DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Economic Analysis of Market Conditions and Incentives for Efficient Utilization of Biomass in Hard-to-Decarbonize Transportation Sectors

04/05/2023

Data, Modeling, and Analysis

PI: Rocío Uría-Martínez

Organization: ORNL

Project Overview

- Context: This project builds from a previous one and changes its focus to reflect evolving programmatic BETO priorities
  - Previous project: “Biofuels National Strategic Benefits Analysis” (2012–2021)
    - It developed tools (BioTrans model, empirical analysis of fuel market data) to assess and quantify the economic and energy security benefits of light-duty vehicle (LDV) biofuels and bioproducts.
- Goal: The new project seeks to understand and enhance **socioeconomic and environmental benefits of biofuels through modeling the effect of prices and policy incentives** on fuel markets for “hard-to-decarbonize” transportation sectors.
  - Contribution toward the “Inform SAF Policy Development” workstream in DOE’s SAF Grand Challenge Roadmap.
- Motivating questions:
  - What are the key **synergies/competitive relationships** between SAF and biofuels used in other transportation sectors?
  - Which policies can be most effective in encouraging **efficient use of biomass** in the transportation sector?
  - What are the **economic equity implications** of different SAF deployment scenarios?

Analysis is performed using a market equilibrium model that covers the biofuel supply chain from biomass supply to biofuel retail activities.

- BioTrans is a market equilibrium model
  [Additional details shown in Supplementary Slides]
  - 30-year horizon; **annual** periods
  - National scope, **by state**
  - Solves for activity levels along the supply chain, prices, investments
  - Solution maximizes social surplus associated with meeting transportation fuel demands.
    - Implies cost minimization (subject to material balance, engineering, regulatory constraints)
- Model boundaries:
  - Transportation fuel markets are endogenous in the model
    - Captures **synergies and competition** for biomass/biofuel from different sectors
      - How is ethanol reallocated as its consumption in LDVs decreases?
      - HEFA for renewable diesel versus SAF applications
      - Processes that deliver output mix serving multiple transportation segments
  - Land allocation decisions are exogenous.
    - Biomass feedstock supply curves constructed from Billion Ton Study data
  - Non-biofuel uses of biomass are depicted as exogenous demands.

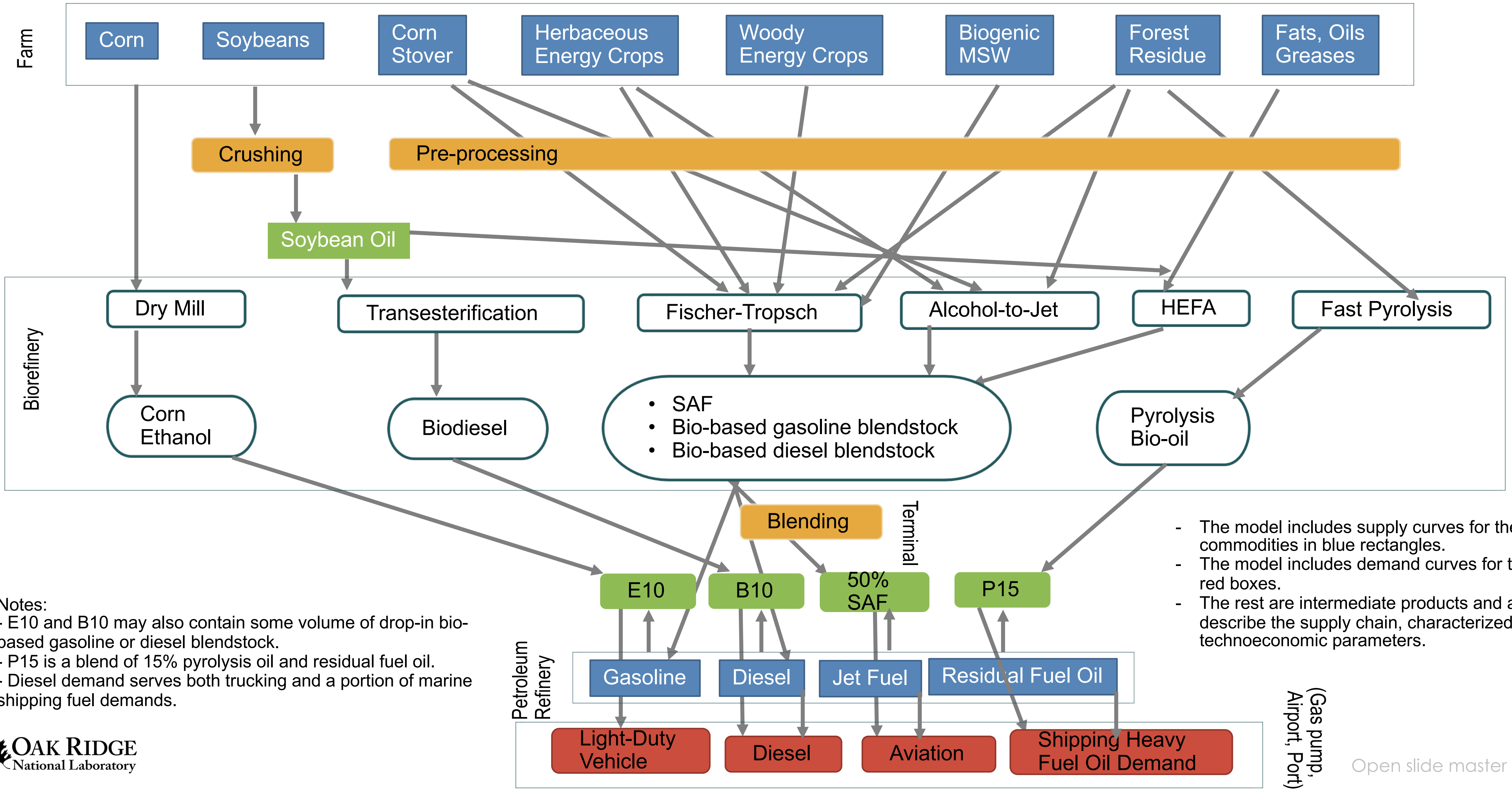
Year 1 (FY22) work modified BioTrans model structure and data inputs to analyze new sectors (aviation & marine fuel demands) and objectives (decarbonization).

