofuels could match current biofuels production volumes at costs within historical spending precedents.**

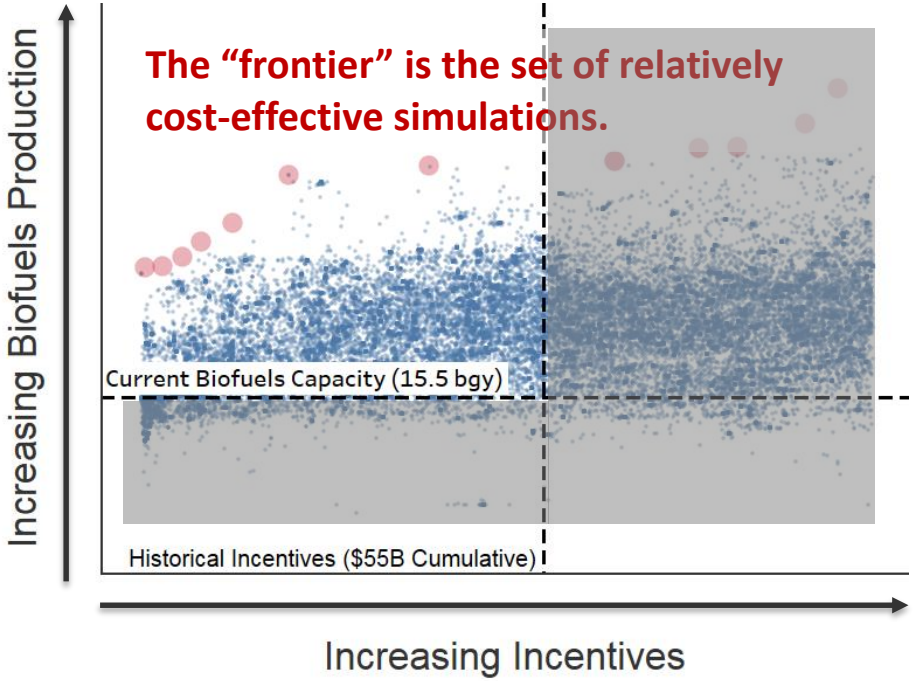
Identifying a Frontier

Conditions for Growth

Relative Cost

Factors that contribute to cost-effectiveness:

- Gasoline price, incentives for capital investment, and agricultural system
- Cellulosic ethanol production in early development
- As the industry matures, cellulosic hydrocarbons production becomes more important

