OAK RIDGE National Laboratory

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

4.1.2.41 - Biofuels National Strategic Benefits Analysis

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Analysis and Sustainability

Rocio Uria-Martinez and Paul N. Leiby

ORNL

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for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Goal Statement

- Project goal:
  - To develop tools and methods for assessing and quantifying potential fuel market impacts and overall economic and energy security benefits associated with biofuels and bioproducts
- Project outcome:
  - Policymakers and industry stakeholders have good tools to incorporate energy security and economic sustainability considerations into the decisions shaping the U.S. bioeconomy future
- Relevance to BETO:
  - Contribute to understand, promote, and communicate economic and energy security benefits of bioenergy
- Relevance to the bioenergy industry:
  - System-wide effects of introducing new biofuels and bioproducts
    - Interactions with incumbent fuels and products
  - Economic sustainability dimension of analysis
    - Identify strategies to enhance resilience of the biofuel-bioproduct supply chains in the context of business cycles and volatility in petroleum and biomass feedstock markets

Quad Chart Overview

Timeline

- BETO funding started in 2012 building on an ORNL internally funded LDRD project
- Current project cycle:
  - Start date: 10/01/2018
  - End date: 09/30/2021
  - Percent complete: 15%

Barriers addressed

At-B: Analytical tools and capabilities for system-level analysis

BioTrans model

At-E: Quantification of economic, environmental, and other benefits or costs

Energy security benefits, value of fuel price volatility reduction

	Total Costs Pre FY17	FY17 Costs	FY18 Costs	Total Planned Funding (FY19-Project End Date)
DOE Funded	$1,450K	$291K	$215K	$980K

Objective

To assess, quantify, and explain the economic and energy security benefits of biofuels and bioproducts.

End of Project Goal

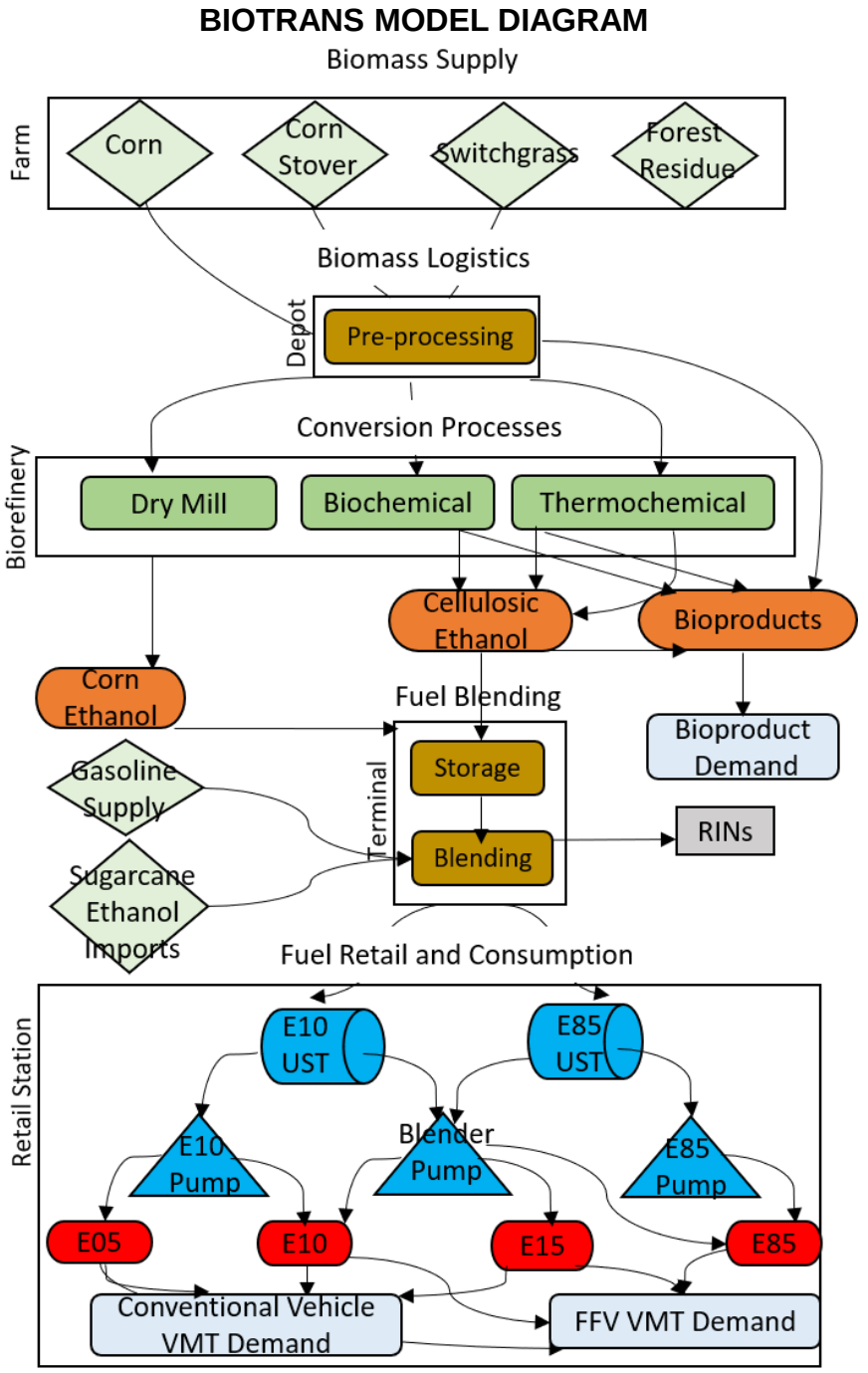
To provide insight on system configurations that advance economic welfare and improve resilience along the biofuels/products supply chain

1 – Project Overview

- 2010-2011: ORNL internal project builds tool to explore fuel market impacts of biofuel
  - Builds on existing ORNL capabilities
    - biomass supply & logistics models
    - oil security premium work for DOE and EPA
    - alternative fuel (hydrogen) transition models
  - Produced initial version of BioTrans model
    - Farm-to-pump equilibrium market model
    - Depicts petroleum-biofuel interactions
- Since 2012: DOE funding for application of BioTrans and other analysis tools to explore
  - Biofuel industry growth prospects and market outcomes in the face of oil price volatility, regulatory uncertainty, declining oil imports

