NREL
Transforming ENERGY

Bioeconomy Scenario Analysis

IETS-IEA Workshop Series
Future Scenarios and Strategic Decision-Making for Industry Transformation: Powered by Systems Engineering

May 6, 2021

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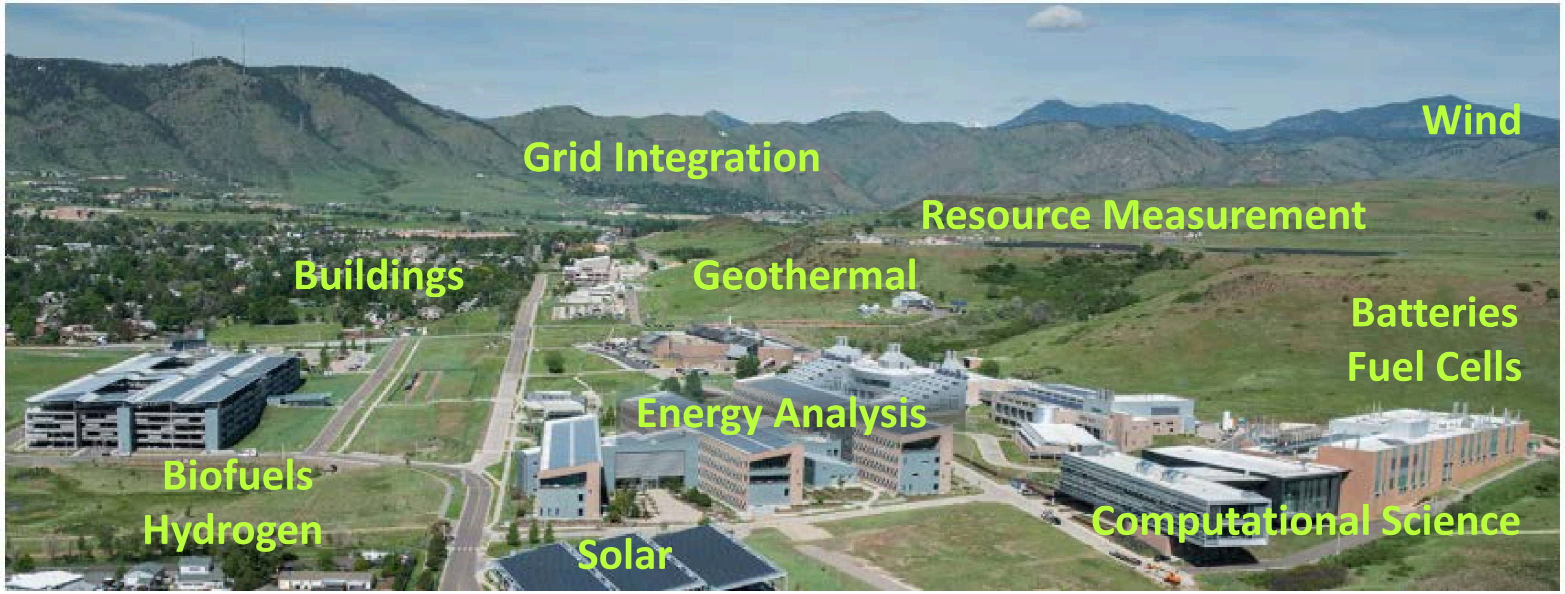
Mission: NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

Example Technology Areas:



- 2050 employees, plus 400 postdoctoral researchers, interns, visiting professionals
- 327-acre campus in Golden, Colorado & 305-acre National Wind Technology Center 13 miles north
- 61 R&D 100 awards. More than 1000 scientific and technical materials published annually

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Bioeconomy Scenario Analysis Project

Support design of bioeconomy strategies by:

- Quantifying metrics for various potential goals (energy, economic, and environmental)
- Facilitating stakeholders in advancing sustainable, nationwide production of biofuels.

Encourage the creation of a bioenergy industry by enabling:

- Industry to understand industry growth potential under different technology and investment conditions, better targeting their development efforts
- Policymakers and federal offices to explore scenarios for economical, nationwide biofuels production
- Universities and other interested stakeholders interested in novel approaches to the bioenergy system.

Approach

We use a system dynamics approach (e.g., Biomass Scenario Model) along with peer-reviewed data to model the bioeconomy, representing system-level feedbacks in the integrated supply chain.

Bioenergy Will Play a Role in Decarbonizing the Economy

GHG emissions are increasing.

Bioeconomy can decrease emissions, especially in aviation and marine, but markets are likely to be driven by policy.

Economies are complex.

Policymakers need tools for developing and evaluating policy options.

Our analysis approach delineates opportunities in this complex, nonlinear environment at every stage in the bioeconomy process.

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

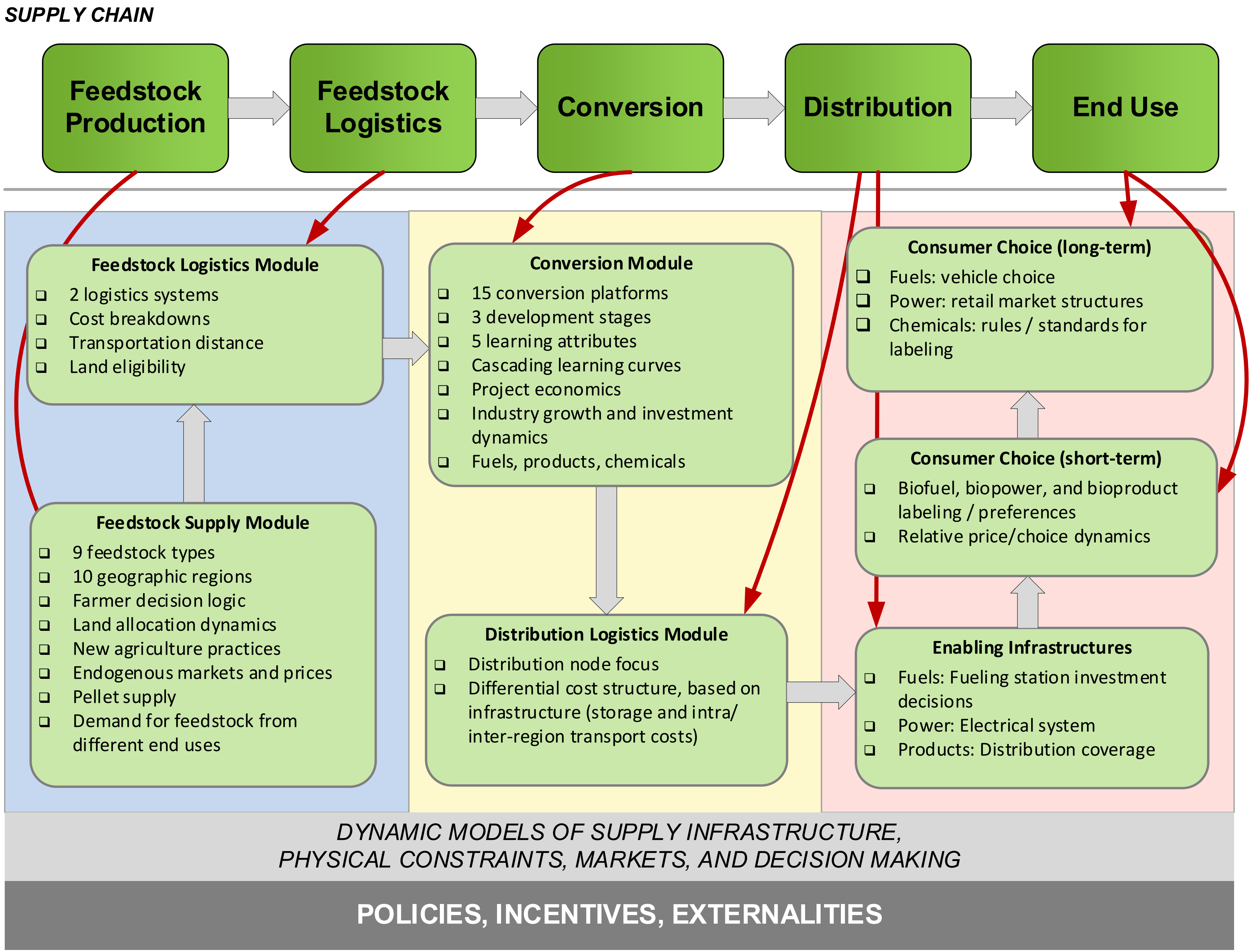
Picture: Dennis Schroeder, NREL (2018)
Analysis: Rhodian Group (2019)*
Quéré, Corinne Le, Robbie M. Andrew, Pierre Friedlingstein, Stephen Sitch, Judith Hauck, Julia Pongratz, Penelope A. Pickers, et al. "Global Carbon Budget 2018." *Earth System Science Data* 10, no. 4 (December 5, 2018): 2141–94. https://doi.org/10.5194/essd-10-2141-2018.