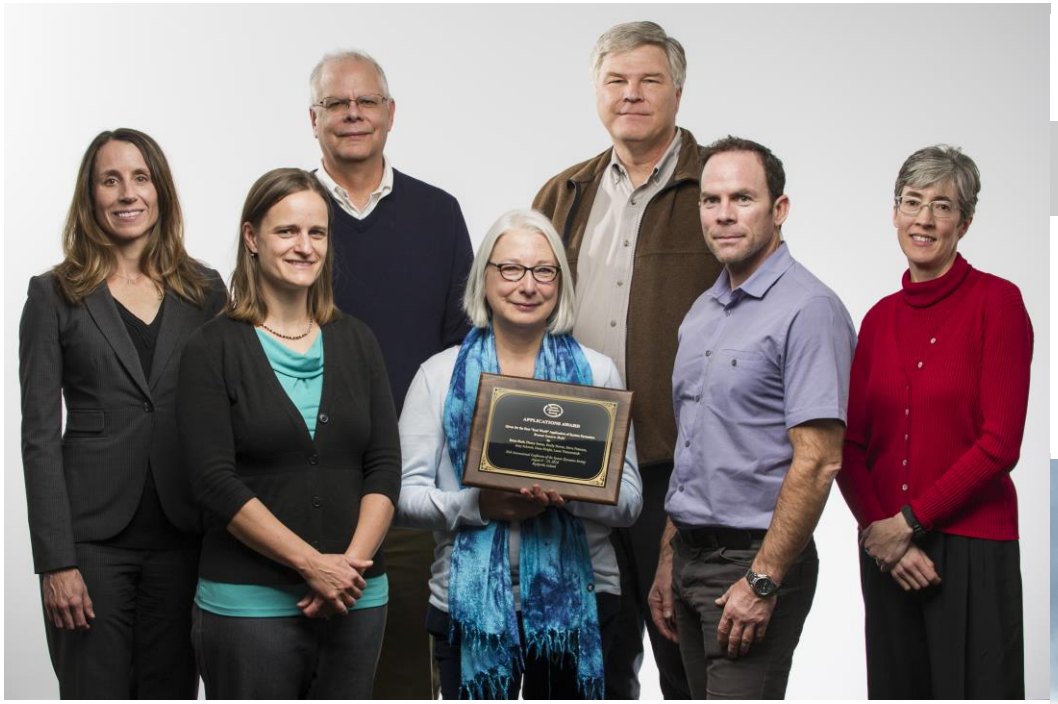


Accomplishments

Milestone/Deliverable History and Status

Period	Milestone/Deliverable	Status
FY17	Q2: Deliver results of external review of BSM in the form of a report or briefing.	Completed on schedule
	Q2: Deliver scenario analysis results on a BETO selected topic, such as BETO strategy analysis or a bioeconomy-related question, in the form of a report or briefing.	Completed on schedule
	Q2: Demonstrate NREL's three-dimensional interactive visualization capabilities, employed with the BSM, to key BETO staff.	Completed on schedule
	Q4: Deliver scenario analysis results on a BETO selected topic such as a bioeconomy-related question or exploration of fuel cuts versus refining to intermediates in the form of a report or briefing.	Completed on schedule
	Q2: Deliver results of external review of BSM in the form of a report or briefing.	Completed on schedule
FY18	Q1: Complete sensitivity analysis of the BSM and present findings to BETO.	Completed on schedule
	Q2: Develop framework that coherently lays out how the BSM can be used to explore questions about the bioeconomy.	Completed on schedule
	Q2: Complete BSM user interface and provide an interactive demonstration to BETO.	Completed on schedule
	Q3: Document updates made to the BSM. This will serve as a living document that will be provided to the public with each public release.	Completed on schedule
	Q4: Complete analysis as defined in Q1 and document in a draft conference paper, technical report, and/or journal article in collaboration with an external stakeholder.	Completed on schedule
FY19	Q1: Select one analysis question to explore for Q4 milestone.	Completed on schedule
	Q2: Provide briefing on at least two modeling options for completing the Q4 milestone	On schedule
	Q3: Document updates made to the BSM. This will serve as a living document that will accompany each public release.	On schedule
	Q4: Complete analysis as defined in Q1 and document in a draft conference paper, technical report, and/or journal article.	On schedule

The BSM Wins International Award!



Picture: NREL, Dennis Schroeder (2019)

System Dynamics Applications Award

Given for the Best “Real World” Application of System Dynamics: Biomass Scenario Model

Summary of Accomplishments (2017-2019)

- **BSM wins System Dynamics Application Award**
  - Presented by the System Dynamics Society as often as every year for the best "real world" application of System Dynamics.
- **Public release of the BSM**
  - Released full model on github (https://github.com/NREL/bsm-public)
  - Produced interactive scenario library browser with direct connection to BSM data infrastructure and access control
  - Developed user interface for model
- **Impactful analyses**
  - Multiple government agencies, NREL, and multiple universities collaboration on aviation biofuels analysis
  - Explored potential impact of generation 1.5 technology on other cellulosic technologies
  - Looked at potential for co-products to aid in biorefinery investment
  - Identified conversion and feedstock coupling impacts on the biofuel industry, with and without shared learning
- **Sensitivity analysis on over 100 model parameters**

Summary of Accomplishments (2017-2019)

- **Model development to meet analysis needs**
  - Incorporated generation 1.5, co-products (conversion technologies) and exports
  - Established dynamic interaction with the Automotive Deployment Options Projection Tool (ADOPT) allowing co-optimization of fuels and engines
  - Created heavy-duty vehicle module
  - Updated techno-economics, feedstock logistics (with INL), and other data
  - Created publicly-available version of the BSM with only publicly available data
  - Integrated shared learning into analysis, using data from multi-lab collaboration
- **Presentations and posters**
  - 2018 Commercial Aviation Alternative Fuels Initiative Biennial General Meeting
  - 2 ASCENT meetings
  - Bioeconomy 2017 (*Domestic Resources for a Vibrant Future)*
  - Public Working Meeting to Discuss Potentially Including Alternative Jet Fuel in the Low Carbon Fuel Standard
- **Publications**
  - Journal articles on sensitivity analysis (2 published, 1 in preparation)
  - Journal articles on supply curves and data process (2 submitted)
  - Book chapter on system aspects of feedstock logistics (1 submitted)
  - Aviation biofuels journal article and report

Support Analysis across Bioenergy Community

Emissions are increasing.