- New transportation **fuel demand curves** (jet fuel, residual fuel oil) ✓
- New set of **biofuel production pathways** ✓
  - Feedstocks, conversion processes, and biofuels
- **GHG emission accounting** ✓
  - Flexibility to consider alternative data sources for carbon intensity coefficients
- Change in spatial units: from Census Divisions to **states** ✓
  - Better suited for policy analysis
- Approach to link part of the model solution to **economic equity metrics** ✓
- Depicting **policies and incentives** for adoption of low-carbon transportation fuels (in progress)
  - Renewable Fuel Standard (RFS), Low Carbon Fuel Standard (LCFS), tax credits

1- Approach

Focus on aviation is displayed through higher technological detail (# of pathways) for that segment but other transportation fuel demands are also included in the model.

BIOTRANS MODEL DIAGRAM



- The model includes supply curves for the commodities in blue rectangles.
- The model includes demand curves for the fuels in red boxes.
- The rest are intermediate products and activities to describe the supply chain, characterized by technoeconomic parameters.

Notes:
- E10 and B10 may also contain some volume of drop-in bio-based gasoline or diesel blendstock.
- P15 is a blend of 15% pyrolysis oil and residual fuel oil.
- Diesel demand serves both trucking and a portion of marine shipping fuel demands.

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Analysis approach includes consideration of the economic equity implications of SAF supply chain development.

- Objective: Quantify overlap between disadvantaged communities and biomass feedstock supply activities that are part of model solution.
- Equity metrics are from the ***Climate and Economic Justice Screening Tool*** (CEJST).
  - Geospatial mapping tool to identify disadvantaged communities (Census tracts) across eight categories of criteria; developed as part of Justice 40 initiative.

CEJST METRICS SELECTED:
[Definitions shown in Supplementary Slides]

1) ***Economically disadvantaged communities***
2) ***High unemployment communities***
3) ***Communities with high expected agriculture loss rate***

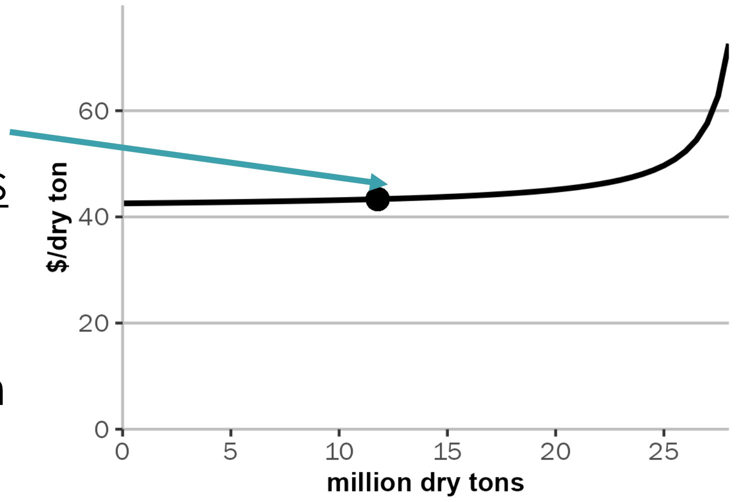
1. Before model run

- Aggregate county-level data from the 2016 Billion Ton study to construct state-level supply curves for the BioTrans model.

2. BioTrans model run

- The model solution identifies the equilibrium supply points for each feedstock-state-year combination

Corn Stover Supply Curve
(Nebraska, High Oil Price scenario, 2050)



3. After model run

- Recover county-level quantities available at prices <= equilibrium price
- Merge with population-weighted county averages of CEJST metrics
- Produce maps to visualize disadvantanged counties with potential, economical feedstock supplies

High performance computing resources and contributions from low-carbon transportation fuel policy experts are being leveraged to achieve project goals.

- High-performance computing (HPC) resources help run many cases in short time.
  - Exploring options to implement an **HPC workflow**:
    - A) Purchase a machine-based license to continue using GAMS (commercial modeling software)
    - B) Migrate model to open-source modeling language (Julia)
      - Uncertainty about performance of open-source solvers in large non-linear models like BioTrans.
    - Development and testing of model features is maintained within the **GAMS desktop workflow** to sustain progress in parallel to HPC workflow implementation.
      - GAMS desktop workflow
        - Code/script-based, in-code documentation
        - Version control of data inputs and model code through Git repository
- Policy detail/complexity (RFS, LCFS):
  - Goal is to include enough detail to capture key policy effects on biofuel volumes/mix and fuel prices while being mindful of overall model complexity
  - **Collaborate with experts at UC Davis Policy Institute** in 1) developing the set of equations and constraints needed for policy representation, 2) designing policy scenarios.