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

Approach

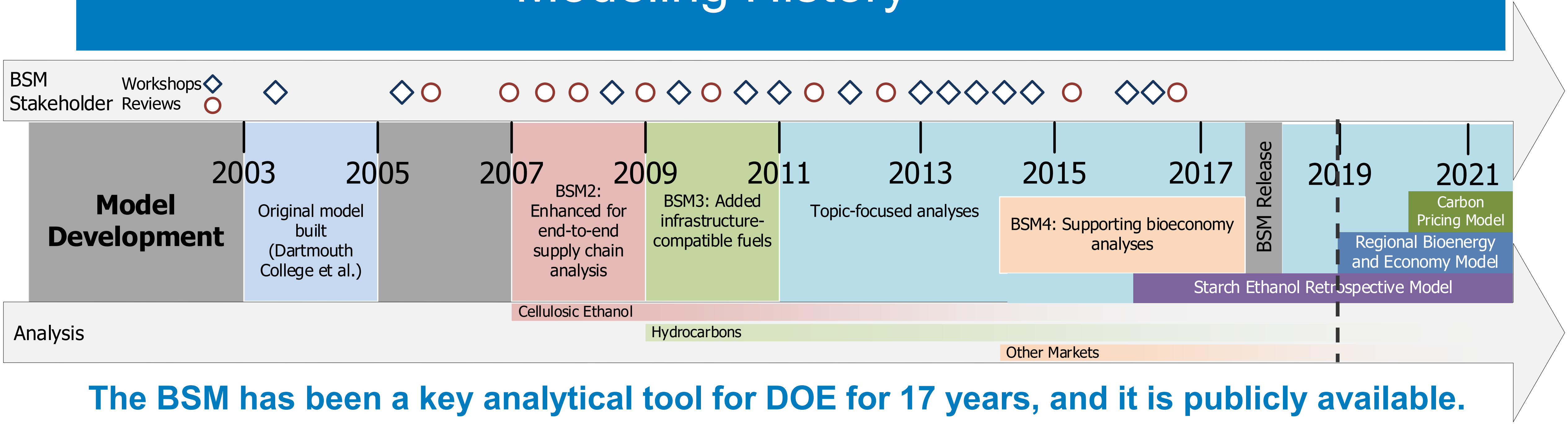
BSM Models the U.S. Bioeconomy

- Supply chain dynamics
- Feedbacks among systems of systems
- Challenge and opportunity identification



Source: MYPP 2016

Modeling History



The BSM has been a key analytical tool for DOE for 17 years, and it is publicly available.

The BSM is:

- Peer reviewed
- Evolving as needs change
- Validated
- State-of-the-art
- Award-winning.

Modeling Methodology Underpinnings

- Use modeling techniques that are appropriate and established
- Carefully consider level of detail
- Solve coupled ordinary differential equations
- Perform analyses using new tools and data when relevant.

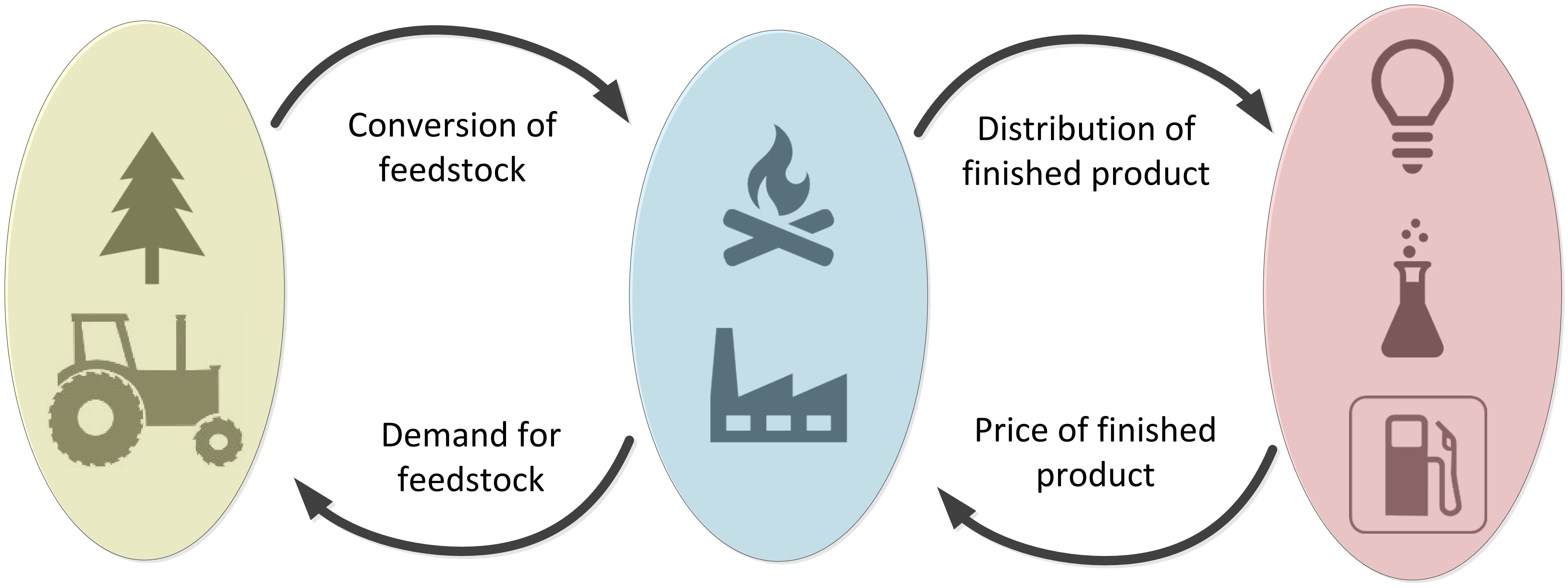
Additional Information

Publicly available BSM and model documentation (https://openei.org/wiki/Biomass_Scenario_Model)

BSM publications (https://www.zotero.org/groups/209264/bsm_publications/library.)

System relationships drive progress across the bioeconomy.