Focus topics in FY16-FY18:

- Cost of oil and biomass supply shocks and effectiveness of biofuel supply chain flexibility levers to mitigate them
- Effect of biofuel blending on fuel price *volatility*



2 – Approach (Management)

- **Quarterly milestones and deliverables set in Annual Operating Plan**
  - Project merit-reviewed in FY18
- **Progress updates to BETO**
  - Monthly and quarterly written updates
  - Participation in monthly A&S calls
  - Quarterly check-in videoconference with BETO
- **Interaction with other BETO researchers**:
  - Bioeconomy Modeling Workshop (June 2018)
  - Co-Optima stakeholder conference calls
  - Discussion with ORNL Conversion platform researchers on bioproduct pathways/markets
- **External communications**:
  - Conference presentations
  - Peer-reviewed publications
  - Interactive web tool (Biofuel-EESR)
    - Presented to other BETO researchers in November 2017 A&S monthly call

Hybrid approach is used to analyze fuel market impacts of biofuels

- Hybrid economic analysis approach:
  - Math programming equilibrium market model (BioTrans) for forward-looking scenario analysis
  - Econometric analysis of historical ethanol and petroleum market data
  - Application of financial theory frameworks for risk management
- Challenges:
  - TEA and market data availability (particularly for bioproducts)
  - Maintain adequate model scope to capture key market interactions
  - Robust treatment of foresight, expectations, shocks:
    - Market participants formulate their investment and operation plans with reasonably accurate near-term information that is periodically updated yet "shocks" (i.e., surprises) arise.
  - Validation of modelling approaches and results
  - Effective communication of insights and results to industry stakeholders and integration with other BETO projects

BioTrans is well-suited to explore long-run market outcomes under incomplete information and volatile market conditions

- Dynamic, partial equilibrium model
- Model scope:
  - 30-year model horizon, annual periods
  - National model disaggregated at the Census Division level
- It solves for *optimal* investment patterns and market outcomes:
  - Maximization of producer surplus + consumer surplus
  - Minimization of costs along the supply chain
- Focus themes:
  - Issues of transition to alternative fuels
  - Depiction of flexibility mechanisms
  - Market responses to shocks; energy security
    - Limited foresight implementation (6-year overlapping solution windows rolled one period forward in each solution iteration) enables the depiction of supply shocks as "surprises"
    - Biomass supply and VMT demand elasticities increase with length of adjustment period

KEY INPUTS
- Reference market conditions
- Biomass supply curves
- Technoeconomic parameters describing biofuel production pathways
- Light-duty vehicle (LDV) stock characteristics
- Regulatory constraints

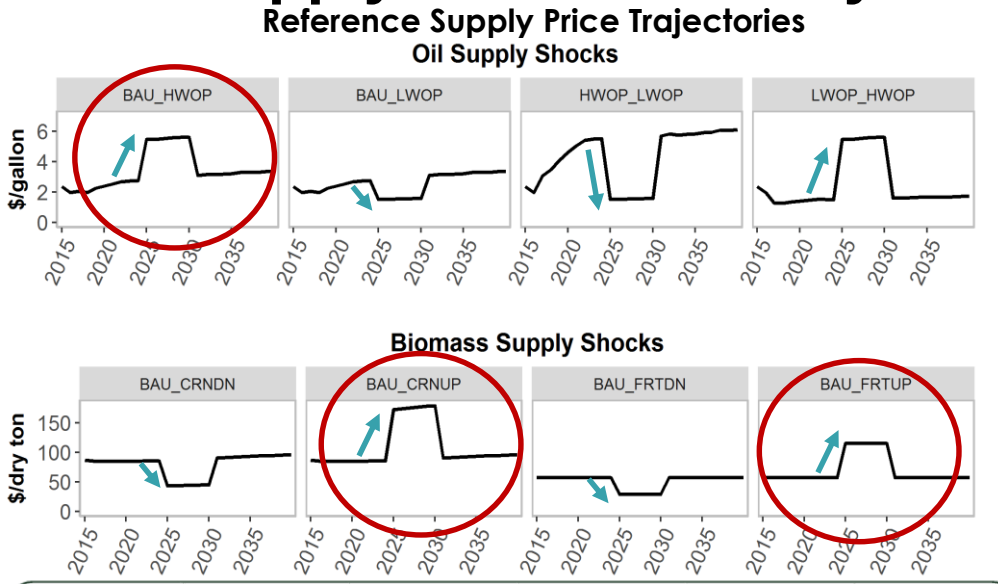
KEY OUTPUTS
- Investment in durable assets: biorefineries and fuel retail infrastructure
- Biomass utilization & prices
- Biofuel production & prices
- LDV fuel mix & prices

Two complementary approaches for valuation of benefits from fuel price volatility reduction: Modern Portfolio Theory & Real Option Value. They measure *different* benefits

- **FY17 analysis estimated 3-10% price volatility reduction from E10 blend, based on 2006-2016 data. Left open the question of *value* of that reduction.**
- **Modern Portfolio Theory** focuses on cost of "risk" (price variability)
  - Explores efficient risk-return tradeoffs (e.g., mean-variance portfolio)
  - Could also focus on unwanted part of risk
    - downside risk return or upside risk for prices (this is a branch of PMPT)
  - Consider alternative static "portfolio weights" (blend levels)
  - *Question: Which static blend level optimizes the mean - volatility tradeoff in fuel prices?*
- **Real Option value** emphasizes value of flexibility in the face of risk
  - Objective is not reducing risk, but responding and benefitting from price variations as opportunities to profit/reduce costs
  - Relative price thresholds govern when the option is exercised (blend level changed)
  - Price volatility governs the frequency of option exercise
  - *Question: How much could be saved in fuel expenditures if ethanol blending level could be flexibly adjusted depending on wholesale gasoline and biofuel price movements?*