2 – Progress and outcomes:

Work to date has focused on modifications to the model to include aviation/marine fuels and generation of insights from set of no-policy baseline scenarios.

Scenario name	**AEO 2021 scenario**	**Aviation emissions constraint**	**Data source for SAF carbon intensity values**
Reference Oil Price	Reference ($90/bbl by 2050)	No	GREET aviation module
Reference Oil Price, aviation emissions limit	Reference	Yes	GREET aviation module
Reference Oil Price, aviation emissions limit, CORSIA	Reference	Yes	CORSIA
High Oil Price	High Oil Price ($170/bbl by 2050)	No	GREET aviation module
High Oil Price, aviation emissions limit	High Oil Price	Yes	GREET aviation module
High Oil Price, aviation emissions limit, CORSIA	Reference	Yes	CORSIA

Note: All scenarios run under perfect foresight conditions.

Aviation emissions constraint:

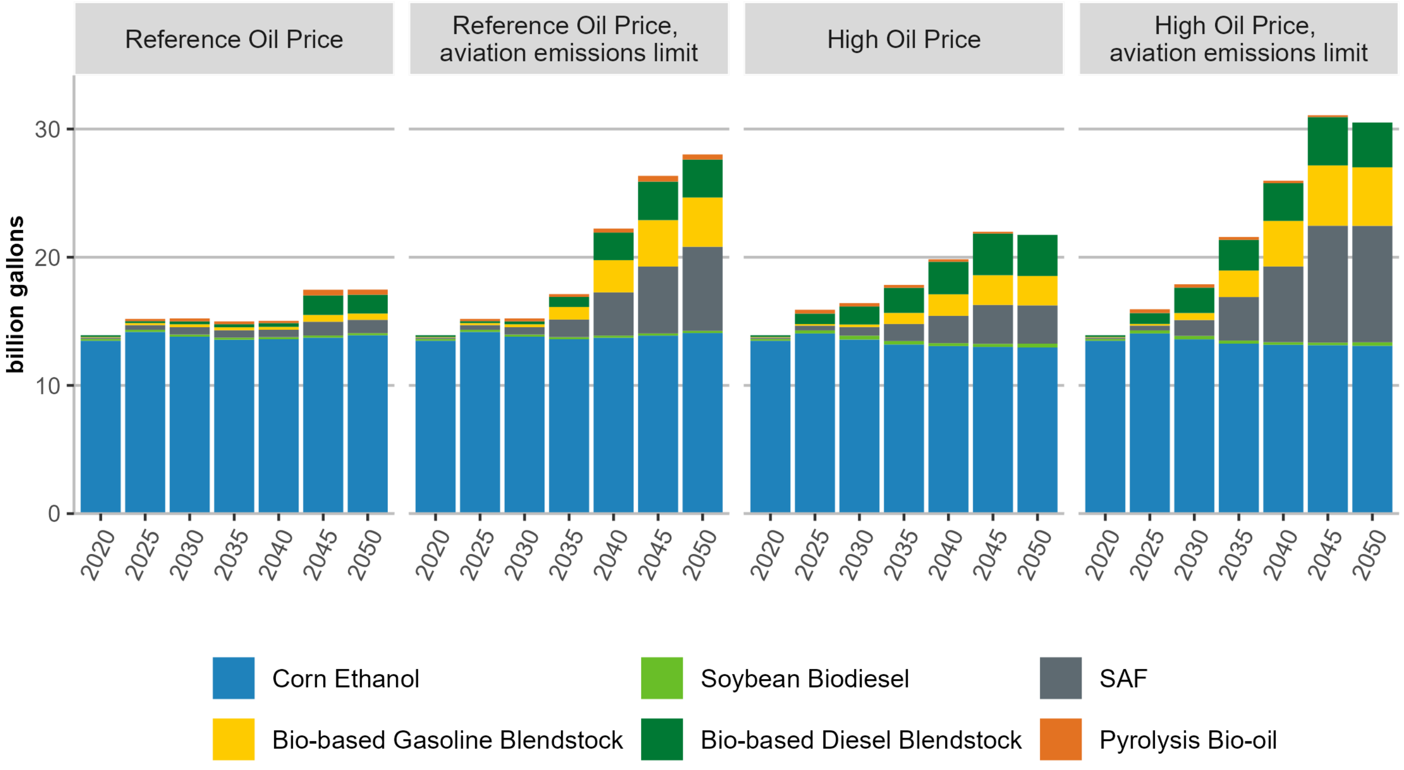
Lifecycle GHG aviation emissions (2050) <= Lifecycle GHG aviation emissions (2005) * (1 – (*PctRedObj* * *SAFShareRed*))

PctRedObj = Percentage emissions reduction objective (50%)

SAFShareRed = Share of reduction to be accomplished with SAF (65%)

Biofuel production levels more than double by 2050 (relative to 2020) with a combination of sustained high oil prices and limits to emissions in the aviation sector.