The BSM enables 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

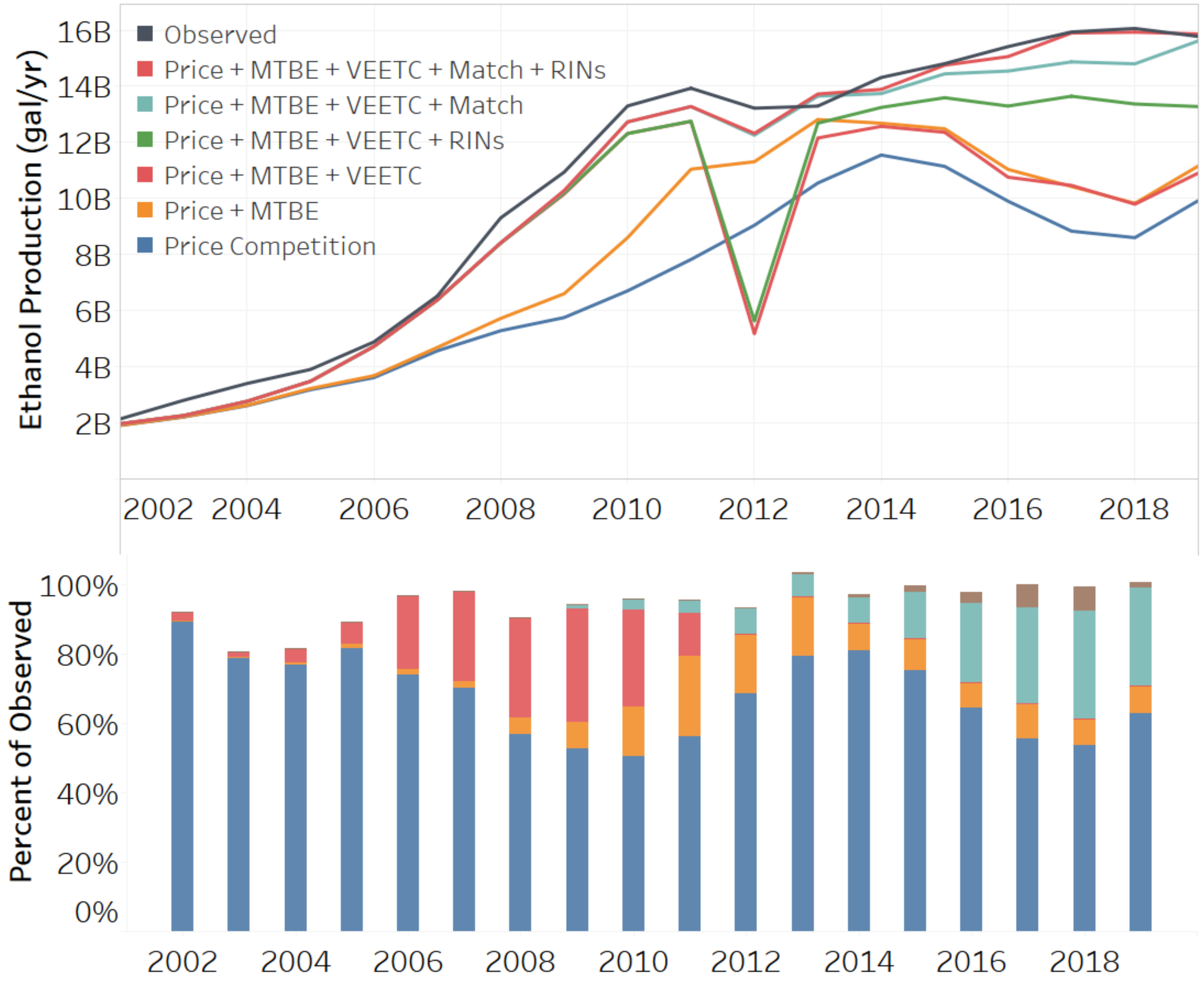
Select BSM Analysis Results

Disclaimer

- **Sources and limitations of information/data used in analysis:**
  - The analysis is based on projections, estimates or assumptions made on a best-effort basis, based upon expectations of current and future conditions at the time they were developed.
  - The analysis was prepared with information available at the time the analysis was conducted. Analysis results could be different if new information becomes available and is incorporated.
- **Limitations on what analysis results should be used for:**
  - This analysis was conducted to meet an immediate need and was based on the best information available within timing constraints.
  - This analysis is a starting point for additional research and consideration of investment or policy options. Other factors that can inform decision-making are not considered here.
  - The analysis results are not intended to be the sole basis of investment, policy, or regulatory decisions.
- **Analysis based on application of specific NREL tools:** This analysis was conducted using the NREL Biomass Scenario Model (BSM - https://www.nrel.gov/analysis/bsm/). BSM is a system dynamics model of the bioenergy supply chain that focuses on how the bioenergy industry could develop over time, given feedbacks in the system and scenario assumptions.

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 herein do not necessarily represent the views of the DOE or the U.S. Government.

BSM-retro Model Used in U.S. EPA Report to Congress



Starch Ethanol Retrospective Model

- Provides original, dynamic policy analysis
- Informs EPA's Third Triennial Report to Congress
- Ethanol price competitiveness with gasoline may have been responsible for at least 50% of ethanol production
- Effect of volumetric ethanol excise tax credit (VEETC) expiration and drought could have been more impactful without match blending.

Preliminary graphic from related pending journal article with EPA

Sustainable Aviation Fuel Policy Analysis Overview

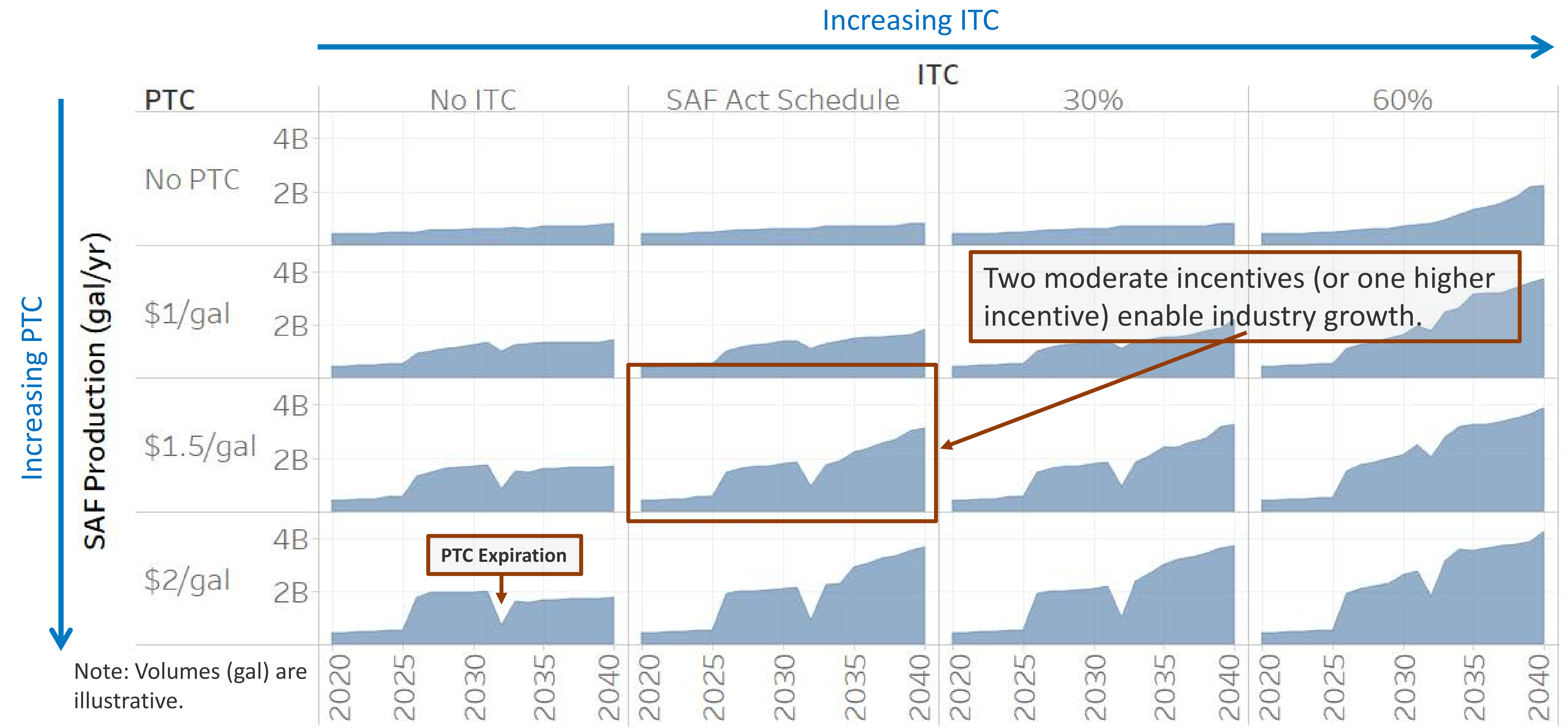
Newes, Emily, Laura Vimmerstedt, Zia Haq, and Alicia Lindauer. “PTC and ITC for Aviation Fuel: Analysis Using the Biomass Scenario Model.” 2021. https://www.nrel.gov/docs/fy21osti/79356.pdf.

- PTC and ITC — individually or in combination — enable industry growth, which leads to increasing production levels even after policy expiration.
- Because FOG (fats, oils, and greases) supply is limited, cellulosic feedstock supply grows to meet industry demand.
- Production levels dip after PTC expiration then may rebound to a lower level, compared to an unlimited PTC. The dip is deeper with higher PTC values (30-60% dip).
- At higher PTC levels and some ITC, production levels reach 20% of 2019 jet fuel consumption by 2040.*
- Modest subsidy levels are more cost-effective (more cumulative, incremental gal per cumulative $ in 2050), but result in 2040 SAF production of less than 10% of 2019 jet fuel consumption.*

*Because the study scope includes only commercial technologies, these results do not estimate the potential for technology innovation to reach higher production levels.

10-Year Policy Expiration

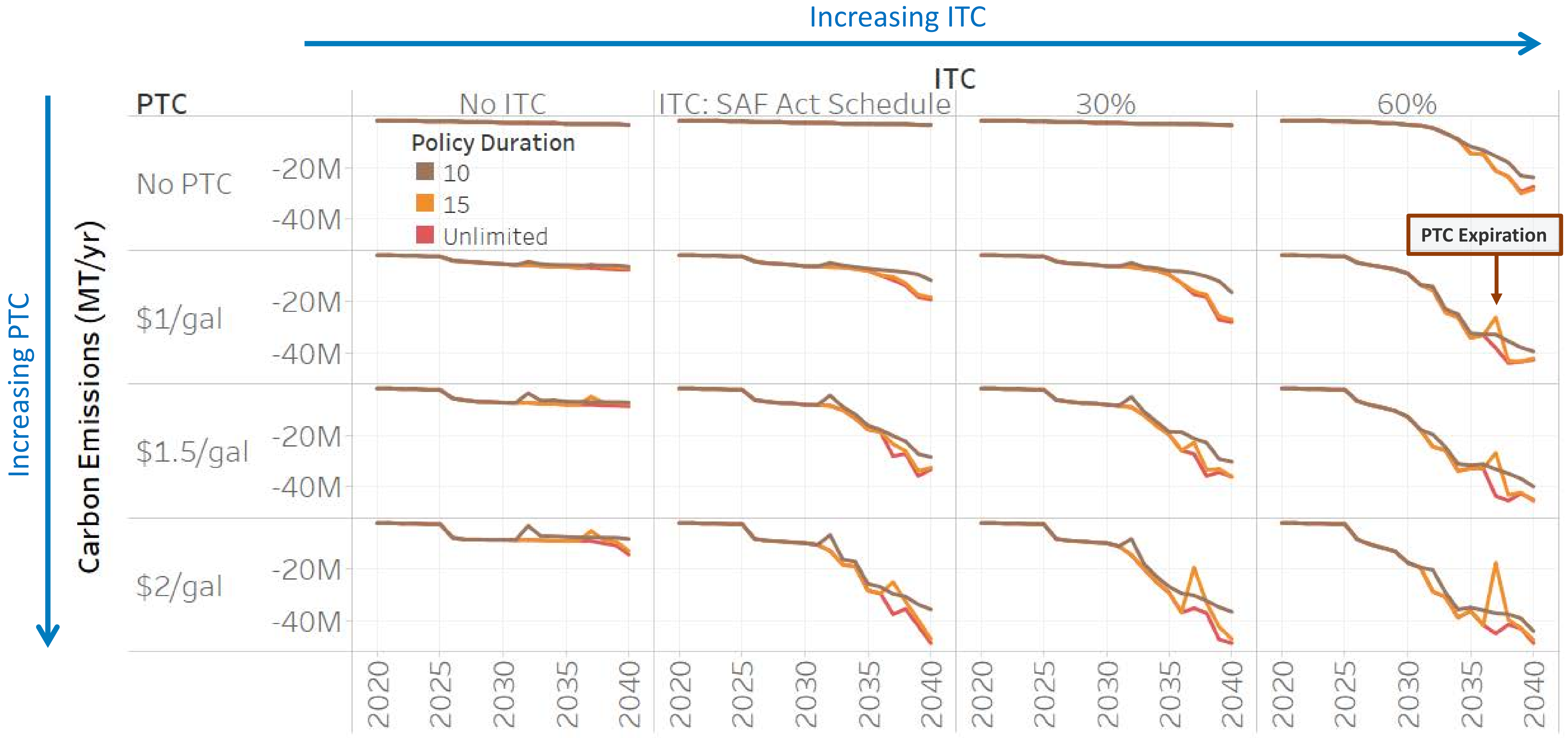
Higher ITC Needed for Greater Production Levels with No PTC