BioTrans scenario analysis explores market impacts of oil and biomass supply shocks under alternative levels of biofuel supply chain flexibility

SHOCKS



FLEXIBILITY LEVERS

Biorefinery Feedstock Flexibility
ON – multi-feedstock cellulosic biorefineries
OFF – single-feedstock cellulosic biorefineries

Advanced Biomass Logistics
ON - biomass feedstocks preprocessed into homogeneous material (e.g., pellets) that can travel long-distance
OFF - biomass transported in bales; stays within local market

Ethanol Blending Flexibility
ON - four gasoline-ethanol blends (E05, E10, E15, E85);
OFF - two gasoline-ethanol blends (E10, E85)

Oil supply shocks (2025-2030) are modeled as supply curve shifts among 3 AEO 2017 cases:

BAU - Business As Usual

HWOP - High World Oil Price

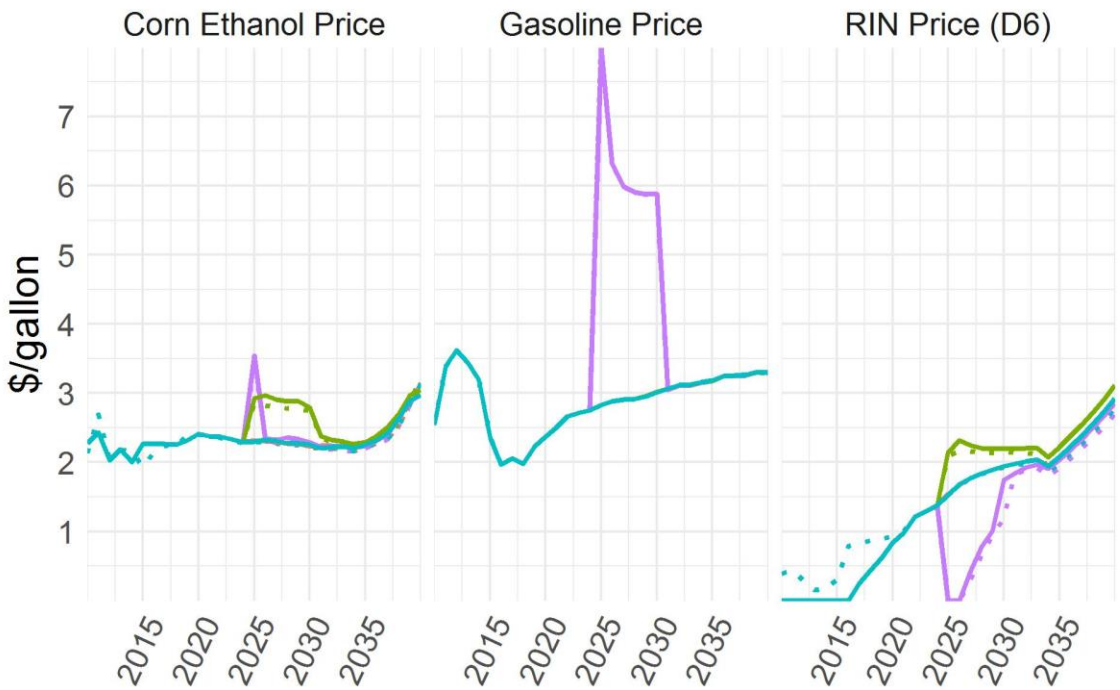
LWOP - Low World Oil Price

BAU prices for corn **(CRN)** and forest residue **(FRT)** are from *2016 Billion-Ton* report $60/dry ton scenario; 2025-2030 biomass supply shocks are modeled as shifts doubling (**UP**) or halving (**DN**) the BAU reference prices.

In the **All Rigid** supply chain configuration, the three flexibility levers are **OFF**

In the **All Flexible** supply chain configuration, the three levers are **ON**

Finding: During supply shocks, price transmission between gasoline and ethanol is not symmetric

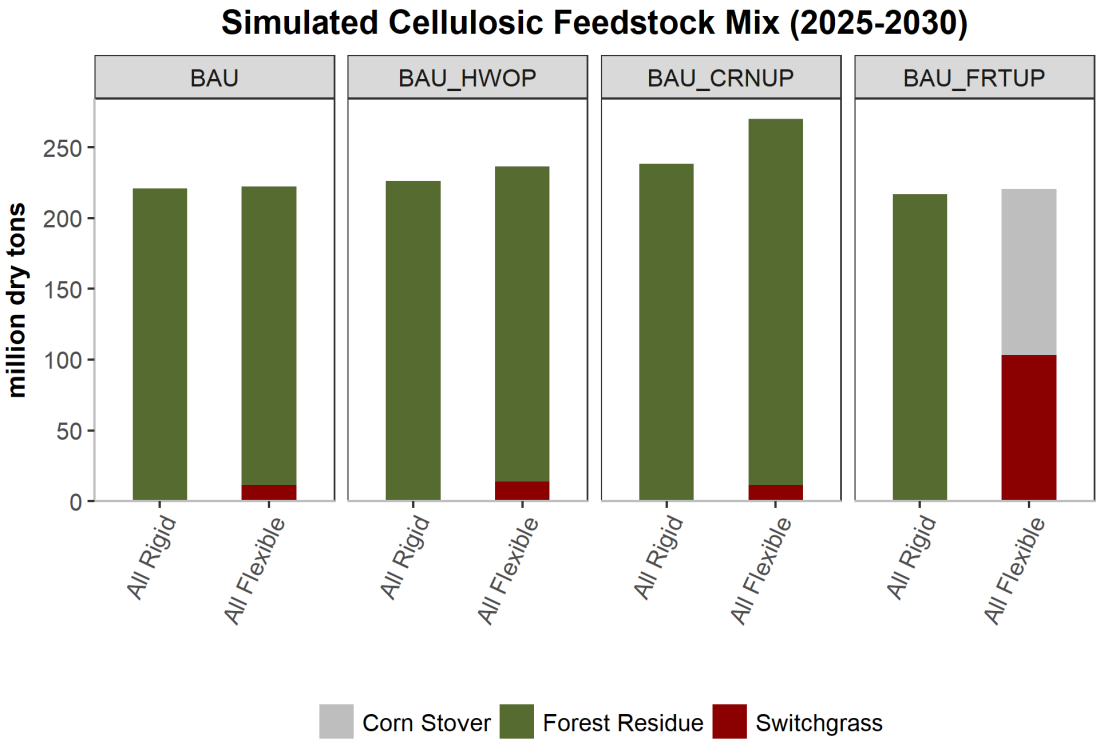


TOTAL NET SHOCK COST
(Billion 2010 $)