Domestic biofuel production mix

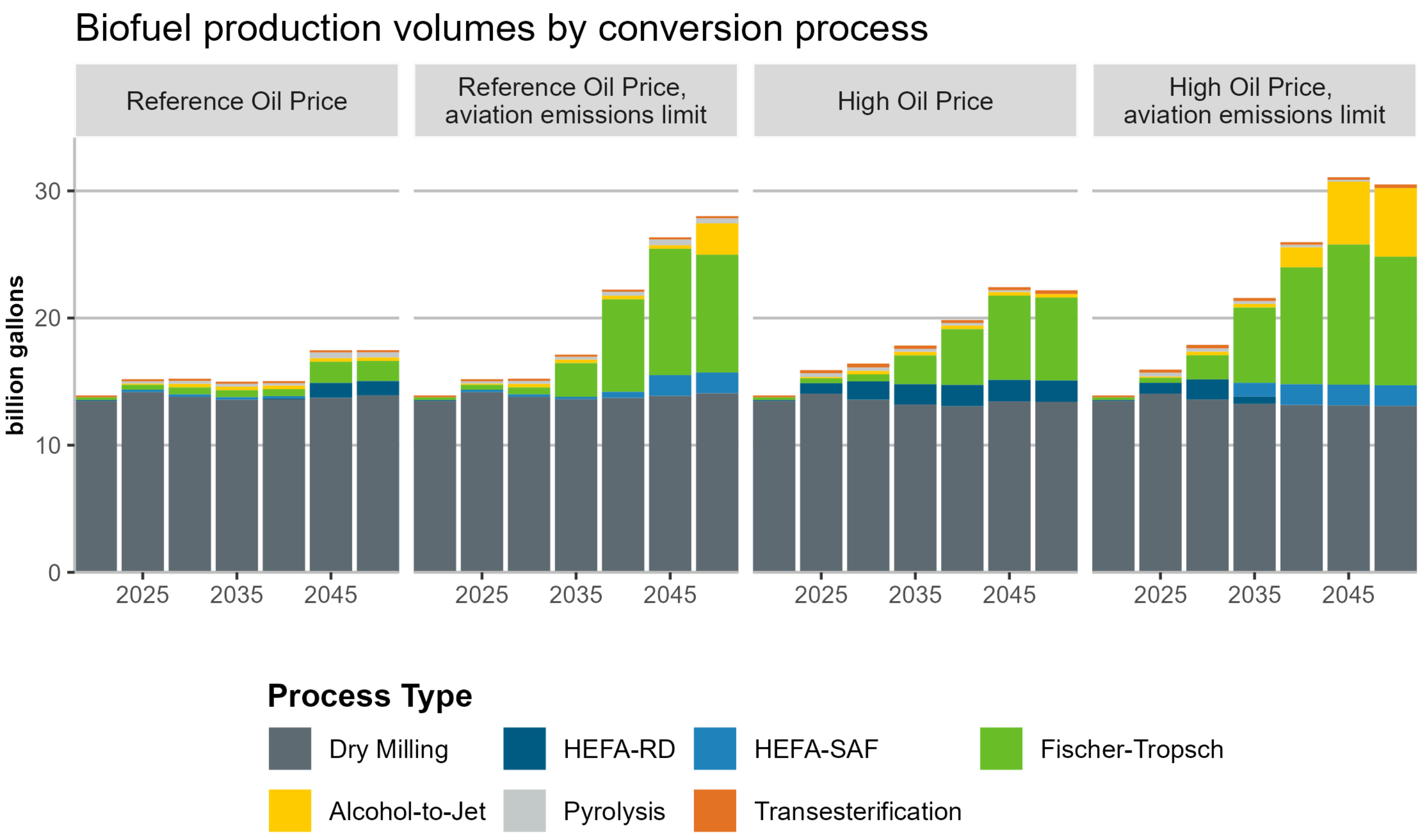


- Corn ethanol production is stable out to 2050.
  - E10 demand trajectories from AEO 2021 imply slow transition to EVs.
- SAF production in 2050 ranges from 1 billion gals to 9 billion gals.
- Fuels co-produced with SAF are blended into the conventional gasoline and diesel pools.
  - Without aviation emissions limit, bio-based diesel blendstock production > SAF production.

Note: Domestic corn ethanol (complemented by sugarcane ethanol imports) serves E10 demand as well as export market and ethanol industrial demand. See supplementary slide for additional details on the components of the material balance equation for ethanol.

2 – Progress and outcomes:

HEFA process maximizes renewable diesel or SAF yield depending on market conditions and emissions limits; HEFA flexibility in input (soybeans or FOGs) and output mix is valuable.