Policy-makers need tools for developing and evaluating policy options.

This project and, in particular, BSM analysis can delineate opportunities in this complex, non-linear environment at every stage in the bioeconomy process:

- Feedstock
- Conversion
- Distribution
- End use.

U.S. carbon emissions increased in 2018, even as coal plants closed

Picture: Dennis Schroeder, NREL (2018)
Analysis: Rhodian Group (2019)*,
Quéré, Corinne Le, Robbie M. Andrew, Pierre Friedlingstein, Stephen Sitch, Judith Hauck, Julia Pongratz, Penelope A. Pickers, et al. "Global Carbon Budget 2018." *Earth System Science Data* 10, no. 4 (December 5, 2018): 2141–94. https://doi.org/10.5194/essd-10-2141-2018.

BSM — and links to other impact-oriented models (JEDI, GREET) — can show benefits of bioeconomy and ensure no unintended consequences for emerging technologies.

Stakeholder Outreach and Engagement

Co-Optima Fuel Pathways Analysis

- Supported assessment of the feasibility, economics, and logistics of adopting Co-Optima by drivers, vehicle makers, fuel retailers, and fuel producers

Alternative Jet Fuel Analysis

- Collaboration with Federal Aviation Administration led to journal article with the Aviation Sustainability Center (ASCENT)
- Analysis supported California Air Resources Board decision-making

University Partners for Model Release and Alternative Jet Analysis

- Washington State University
- Purdue University

Advanced Biomass Logistics Scenario Analysis

- With Idaho National Lab, explored advanced feedstock interactions with biorefinery size, biomass logistics, and timing of industry growth

Bioenergy Technologies Office (BETO) Program Analysis

- BSM used in engagement of federal staff and documentation of planning for BETO, including combined options across feedstock, conversion, and deployment.

Relevance

BSM Helps BETO Attain Goals and Objectives

Goals	BSM Support
BETO	
Enable sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure, can reduce greenhouse gas emissions relative to petroleum-derived fuels, and can displace a share of petroleum-derived fuels to reduce U.S. dependence on foreign oil.	Allows BETO to explore the biomass-to-biofuels supply chain and its evolution by: • **Generating plausible scenarios** for bioenergy market penetration. • Understanding the transition dynamics to a bioeconomy. • Analyzing prospective policies, incentives, investments, R&D impacts, and strategies. • Identifying high-impact drivers, points of leverage, and bottlenecks. • Studying competition for biomass resources and between bioenergy technologies.
Encourage the **creation of a new domestic bioenergy** and bioproduct industry.	
Strategic Analysis	
Provide context and justification for decisions at all levels by establishing the basis of quantitative metrics, tracking progress toward goals, and informing portfolio planning and management.	Demonstrate the potential **impacts of different BETO strategic directions** and synergies across the supply chain.
Convey the results of analytical activities to a wide audience, including DOE management, Congress, the White House, industry, other researchers, other agencies, and the general public.	**Facilitation and Collaboration** • Has informed all levels of the U.S. Government • Facilitation of stakeholders groups • Broad dissemination of analysis to the public (see below)
Ensure high-quality, consistent, **reproducible**, peer-reviewed analyses.	High Impact and Reproducible Analysis: • **Data infrastructure for study reproducibility** • 10+ years of peer-reviewed publications and model technical reviews. • **30+ analysis reports**, many of which have been published. • Direct collaboration has enhanced BETO understanding of the bioeconomy.
Develop and maintain analytical tools, models, methods, and datasets to **advance the understanding of bioenergy** and its related impacts.	