	All Rigid	All Flexible
BAU_ HWOP	119	18
BAU_ CRNUP	24	22
BAU_ FRTUP	5	0.7

- Gasoline supply shock (**BAU_HWOP**) results in a significant increase on the equilibrium corn ethanol price, but shocks on biomass do not visibly affect the gasoline price
- RIN price depends on relative prices of gasoline and ethanol and is affected by both kinds of shocks
- Flexibility helps mitigate increase in equilibrium price of corn during **BAU_CRNUP** shock

Finding: Flexibility improves the ability of cellulosic ethanol to replace expensive corn ethanol or gasoline during corn or crude oil supply shocks (price increases)



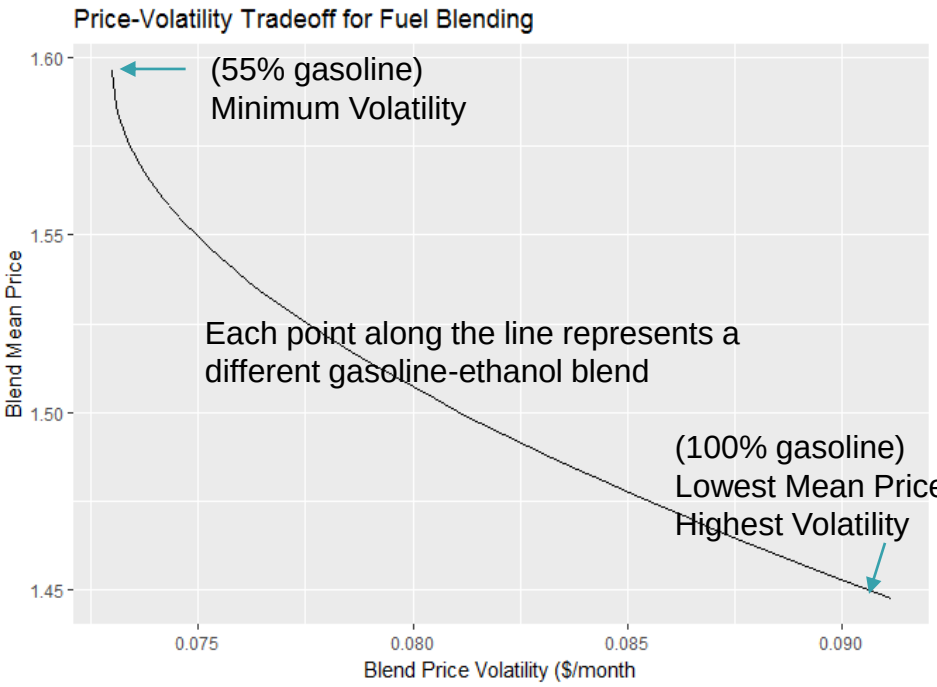
- Cellulosic biofuel production ramps up during corn (**BAU_CRNUP)** and gasoline **(BAU_HWOP)** supply shocks.
- With *All Flexible* supply chain, switchgrass and stover replace forest residue during **BAU_FRTUP** shock.
  - Significant changes in regional distribution of farmer revenue.
- Average annual farmer revenue is lower but more stable with the *All Flexible* supply chain.

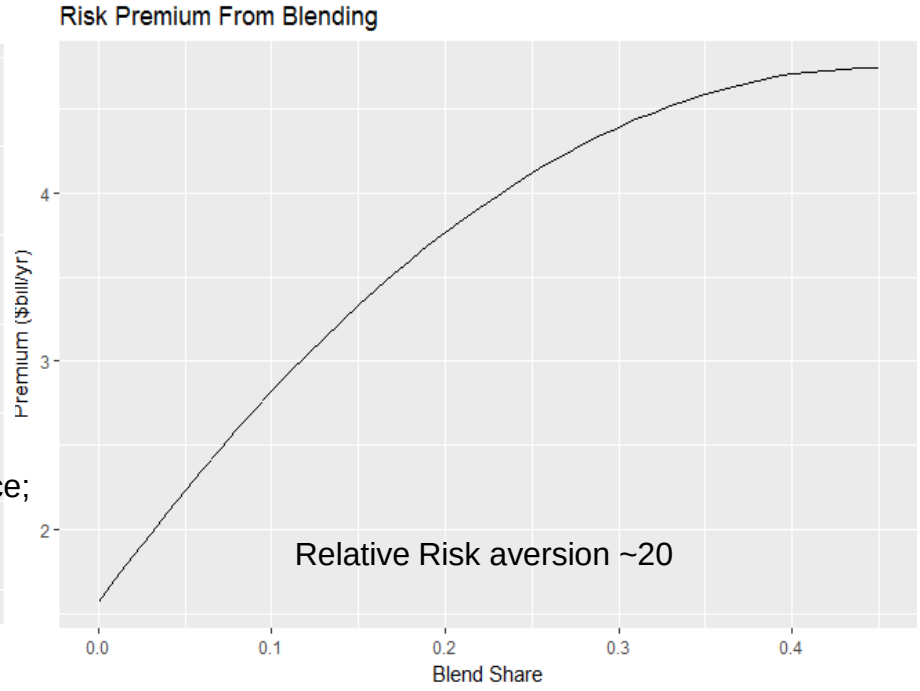
CELLULOSIC FEEDSTOCK FARMER REVENUE (2025-2030)

	Average (million $/yr)	***Coefficient of variation***
All Rigid	145	35%
All Flexible	109	15%