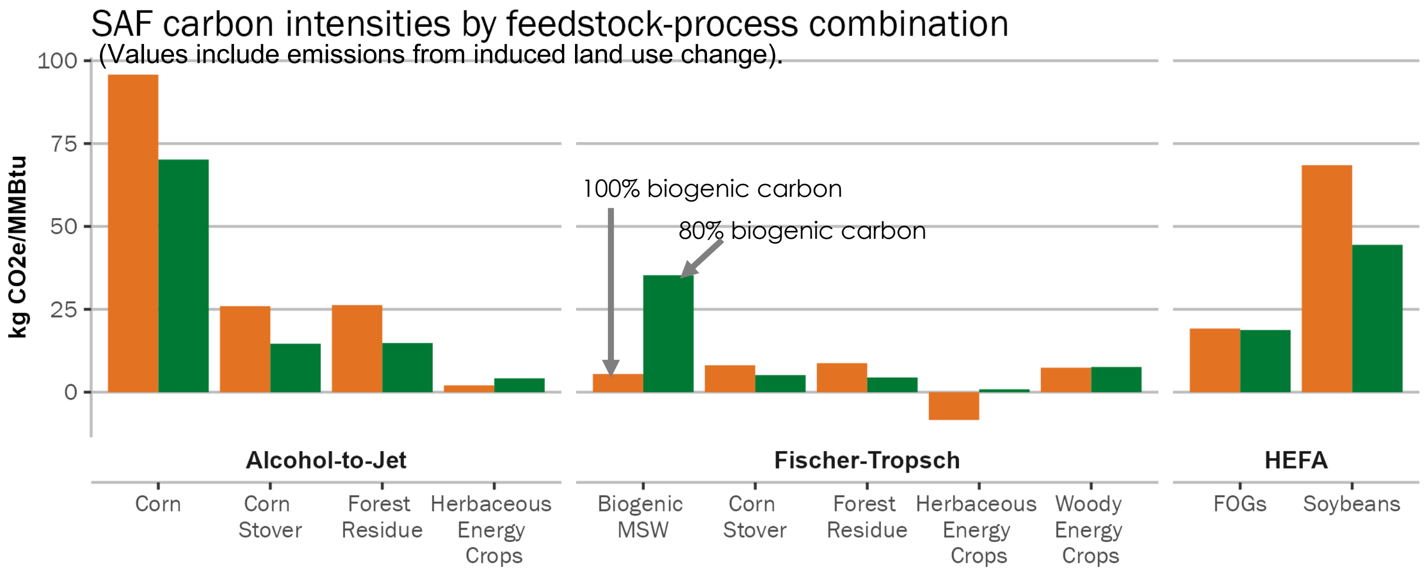


- From 2035 onward in scenarios with high oil prices, HEFA output is resource-constrained.
- Besides dry milling, Fischer-Tropsch is the preferred process.
  - Fischer-Tropsch has a lower SAF output share than HEFA or alcohol-to-jet.
  - Wholesale prices of gasoline and diesel are higher than for jet fuel; the economics of SAF biorefineries producing large shares of fuels in those ranges more attractive.

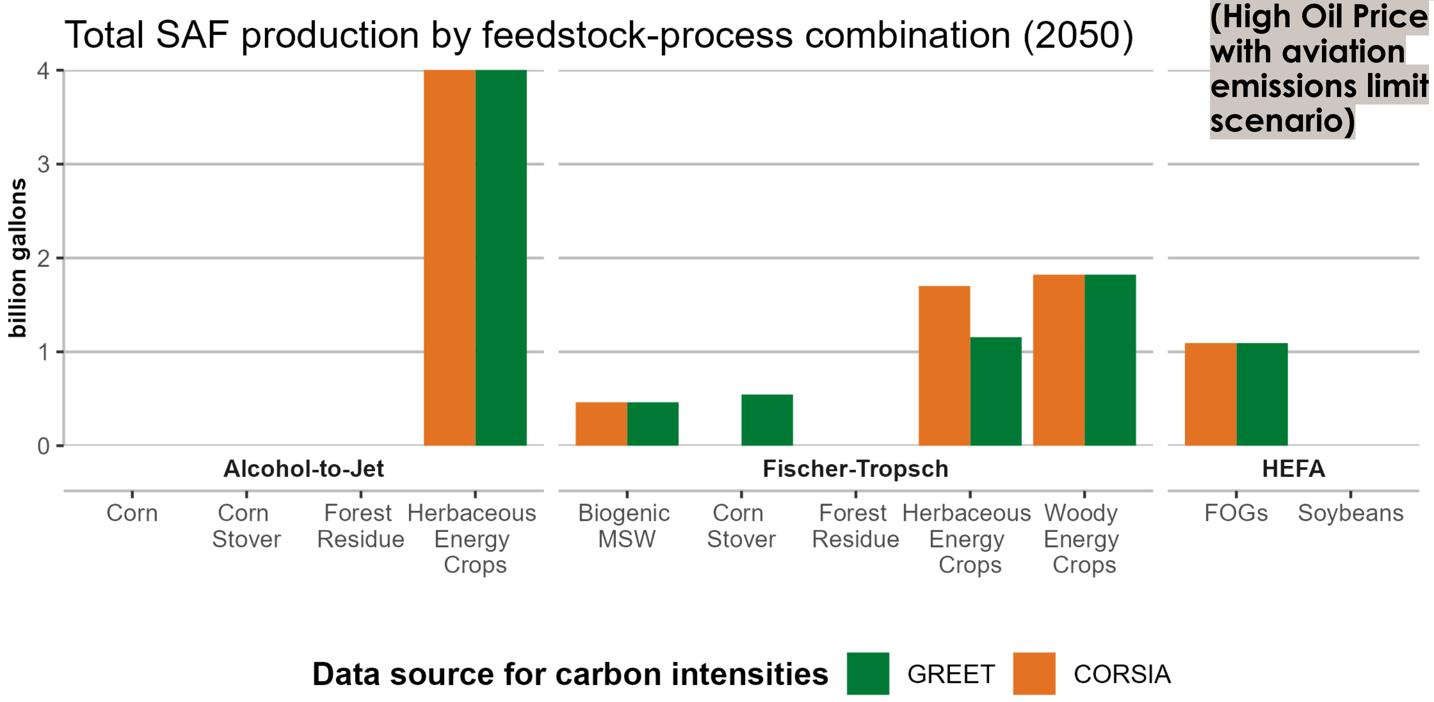
2 – Progress and outcomes:
The lowest cost option to meet the simulated aviation emissions limit involves a mixture of processes and feedstocks with low carbon intensities.