Support BETO with Cross-cutting Analysis

BETO Feedstock Supply & Logistics

"develop technologies to provide a sustainable, secure, reliable, and affordable biomass feedstock supply"

- Analysis of transition to advanced logistics

BETO Conversion

"develop commercially viable technologies for converting biomass feedstocks"

- Analysis of effects of industrial learning
- Study of generation 1.5 technology and co-products

BETO Advanced Development & Optimization

"develop commercially viable biomass utilization technologies that build and validate integrated biorefineries; develop supporting infrastructure to enable a biomass-to-bioenergy value chain "

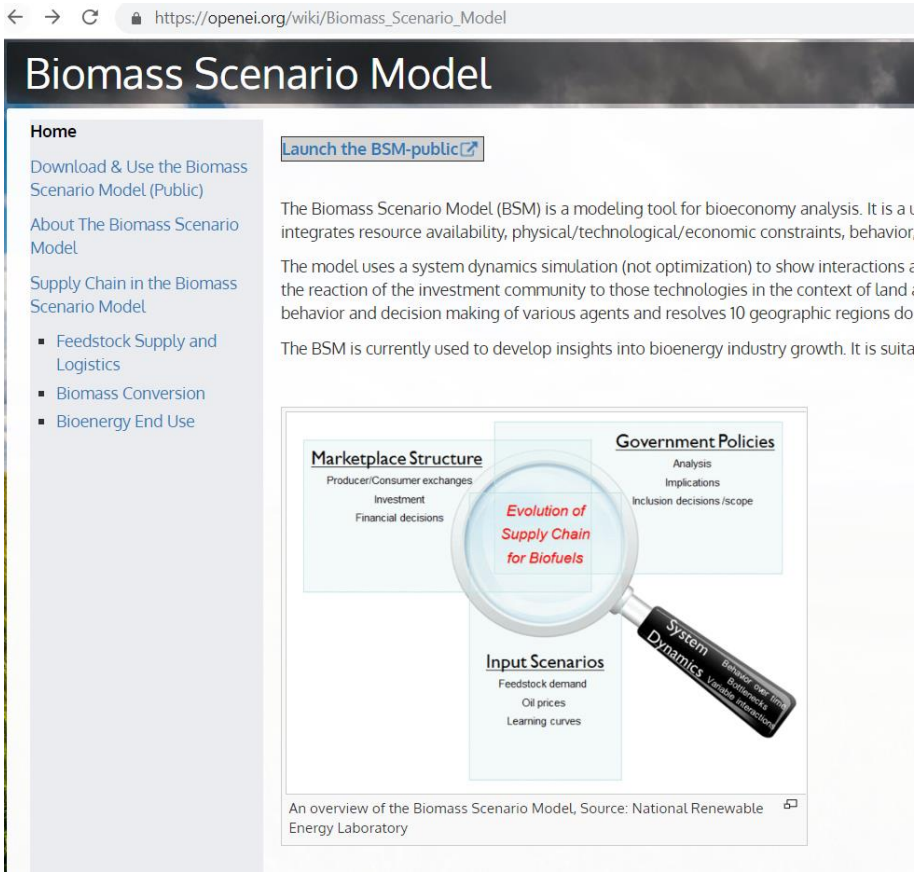
- Analysis of impacts of a transition to high octane fuel
- Studies of airport infrastructure to enable biofuel integration

Source: BETO MYPP

Overview

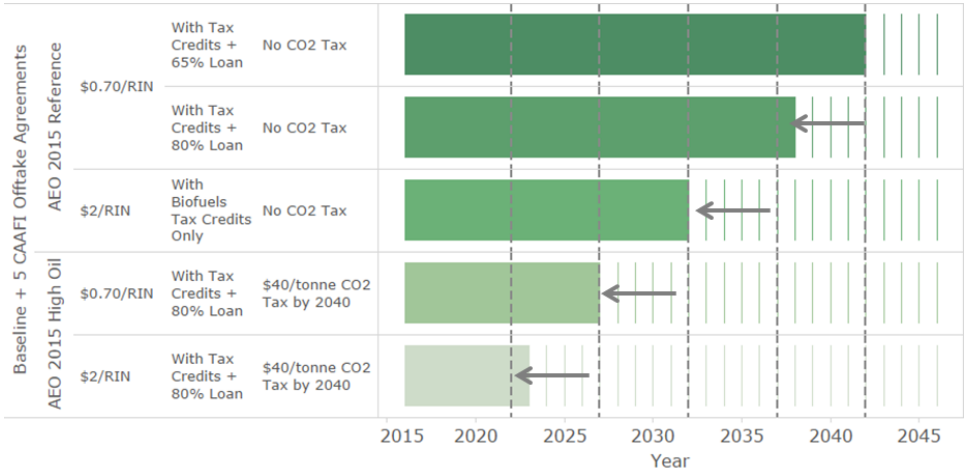
Inform BETO, stakeholders, and policy-makers of the implications of policy choices and market developments to **enable prioritization and evaluation** of various actions and enable researchers to design and analyze the impacts of additional biomass-to-biofuels scenarios.