Note: In the *All Rigid* supply chain, thermochemical biorefineries are only allowed to use forest residue which is the preferred feedstock for those biorefineries in unrestricted **BAU** case

Modern Portfolio Theory Results: price volatility reduction tradeoff peaks for blend share of 45%. Reasonable estimate of the risk premium (benefit) from blending is $2 - $6 billion/year



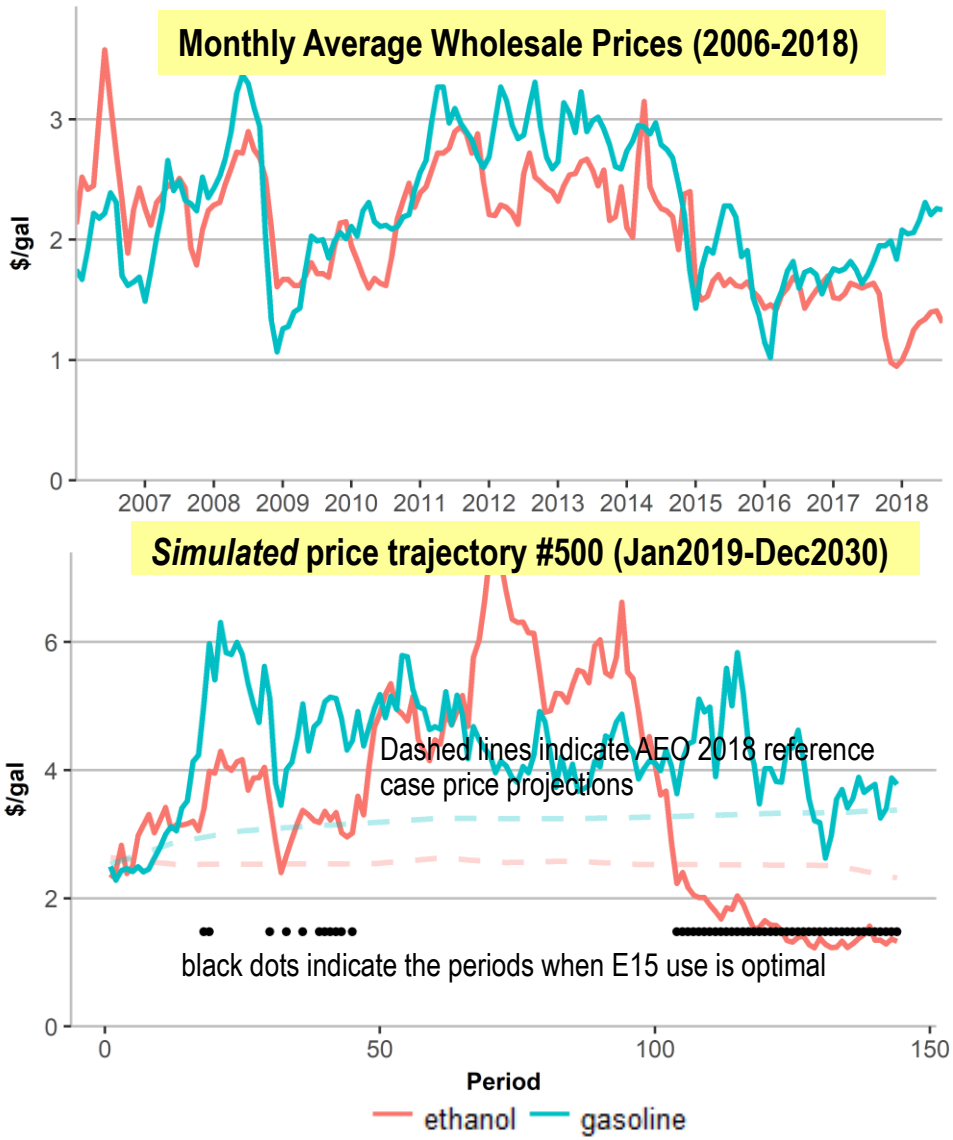


- Based on 2006-2018 wholesale gasoline and ethanol price history
- Risk premium (benefit) from blending depends on: blend volatility, fuel consumption volume, and (uncertain) risk tolerance by consumers

Method for estimating future option value of ethanol blending: Simulate gasoline & ethanol price trajectories, accounting for their correlation and volatility patterns

- What fuel cost savings could be achieved if ethanol blend (E05-E15) were adjusted monthly based on relative gasoline-ethanol prices?

1. Estimate ethanol and gasoline price patterns
   - Selected stochastic process (MGARCH) reflects price variability, with correlation & volatility clustering
2. Monte Carlo simulation of price trajectories (2019-2030)
   - Mean price growth rates from AEO 2018. 1000 random variant paths.
3. For each simulated trajectory:
   - Select ethanol blending content for each monthly period based on $/gge cost
   - **Option value is difference in fuel expenditures in the rigid (E10 only) baseline versus the flexible alternative**
4. Compute summary distributions, statistics