Note: Volumes (gal) are illustrative.

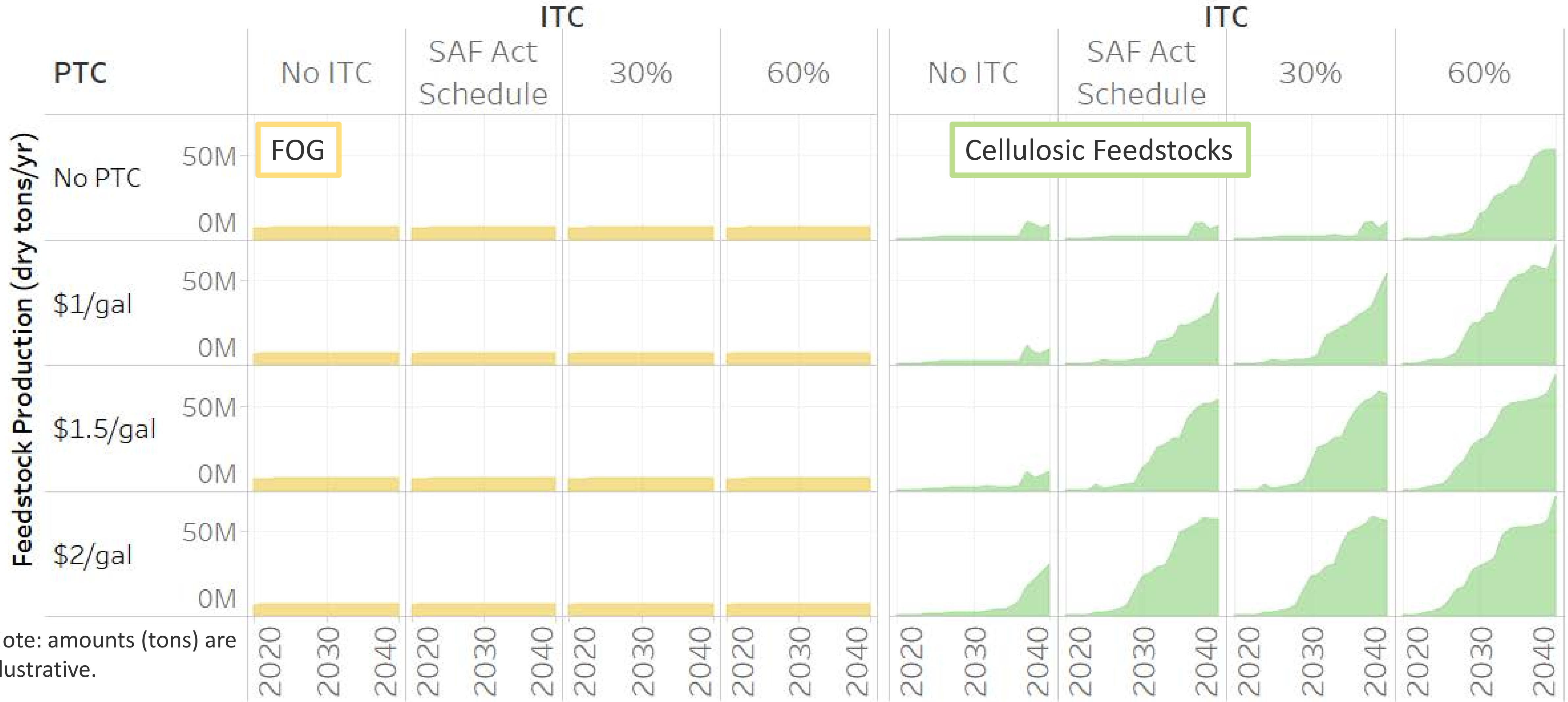
Duration of ITC and PTC policy = 10 years (SAF ACT schedule unchanged); no carbon tax

Annual CO_2 emissions decrease by up to 48 million MT by 2040.



No carbon tax

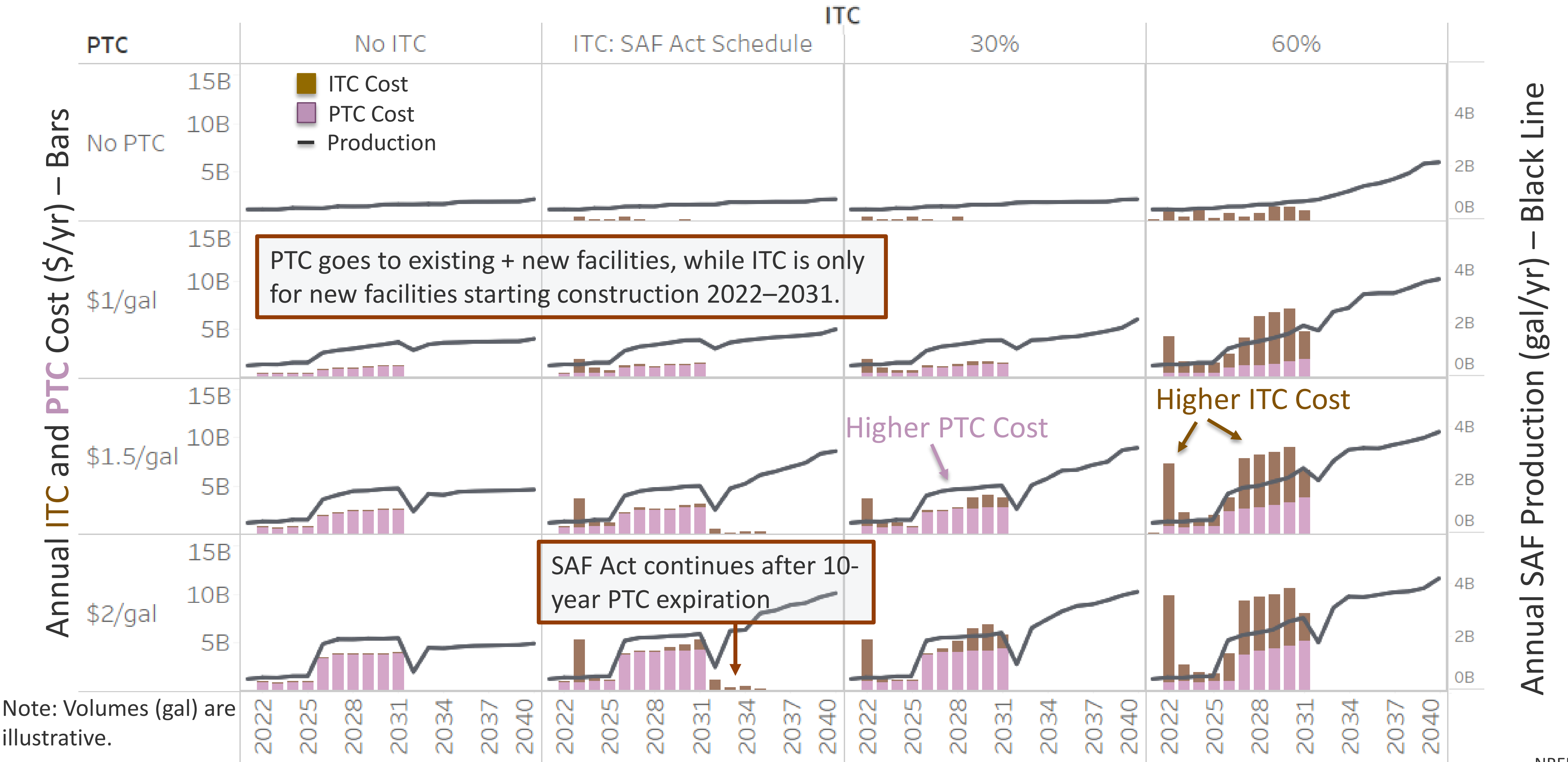
FOG supply is limited; cellulosic supply grows to meet industry demand.