- Despite differences in absolute values, the ranking of SAF production pathways in terms of carbon intensity is very similar across the two data sources considered.
- Small differences in the feedstock mix for the Fischer-Tropsch process to meet the emissions limit are consistent with the differences in carbon intensity across the two data sources.

MODEL INPUTS

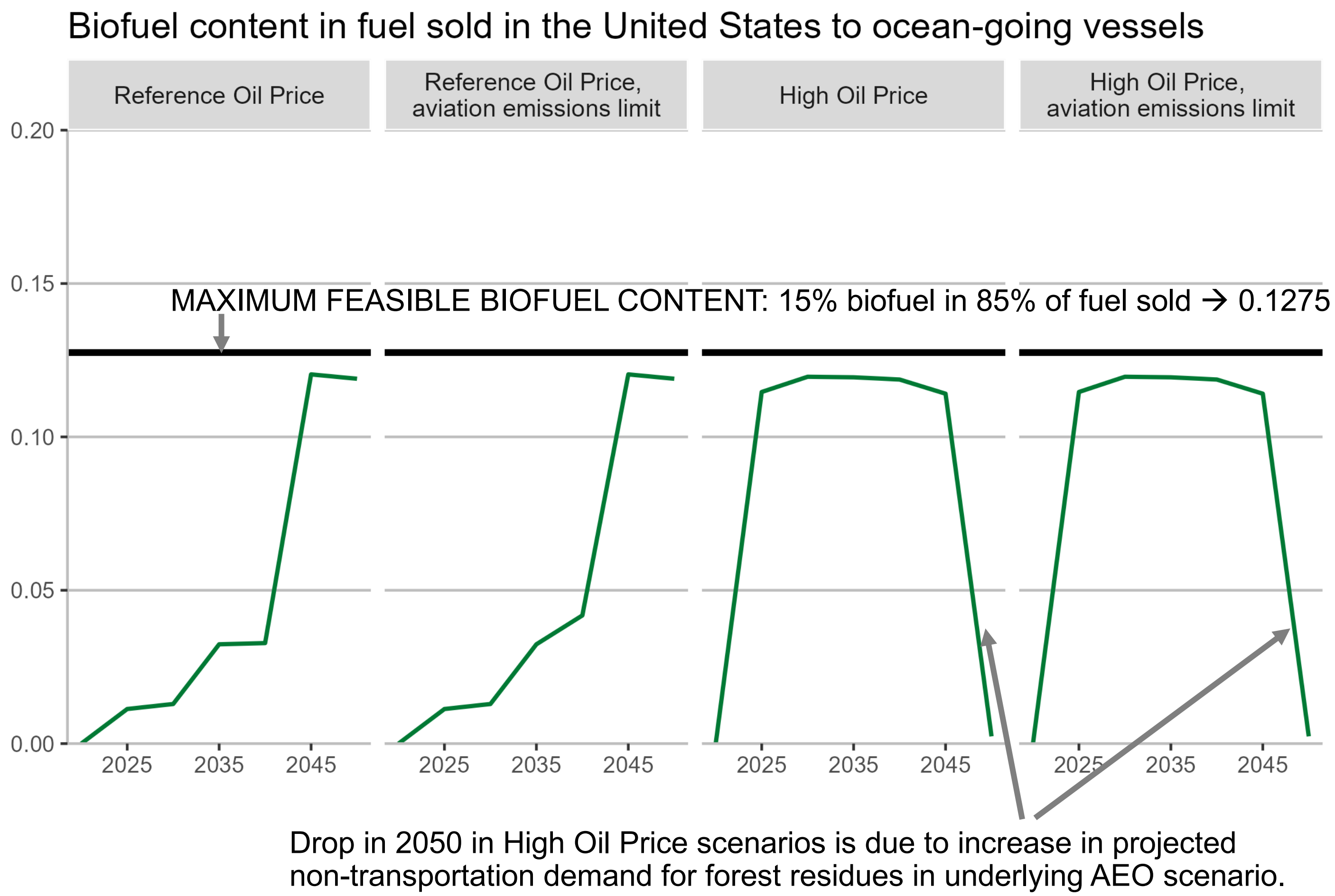


MODEL RESULTS (High Oil Price with aviation emissions limit scenario)



Note: MSW supply in BioTrans only includes MSW with 100% biogenic carbon so the carbon intensity for that pathway was not modified in the CORSIA model run.