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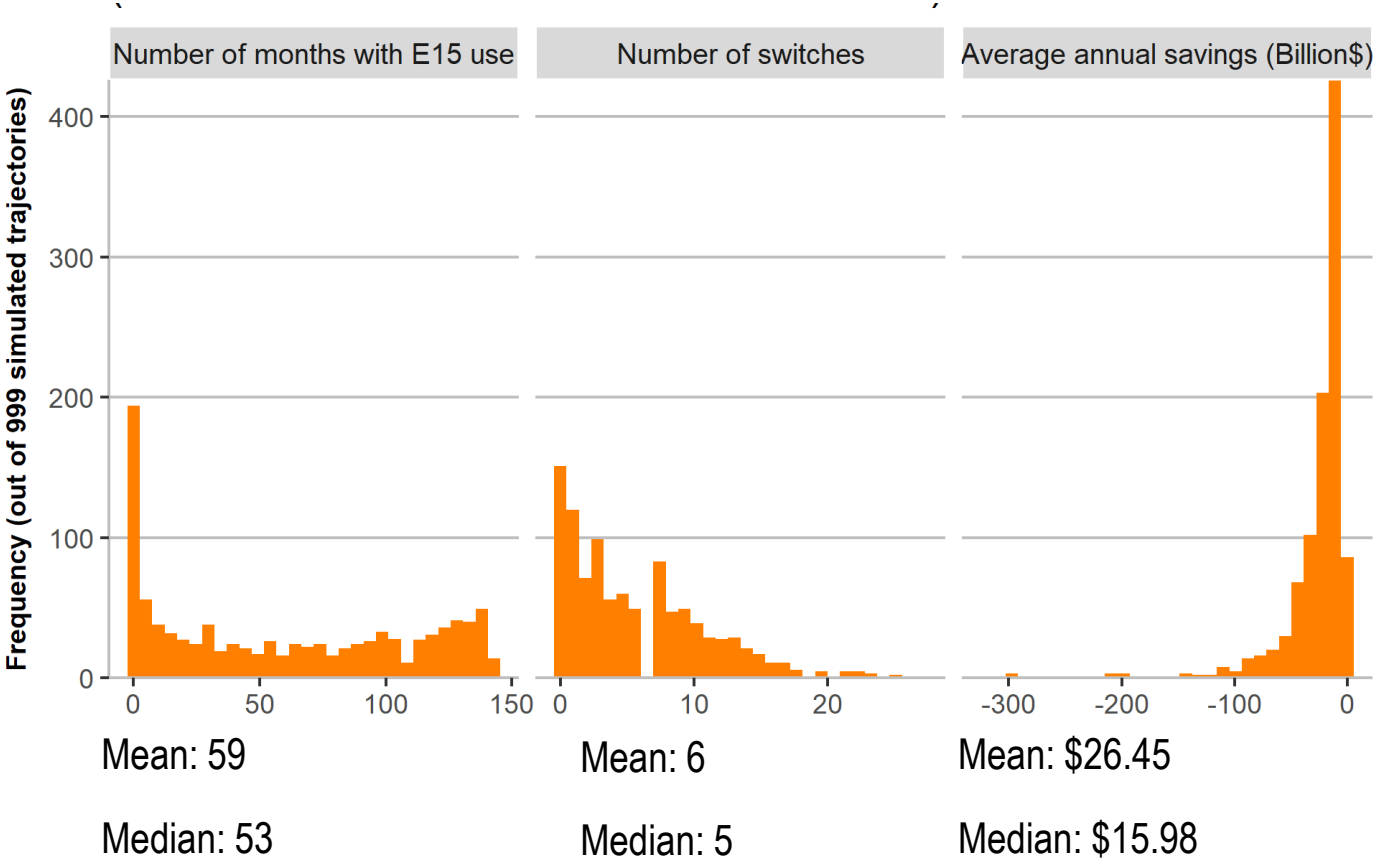
Option Value Results: On average, option to switch between E05 and E15 would be used 6 times in 12 years and reduce wholesale fuel expenditures by 5%

(assuming mean price growth rates from AEO 2018 reference and mean reversion and volatility patterns similar to those in 2006-2018)



Caveats:

- Assumed switching threshold depends only on relative ethanol and gasoline supply prices
  - Accounting for other ethanol benefits (octane value, energy security, environmental) changes the threshold
- No switching costs are modeled

Note: 1 outlier trajectory was excluded from the histograms and results presented in this slide

4 – Relevance

- This project aims to measure and communicate economic and social benefits (also potential risks) of increased U.S. biomass utilization for biofuel and bioproducts under various 1) market and policy futures, and 2) biofuel supply chain configurations

- Highlights importance of understanding interactions and flexibilities (gasoline/biofuel, bioproducts/petroleum-based alternatives) to analyze market outcomes for the bioeconomy.

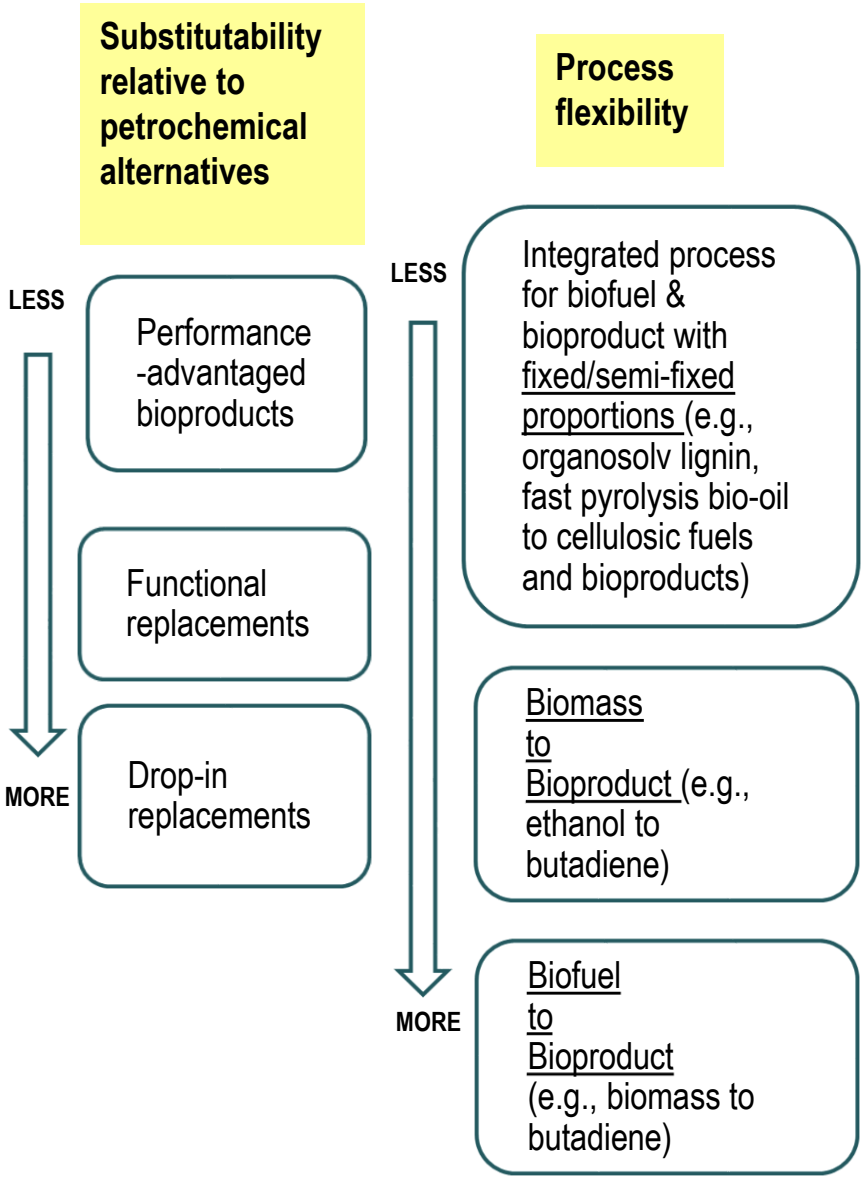
- Contributions to BETO goals:

Project Task	BETO Goal
Estimation of benefits of volatility reduction enabled by biofuel blending	"*by 2018, complete analysis on impact of advanced biofuels use on gasoline and diesel prices*" (BETO MYPP 2016)
Scenario analysis to identify effectiveness of flexibility levers across biofuel supply chain	"*develop and demonstrate innovative and integrated value chains for biofuels, bioproducts, and biopower that can respond with agility to market factors while providing economic, environmental, and societal benefits*" (BETO Strategic Plan, 2016)

- Relevance to the bioenergy industry
  - Resilience to supply shocks should be one of the criteria, along with cost and environmental sustainability targets, for biofuel supply chain design; also important for bioproduct selection.
    - For flexibility to be effective, it must be present throughout the supply chain which requires coordination among investment and operation decisions by farmers, biorefiners, fuel retailers.
  - Volatility and risk are important considerations for bioeconomy supply chain investment choices. Our approaches address 1) Trade-offs between return and risk (MPT) and 2) Business case for flexible supply chain in face of price volatility in (real option value).

Task 1: Assessment of the value of bioproducts to support the growth and improve the resilience of the U.S. advanced biofuel industry

- Estimate systemwide responses from:
  - introduction of bioproducts
    - Examples representative of different degrees of 1) substitutability relative to petrochemical alternatives, 2) process flexibility
    - Allow bioproduct imports/exports
    - Depict competing petroleum-based pathways
  - oil and biomass supply shocks with and without bioproducts
- Estimate elasticities of substitution: responsiveness of biorefinery product slate to changes in input costs or product prices
  - Depends on technoeconomic parameters but also logistic/capacity/regulatory constraints (captured in BioTrans model)
  - Published estimates for proxy processes (petrochemical industry, Brazilian sugarcane mills) can be used for validation



Task 2: Analysis of potential impacts for biofuel industry of a fuel-neutral octane performance standard

- Effect of octane standard on biofuel use depends on:
  - RON number (95, 98)
  - Implementation schedule
  - post-2022 RFS future
  - Oil prices
- Year 1 work involves:
  - Gathering technoeconomic data to characterize a set of candidate high-octane blendstocks
    - bio-based blendstocks selected by Co-Optima
    - petroleum-based reformate and alkylates
  - Synthesis of key concerns and opportunities for biofuel industry under an octane performance standard as identified by industry stakeholders, research community and initial economic analysis
- This work leverages prior NREL-ORNL market assessment of high-octane mid-level ethanol fuels

Stakeholder perspectives (based on review of public comments to EPA/NHTSA *Safe Affordable Fuel-Efficient Vehicles* NOPR):

- **Oil industry**: EPA should not regulate octane number under SAFE
  - In previous pronouncements, showed support for 95 RON
- **Retail station operators**: fuel-agnostic as long as they can sell legally and with little risk
  - Against *requirement* to sell E25-E30
- **Automakers**: At least 95 RON; agnostic about which octane boosting additive to use
  - Should not be sold as *premium* fuel
- **Farmers, Ethanol industry**: 98-100 RON provided through E25-E30
  - Ethanol is cost-effective, low-carbon and clean-burning (relative to the fuel additives it replaces)
  - Regulatory barriers are the key impediments to bring E25-E30 to market and should be removed

Summary

Overview:

- Develop tools and methods to explore interactions between petroleum and biofuel/bioproduct markets and assess energy security benefits of the bioeconomy (with particular emphasis on identifying strategies for enhanced resilience of bioeconomy supply chains)

Approach:

- Recent work combines equilibrium market model (BioTrans) for scenario analysis and empirical analysis of historical gasoline and ethanol market data, with a special emphasis on flexibility and risk

Technical Accomplishments/Progress/Results:

- Scenario analysis of oil & biomass supply shocks under various levels of biofuel supply chain flexibility
- Estimates of the value of fuel price volatility reduction enabled by biofuel blending

Relevance:

- Contributes to comprehensive understanding of impacts of advanced biofuels on LDV fuel prices
- Highlights flexibility and resilience as important considerations for supply chain investment and operation decisions. Provides estimates of their value.

Future Work:

- Analysis of the potential impacts of a fuel-neutral octane performance standard on the biofuel industry
- Assessment of the value of bioproducts to support the growth and improve the resilience of the U.S. advanced biofuel industry

Additional Slides

Responses to Previous Reviewers' Comments

C1: There would be much value in seeing planned future work integrated with the results of work to date in an interim report. The project appears to be developing numerous sub-analyses of the fuels and bioenergy market. However, the material and conclusions need to be periodically tied together so broader themes are easier to follow.

We acknowledge the need to better tie up together the results and insights from the various tasks and modeling approaches we are using in this project. In FY17 and FY18, we have developed a website *(https://biowit.shinyapps.io/biofuel-eesr6/)* to summarize results from the various sub-analyses (BioTrans model applications and empirical analysis of market data) under the umbrella of economic and energy security role of biofuels (and bioproducts).