Note: amounts (tons) are illustrative.

Duration of policy = 10 years (SAF ACT schedule unchanged); no carbon tax

Annual cost for PTC or ITC depends on subsidy level of each policy (**10 years**).



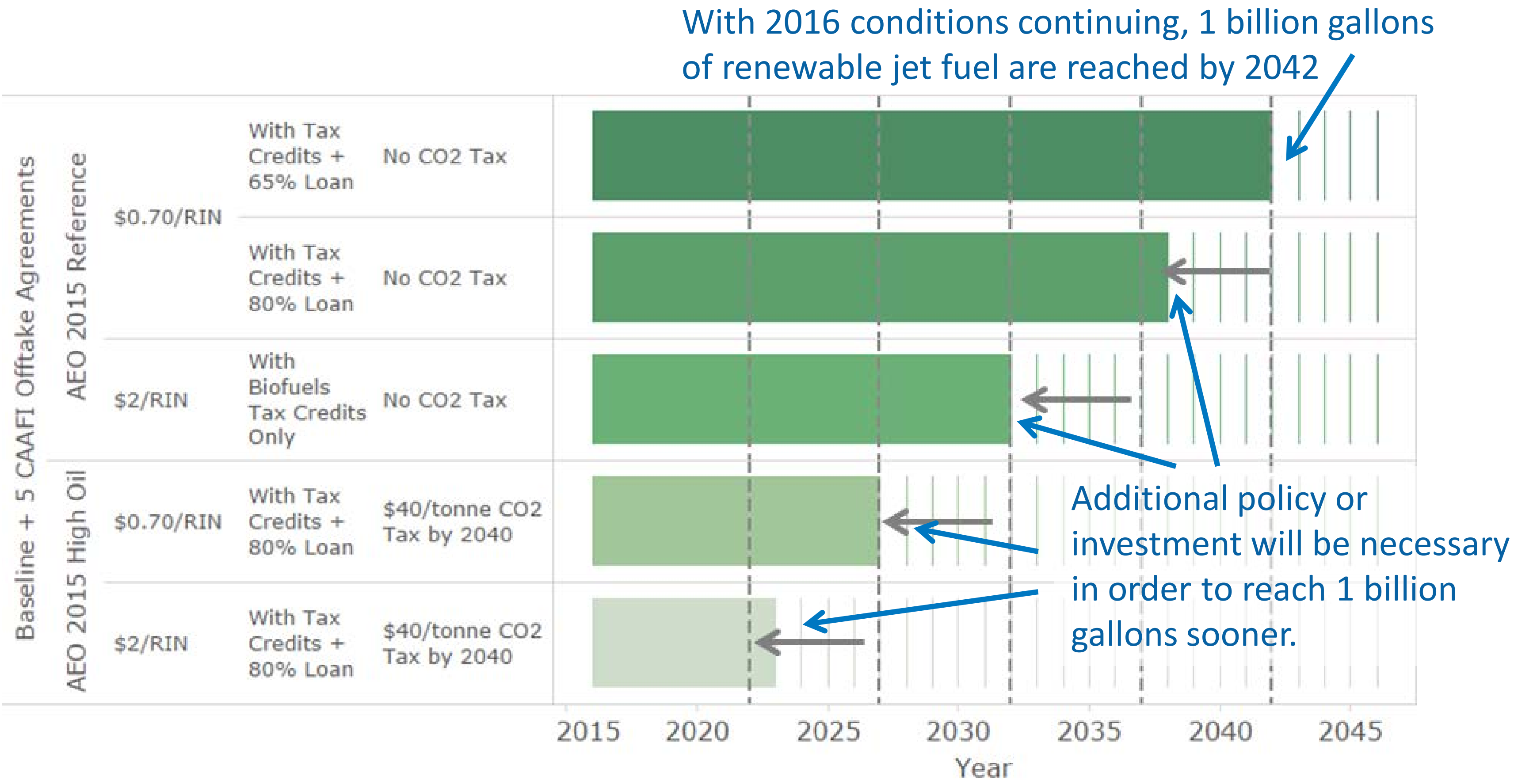
Note: Volumes (gal) are illustrative.

Duration of ITC and PTC policy = 10 years (SAF Act schedule unchanged); no carbon tax

Interagency Study on Sustainable Aviation Fuel 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?



Lewis, Kristin C., Emily K. Newes, Steven O. Peterson, Matthew N. Pearlson, Emily A. Lawless, Kristin Brandt, Dane 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* 0, no. 0 (December 7, 2018). https://doi.org/10.1002/bbb.1951.

Sensitivity Analysis Characterizes Cost-effective Biofuel 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.**

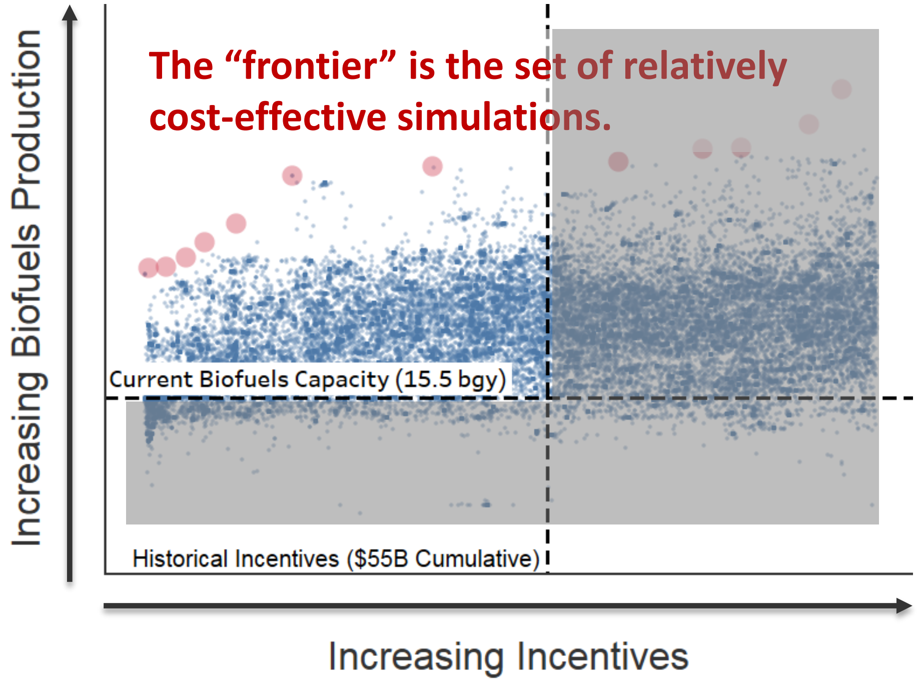
Identifying a Frontier

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



Visualizing and Communicating Impact of U.S. DOE Strategy

Additional investment in deployment of integrated biorefineries (IBRs) helps the biofuels industry reach a tipping point for substantial growth.

The precise quantity and timing of production is sensitive to a variety of assumptions, including

- Techno-economic analysis (TEA)
- Timing of plant starts
- Learning
- External conditions.