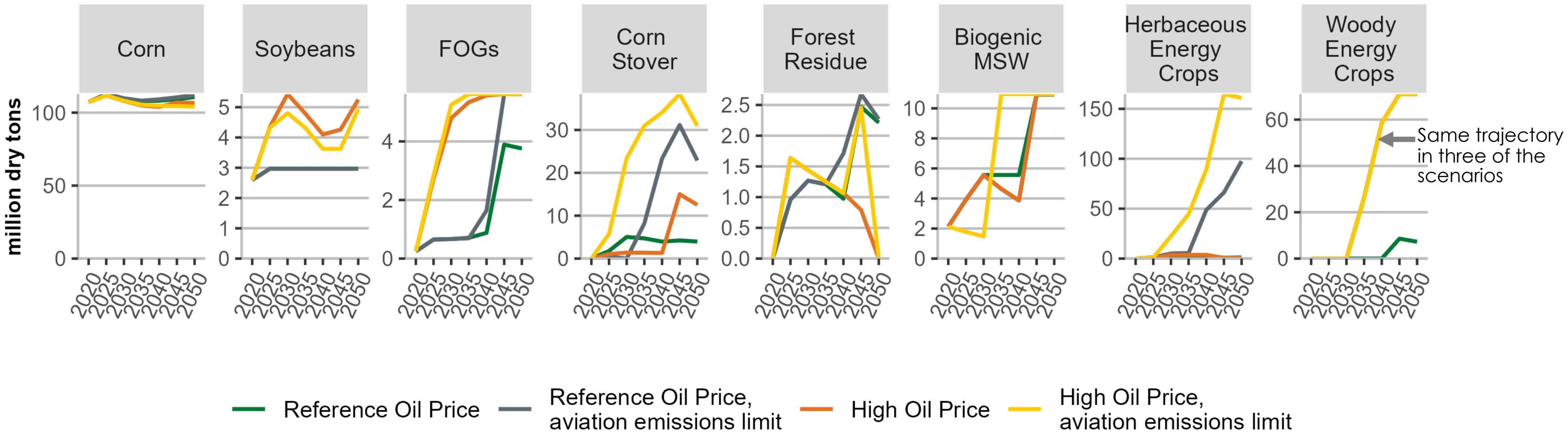
Recent new sulfur regulations for fuel used by ocean-going vessels help biofuels be more competitive; non-transportation demands limit feedstock availability for marine biofuel.



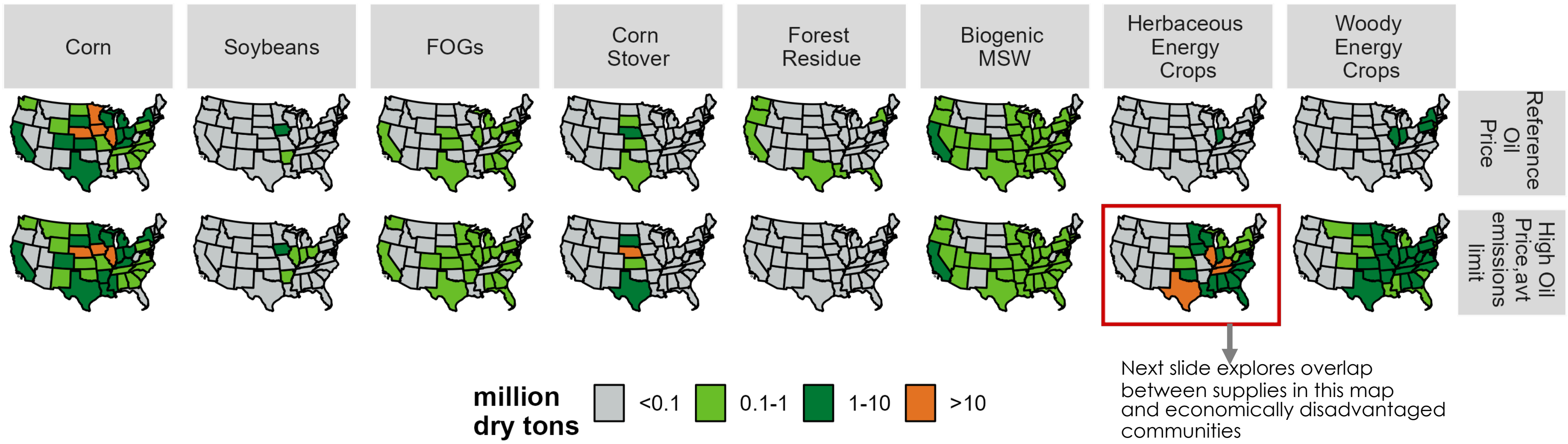
- The only (non-distillate) marine biofuel pathway considered is a fast pyrolysis bio-oil using forest residue as feedstock that can be blended (up to 15% by volume) with residual fuel oils.
- Assumptions:
  - 15% of fuel demand for international shipping is from vessels with scrubbers that only consume the lowest cost high-sulfur fuel oil (HFO).
  - The rest use very low sulfur fuel oil (VLSFO) to comply with the new sulfur limits on marine fuel implemented in 2020.
    - VLSFO continues to trade at the average premium of 25% relative to HFO observed in the U.S. Gulf Coast in 2019–2020.

2 – Progress and outcomes:
With high oil prices or an aviation emissions limit, energy crops provide the largest share of feedstock for production of SAF and marine fuel by 2050.

Feedstock volumes used for biofuel production



Spatial distribution of feedstock supplied for biofuel production in 2050



- The total feedstock volume used for biofuel production in 2050 ranges from 143 million dry tons (*Reference Oil Price*) to 389 million dry tons (*High Oil Price with aviation emissions limit*).
- Four states (TX, NE, IL, IA) provide 45% of total biomass feedstock dedicated to biofuel supply in the *High Oil Price with aviation emissions limit scenario* in 2050.
  - 32 states supply more than 1 million dry ton of feedstock.