1. Support Public Release of the BSM



An overview of the Biomass Scenario Model, Source: National Renewable Energy Laboratory

2. Run analyses using the BSM when relevant



3. Perform analyses using new tools and data when relevant

Future Work

Aviation Biofuel Infrastructure Scenarios

Support airports

- What synergies exist in integrating biofuels with other future modernization strategies?

Support other stakeholders, including BETO

- Which potential locations for alternative jet fuel production may benefit from proximity to interested airports or easy integration of biofuels into those airports?

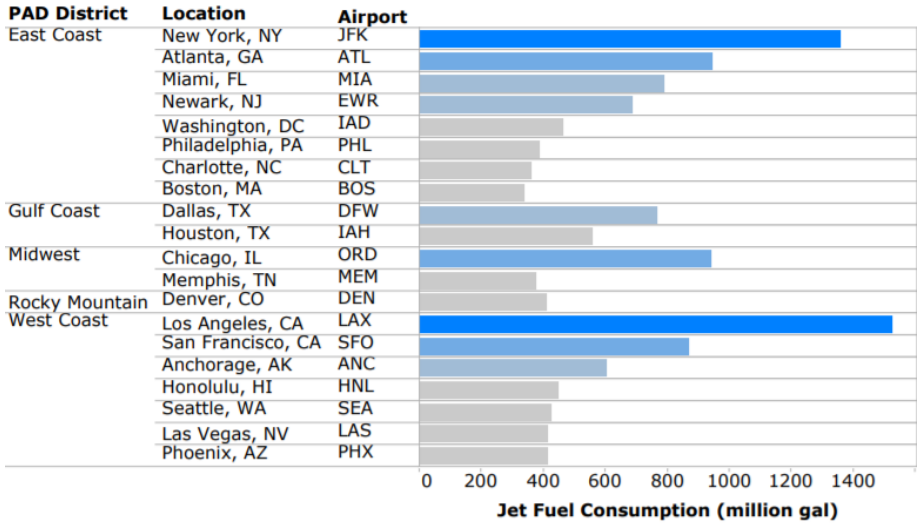


Figure 9. Jet fuel consumption (Jet A) dispensed by airport in 2012 for selected airports

Source: Airlines for America Unpublished

Audience: BETO, airlines, airports, policy-makers, biofuel producers

- Clear documentation on how biofuels could be integrated into airports.
- Investigation of specific major airports for biofuel integration potential to aid in biorefinery proposal selection by BETO.
- Integrated solutions for airport modernization, keeping biofuels in the conversation.
- A broad audience will gain high-level awareness of the results, and a targeted audience will use them to determine their strategy for including biofuels in airport planning.

Future Work

Systems Analysis Enhancing Integrated Assessment Modeling

Integrated Assessment Models ([IAMs]) are often used to model policy impacts on energy systems.

Breadth of coverage/integrated perspective can be very helpful. However,

bioenergy is typically implemented at very high level of granularity

Long time-steps between calculations and typical assumption of equilibrium creates potential to “miss” potential nonlinear industry dynamics.

Potential questions that we could answer:

- To what degree are the two approaches compatible with one another?
- How might a synthesis of IAM and a dynamic model lead to different results relative to the IAM in isolation? To the dynamic model in isolation?
- What are the implications of differences in results for system responsiveness to outside factors (e.g., initiatives, weather, oil prices)?

Future Work

Local Dynamics of Bioeconomy Buildout

Many industries have begun their development at a local level, either due to supply (feedstock) or demand (end use).

We do not have a model that explores bioenergy development at a local scale, exploring feedstocks or end uses of interest to BETO.

Development and analysis of a model could help to shed light on both local and broader-scale issues.

- How quickly, and under what biofuel development circumstances might producers in the Northern Plains shift agricultural practices toward production of herbaceous feedstocks such as switchgrass?
- To what extent could a high-population, resource-rich region play a role in jump-starting aviation biofuel?
- To what extent might biofuel development catalyze rural revitalization?