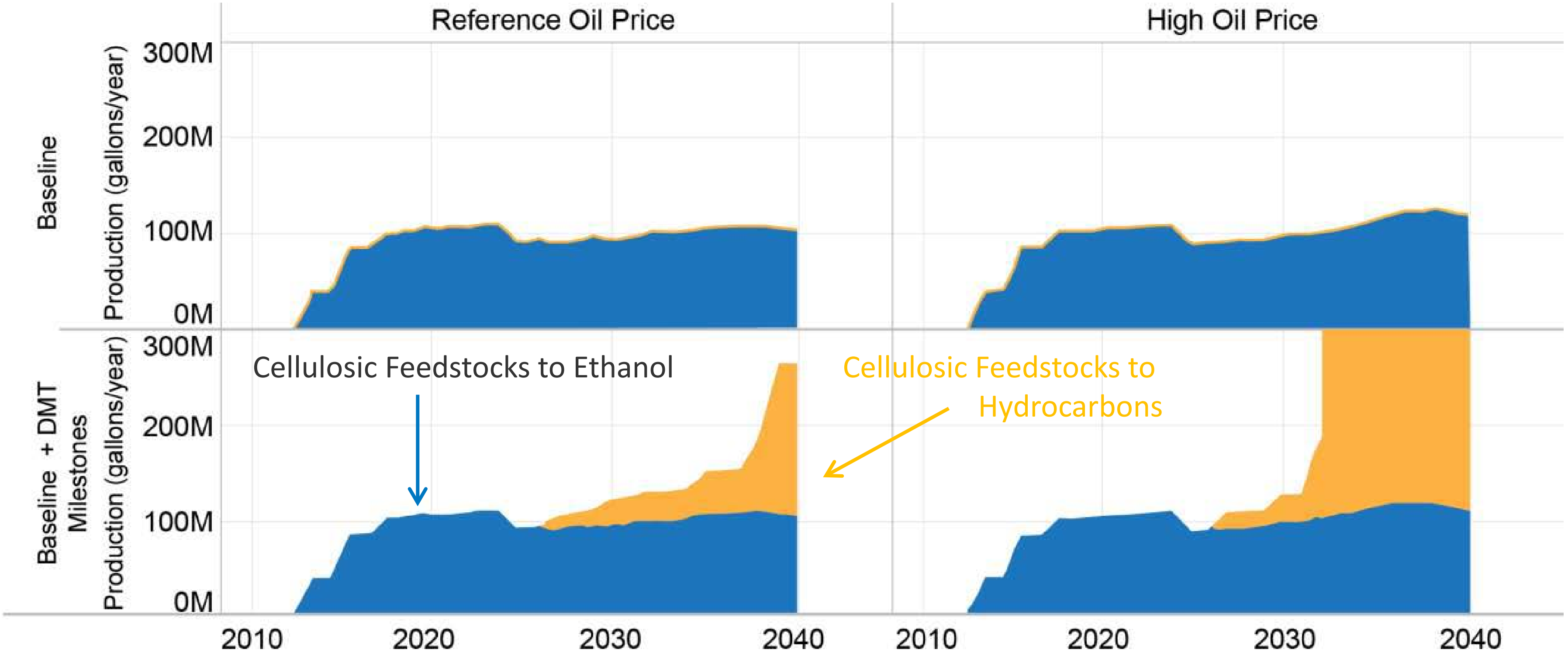


Figure from Bioenergy Technologies Office's Multi-Year Program Plan (MYPP).

Vimmerstedt, Laura J., E. Warner, and D. Stright. "Effects of Deployment Investment on the Growth of the Biofuels Industry: 2016 Update." Technical Report. Golden, Colorado: National Renewable Energy Laboratory, 2016. http://www.nrel.gov/docs/fy16osti/65903.pdf.

Thank you!

www.nrel.gov

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NATIONAL RENEWABLE ENERGY LABORATORY

Bioeconomy Scenario Analysis Team

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PhD chemical engineer with 10+ years of experience in advanced conversion technologies

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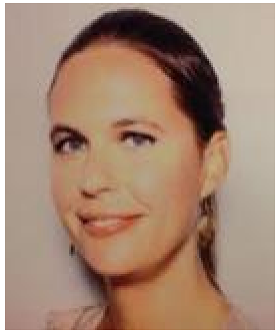
5+ years of experience in economics, energy data, modeling, and analysis

Jay Huggins
16+ years of experience in software and systems development

Danny Inman
PhD soil scientist with 15+ years of experience in bioenergy feedstocks, modeling, and advanced statistics



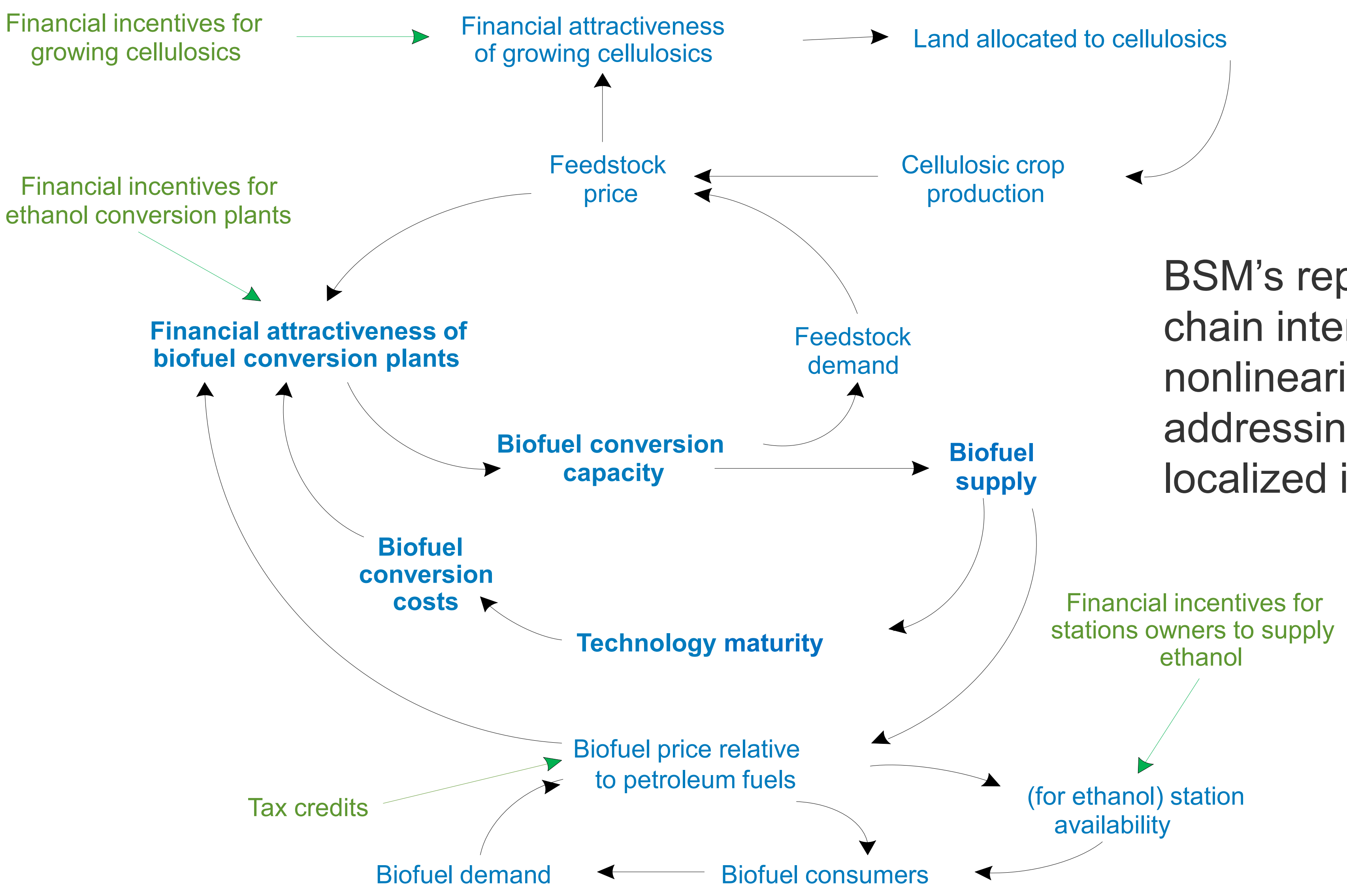
Kristi Moriarty
Expert in the area of infrastructure and biofuel testing and compatibility requirements

Swaroop Atnoorkar
Trained in energy systems engineering, with a focus on transportations systems and environmental analysis

Laura Vimmerstedt
25+ years of experience managing major transportation and energy analysis projects at NREL

Steve Peterson
Principal BSM model architect; teaches System Dynamics at Dartmouth College

System Insights Show Potential Barriers and Leverage Points



BSM's representation of supply chain interactions captures nonlinearities and evolving markets, addressing systemic implications of localized initiatives and decisions.

Modeling and Analysis to Explore Pressing Questions

Reliance system-dynamics modeling framework

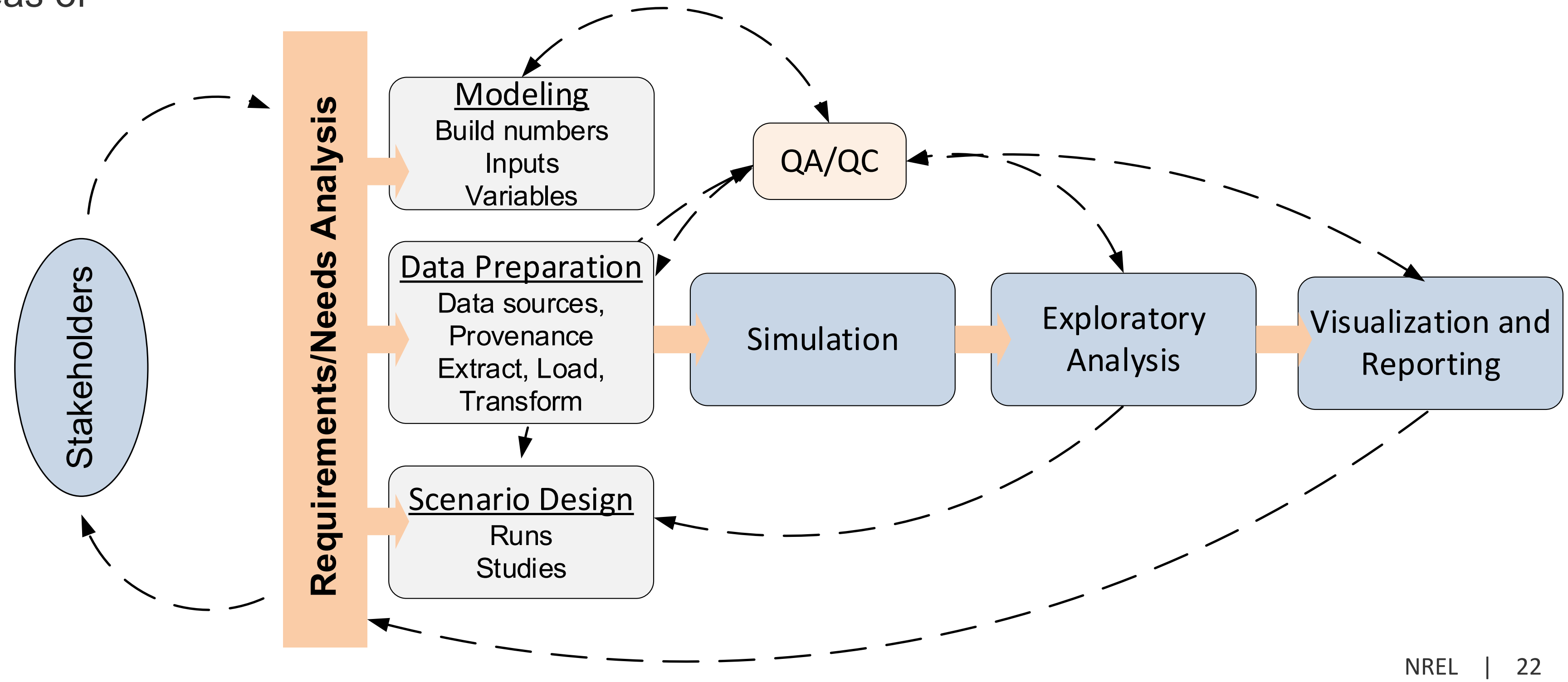
- Appropriate and well-established
- Robust methodology for analyzing behavior of complex real-world feedback systems over time