C2: One of the more compelling arguments for biofuel development may be as a sort of hedge against uncertainty in the supply and prices of other energy sources and it might be useful to consider how this would be expressed via a real options approach

Real option theory is particularly well-suited to analyze investment decisions including some element of flexibility that can be exercised or not depending on the evolution of market conditions. In FY18, we have applied real option theory to estimate the value of ethanol blending flexibility (E05-E15 range) for enabling savings in consumer fuel expenditures across thousands of potential future oil and ethanol price paths.

C3: For this project to have an impact, the results must be published, preferably in peer-reviewed journals.

In FY17 and FY18, we focused on result dissemination resulting in publication of 2 peer-reviewed journal articles.

Publications and Presentations

Publications:

- Uría-Martínez, R., Leiby, P.N., and Brown, M.L. (2018). "Energy Security Role of Biofuels in Evolving Liquid Fuel Markets." *Biofuel, Bioproducts and Biorefining*. https://doi.org/10.1002/bbb.1891
- Uría-Martínez, R., Leiby, P.N., and Brown, M.L. (2018). "Cost of oil and biomass supply shocks under different biofuel supply chain configurations." *Transportation Research Record*. https://doi.org/10.1177/0361198118756876.

Interactive web tool:

Biofuel-EESR (https://biowit.shinyapps.io/biofuel-eesr6/). It allows exploratory analysis of scenarios analyzing the economic and energy security role of biofuels. Presented to other BETO researchers during monthly A&S call.

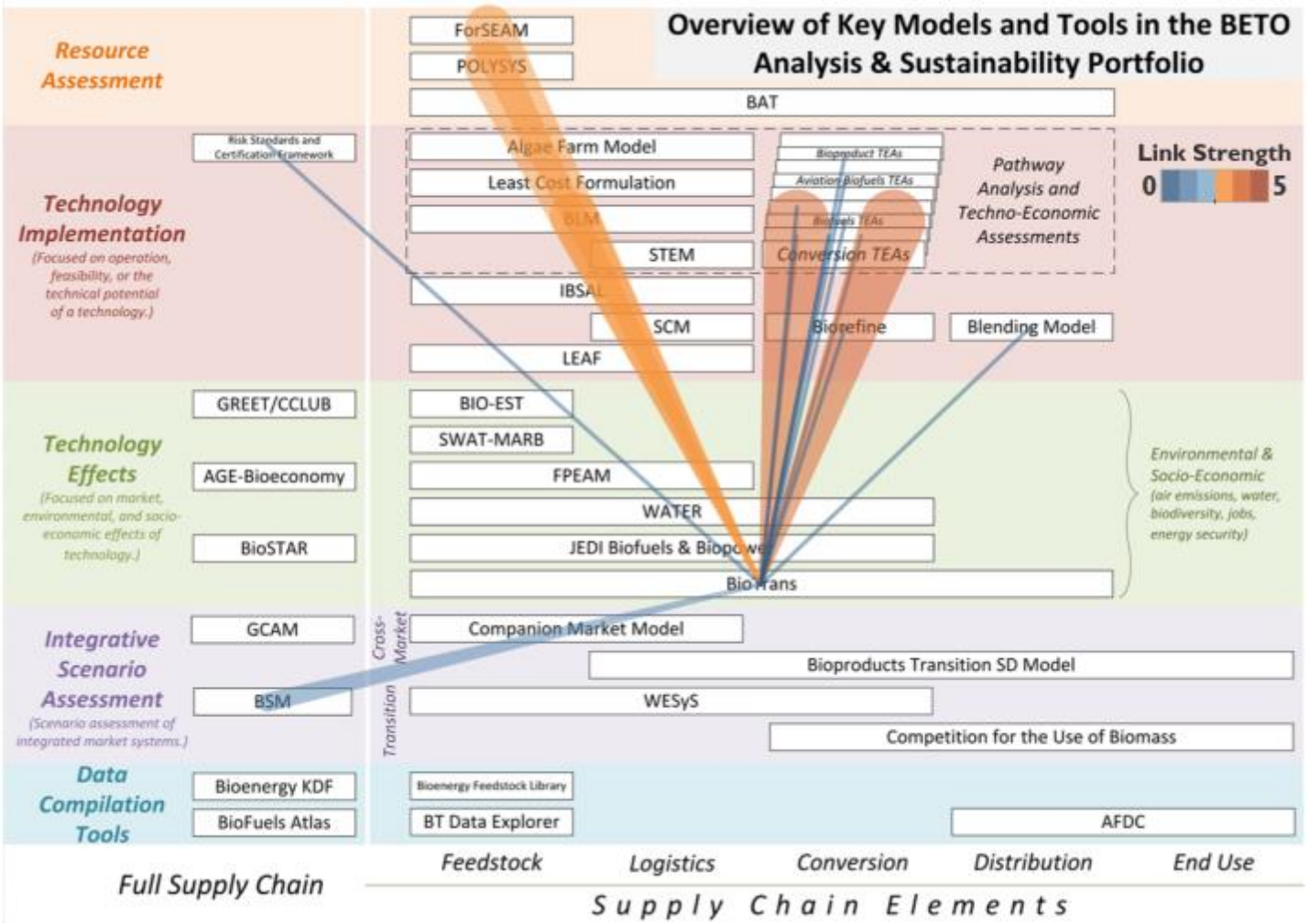
Presentations:

- Uría-Martínez, R., Leiby, P.N., & Brown, M.L. (2017). "Energy Security Implications of Biofuels: Welfare Effects of Biomass Supply Shocks." Presentation at the 35th International Association of Energy Economics (USAEE/IAEE) North American Conference. Houston, Texas. November 13, 2017.
- Uría-Martínez, R., Leiby, P.N., & Brown, M.L. (2018). "Cost of oil and biomass supply shocks under different biofuel supply chain configurations." Poster presentation at the 2018 Transportation Research Board Annual Meeting. Washington, DC. January 9, 2018.

Internal report to BETO:

Uría-Martínez, R., & Leiby, P.N. (2018)."Exploring the role of bioproducts on bioeconomy supply chain configuration and resilience using the BioTrans model".

Model mapping – BioTrans inputs



Model mapping – BioTrans outputs