Audience: BETO, academia, policy-makers

- Ability to look at bioenergy-related questions from both a top-down (BSM) and bottom-up (this effort) perspective.
- Potential mechanism for exploring different geographic areas of interest for BETO-defined supply or demand targets.
- A broad audience will gain high-level awareness of the results, and a targeted audience will use them to determine their strategy for local planning.

Summary

Challenge/Objective

Inform BETO, stakeholders, and policy-makers of the implications of policy choices and market developments to enable prioritization and evaluation of various actions and enable researchers to design and analyze the impacts of additional biomass-to-biofuels scenarios.

Approach

- System dynamics modeling methodology
- State-of-the-art approach to reproducibility and quality
- Collaboration with external stakeholders

Accomplishments

- Multiple external collaborations, including interagency study on aviation biofuel
- Sensitivity analysis characterizes cost-effective biofuels industry growth
- Many journal articles, presentations, posters, technical reports
- BSM is publicly released and wins international award

Relevance

- Policy-makers need tools for developing and evaluating policy options.
- BSM — and links to other models — can highlight potential unintended consequences.

Future Work

- Impactful analyses (BSM, airport infrastructure, local dynamics, and systems modeling and IAMs)
- Updating/maintaining BSM.

Multi-disciplinary Team

Brian Bush
has 20+ years of experience with infrastructure, energy, and transportation modeling, simulation, and analysis.

Emily Newes
has 10+ years of experience in economics, energy data, modeling, and analysis.

Danny Inman
a PhD soil scientist, has 10+ years of experience in bioenergy feedstocks, modeling, and advanced statistics.

Mary Biddy
a PhD chemical engineer, has 10+ years of experience in advanced conversion technologies.

Laura Vimmerstedt
has 10+ years of experience managing major transportation and energy analysis projects at NREL.

Steve Peterson
is the principal BSM model architect and teaches System Dynamics at Dartmouth College.

The multi-disciplinary team is positioned to support bioeconomy model development and analysis.

Thank You

www.nrel.gov

Emily.Newes@nrel.gov

This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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Response to Reviewers' Comments 2017

"More emphasis on informing stakeholders of the findings of the BSM then of taking input from stakeholders for the BSM. While the BSM is characterized as having been "validated", my sense of the downside of SDMs is that they may yield implausible out-of-sample predictions if parameters are not chosen carefully."

- We have addressed different aspects of model validation, including historical validation, stakeholder review of quantities and logic, and stakeholder review of interpretations. As a specific example of a historical validation, we were able to replicate the growth of the starch ethanol industry using current model structure. We have validated the model through a decade-long engagement with stakeholders and subject-matter experts, who have reviewed each major module and BSM revision.

"Ensure the scenario modeling provides transparent information on the economics, particularly the costs and economic benefits to the government and private actors. Include consideration of environmental sustainability metrics as outputs of the modeling, as well as sensitivity analysis to key parameters, scenarios and assumptions."

- We have combined with ANL's Bioeconomy AGE model and NREL's JEDI model to provide sustainability metrics for BSM outputs. We have a draft article that will explore more economic metrics, such as policy costs, and we have 2 published articles on a sensitivity analysis on the BSM and a related learning model.

"It will be important to get the model…into the hands of policy makers and other decision makers. Making the model accessible to the public will be a good start. Due to the complexity of the model, will it require someone with a specific skill set or certain level of expertise to use the model? "

- We have a browser of model results where the user can filter on specific input criteria.
- We developed a user interface for the BSM where the user can change key model parameters and explore the related output, offering the full model capability without the complexity.
- For the user that would like to change model logic, we (1) developed an interactive wiki with extensive model documentation, (2) engaged with an identified initial alpha-testing user group to further refine documentation, and (3) hosted graduate students at NREL to directly train them on using the model.

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Lewis, K., E. Newes, S. Peterson, M. Pearlson, E. Lawless, K. Brandt, D. Camenzind, et al. "US Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons,." *Biofuels, Bioproducts and Biorefining* (2018). https://doi.org/10.1002/bbb.1951.

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Lewis, K., E. Newes, S. Peterson, M. Pearlson, E. Lawless, M. Wolcott, K. Brandt, and D. Camezind. "ASCENT 1 Scenario Analyses Using the Freight and Fuel Transportation Optimization Tool (FTOT) and Biomass Scenario Model (BSM)." Arlington, VA, 2017.

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