Frequent communication and reporting to BETO

- Team members with specialized areas of expertise
- Collaboration with external subject matter experts
- Adaptive adjustment of analysis plans
- Flexible, modular modeling architecture
- Exploration of collaborative results with stakeholders using interactive web browser (bsm-viewer.nrel.gov)

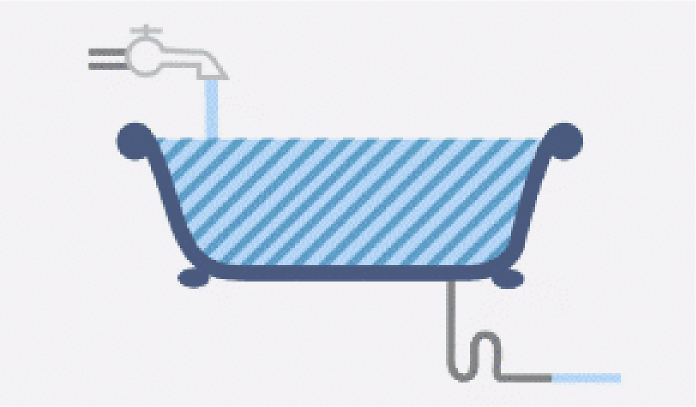
State-of-the-art approach to reproducibility and quality

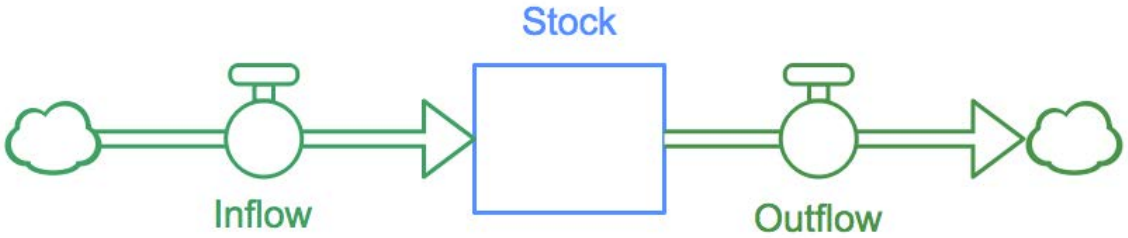
- Defensible and traceable inputs, with metadata
- Full archives of analysis results
- Configuration management and issue tracking systems



System Dynamics: Complex Nonlinear Systems

- System dynamics (SD) modeling is grounded in the theory of nonlinear dynamics and feedback control systems. SD uses coupled ordinary differential equations to represent complex (nonlinear) systems.
- SD was originally developed in 1950s at MIT. It originally focused on supply chain dynamics and has subsequently been used by wide range of organizations (e.g., GE, GM, DOE, and DOD) in a broad set of application areas.
- Key concepts include accumulation, flow, feedback, and nonlinearity.
- Visual languages create system of finite difference equations that are solved using standard numerical methods
- Top-down approaches are used to develop models focused on system performance over time.



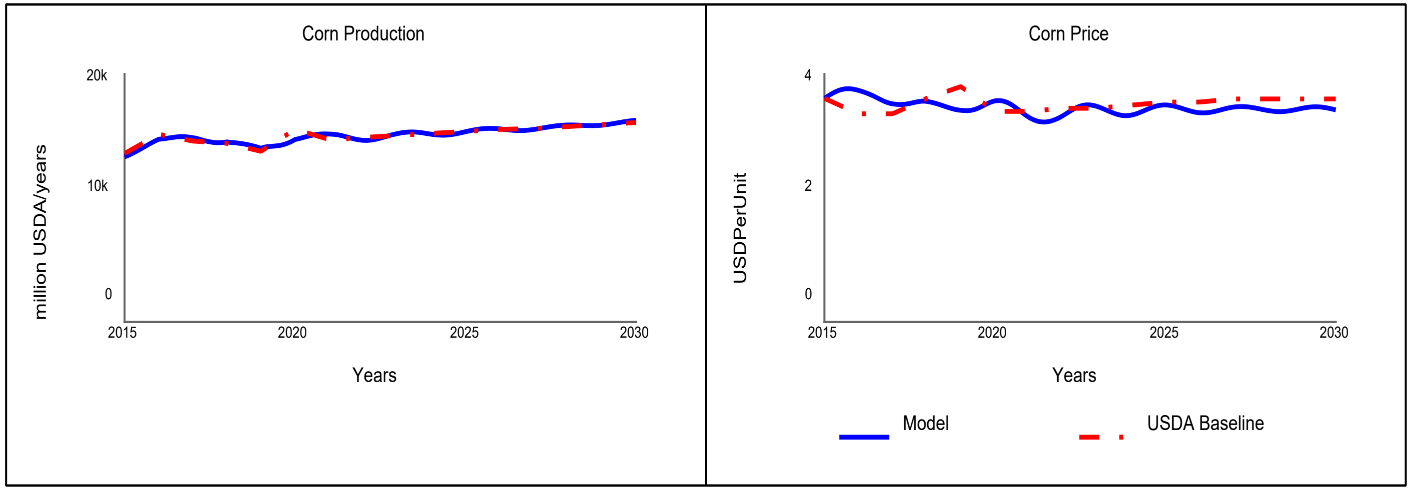


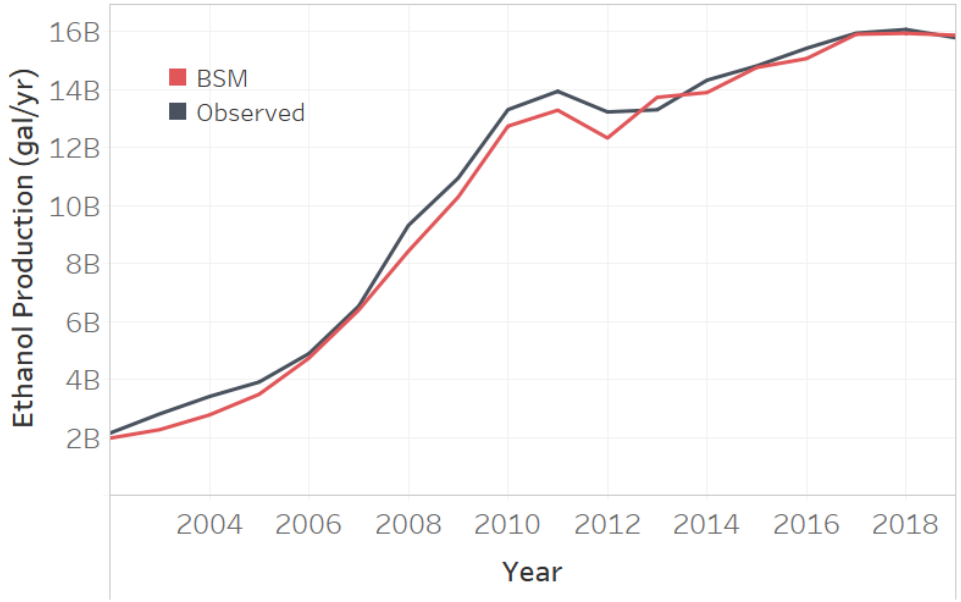
$$Stock(t) = stock(t_0) + \int_0^t [inflow(s) - outflow(s)]dt$$

Model Calibration and Validation

Calibration Example: BSM Simulated Corn Production vs. USDA Long-Term Forecast (2020)

- Annual calibration: adjust assumptions to represent an industry
- Builds confidence in modeling assumptions
- For example, we calibrate crop production in the BSM against the USDA long-term forecast each year.



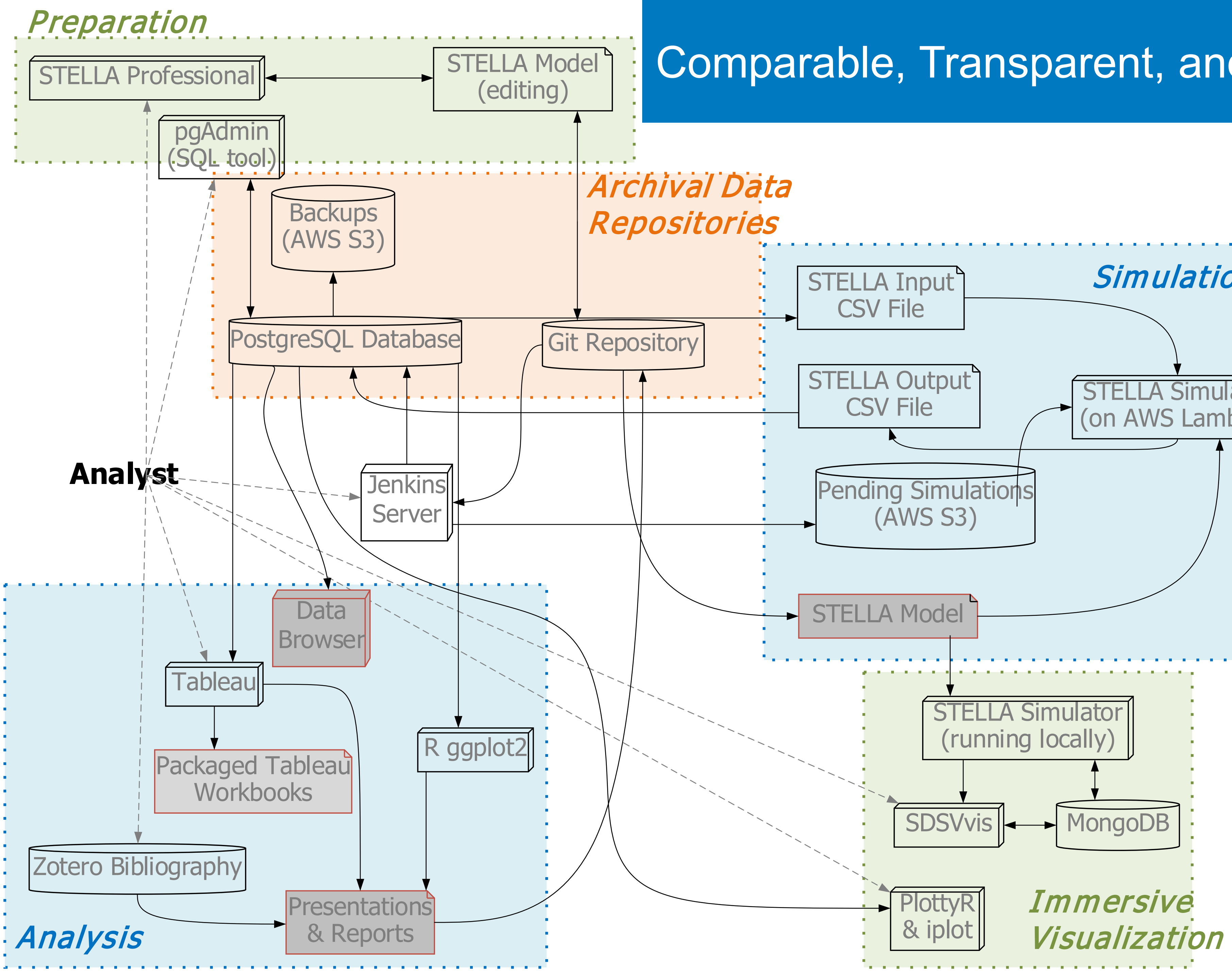


Validation Example: BSM-Simulated Starch Ethanol Production vs. Historical Data

- Production levels, installed capacity, and timing of simulated results match observed production levels, installed capacity, and timing.
- Simulates human behavior
- With existing logic and structure, the BSM can adequately reproduce the historical development of the starch ethanol industry in the United States.

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



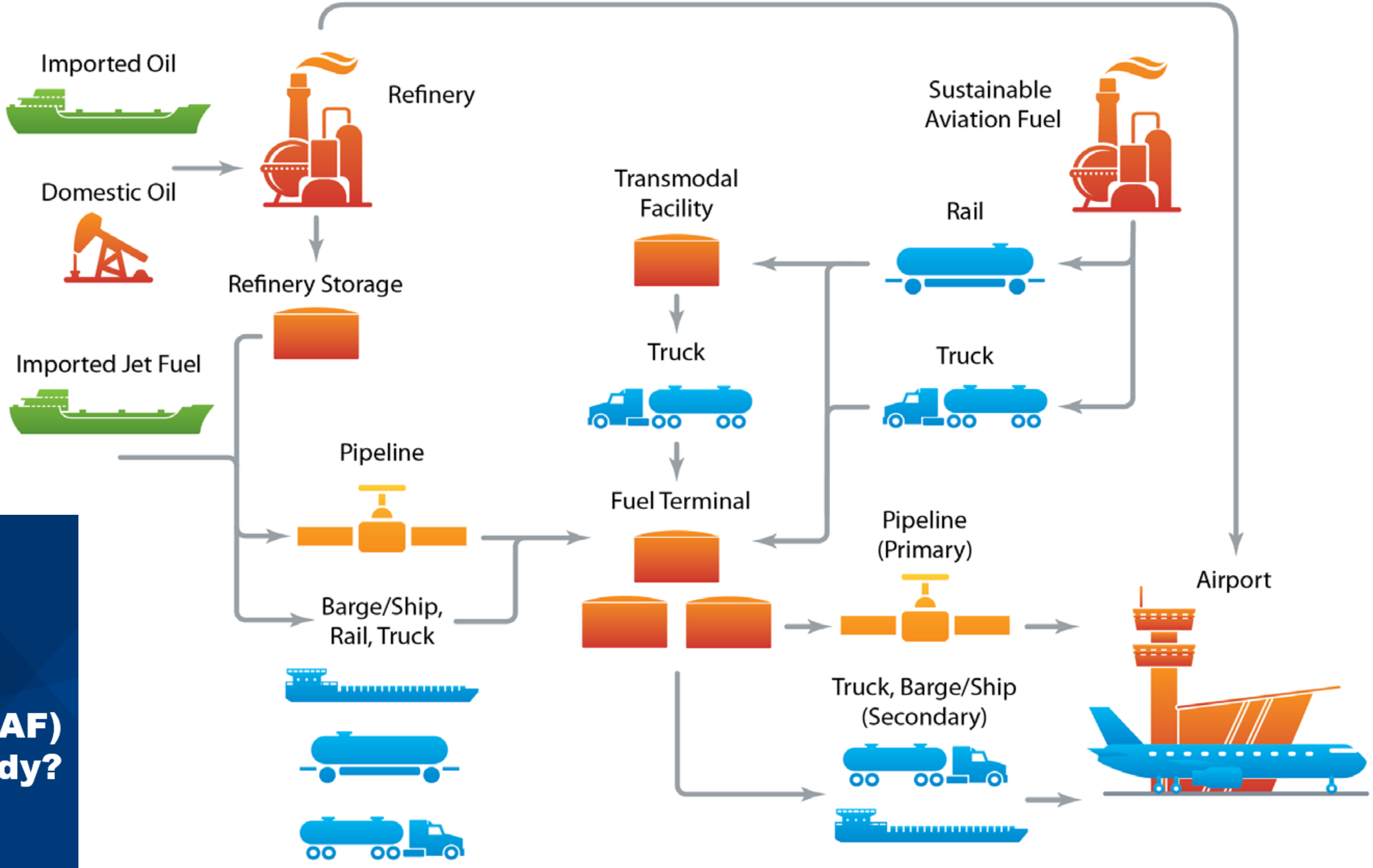
Comparable: robust visualization and quality control

Transparent: documentation embedded in model variables

Reproducible: sophisticated information architecture to enable inventorying and mining of results

Scenario Analysis of Aviation Biofuel Deployment at Airports

Technical report provides airports with critical information on different infrastructure scenarios and potential biofuel integration, depending on infrastructure components and regulations.



https://www.nrel.gov/docs/fy21osti/78368.pdf

BSM Caveats for ITC/PTC Analysis

BSM results should not be interpreted as predictive. Rather than magnitude, focus should be on directional impacts among different scenarios. Volumes are illustrative.

Factors other than policy can also impact market dynamics (e.g., oil prices, drought, and offtake agreements).

The BSM models various feedstock-to-conversion pathways. For this analysis we limited the pathways to only those that are currently commercially available.

The BSM has limited foresight regarding future conditions, resulting in abrupt changes when policies change.

Additional Information

- Publicly available BSM and model documentation (https://openei.org/wiki/Biomass_Scenario_Model)
- BSM publications (https://www.zotero.org/groups/209264/bsm_publications/library.)