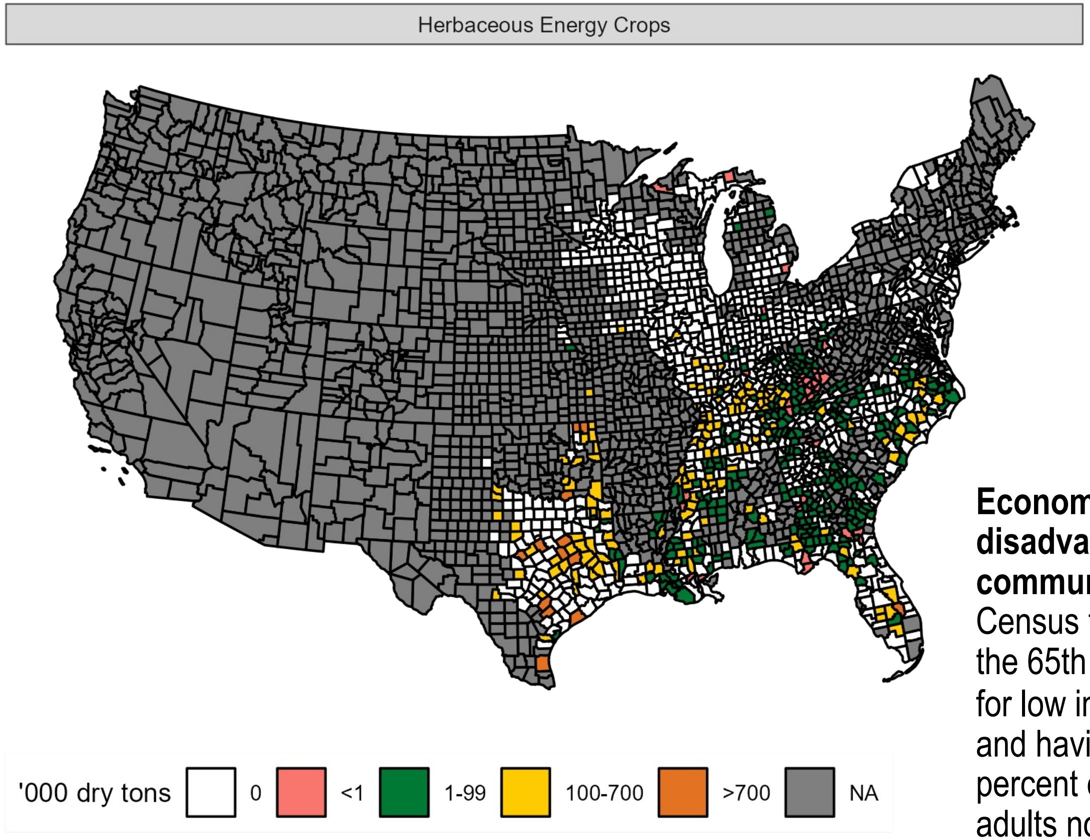
2 – Progress and outcomes:

Substantial potential volumes of herbaceous energy crops overlap with disadvantaged communities that could especially benefit from new economic activity.

Feedstock	Supply percentage originating from counties with >= 50% population in economically disadvantaged communities	Gross sales revenue in counties with >= 50% population in economically disadvantaged communities (million 2020 US$)
Herbaceous Energy Crops	37%	3,355

- There are substantial (potential) volumes of low-cost switchgrass and miscanthus in counties with a large fraction of economically disadvantaged population (28 counties in FL, OK, TX have sufficient volumes to feed one or more standard size biorefineries).

BioTrans biomass feedstock supply quantities
in counties with >=50% economically disadvantaged population
(High Oil Price, aviation emissions limit scenario, 2050)



Economically disadvantaged communities: Census tracts above the 65th percentile for low income and having 80 percent or more of adults not enrolled in higher education

Analysis is aligned with BETO goals of decarbonization and just transition.

- **Decarbonization**:
  - Policy and incentives are necessary to enable growth of the nascent SAF industry.
  - BioTrans is well-suited to analyze policy impacts; identify gaps/needs.
    - Appropriate scope: state-level detail, all transportation biofuels included
    - Will depict policy ecosystem
    - Can explore impact of international policies through biofuel import supply/export demand curves
- **Just transition**:
  - Meeting the SAF Grand Challenge will require developing new feedstocks and supply chains.
  - Information on economic equity implications of different SAF scenarios/feedstocks is a useful input to mobilize resources in the context of the *Justice40* initiative.

U.S. biofuel policies:
- *RFS*
- *BTC*
- *IRA tax credits*
- *LCFS (CA,WA,OR)*
- *Other state incentives*

What is the total incentive stack for different biofuel types in different states/years?

Which communities could especially benefit from workforce development/financial incentives to participate in SAF industry as biomass feedstock providers?

A nimble tool for exploring uncertainties and scenarios related to aviation and marine biofuels markets and policy.

- System analysis tools that can help evaluate efficiency and distributional implications of different biofuel use scenarios are valuable to inform R&D and policy decisions.

BioTrans scenarios combine:

- **AEO scenarios**
  - Oil price levels, LDV electrification trends
- **Billion Ton Study scenarios**
  - Feedstock supply availability and cost
- Alternative datasets for **carbon intensity values** of each biofuel pathway
  - CORSIA/GREET
- Existing and proposed **policies and incentives** (federal and state-level)
- Other sensitivities: **biomass use for non-transportation purposes** (biopower, bioproducts), technoeconomic and market **parameter uncertainties**;

- Effort to develop a model structure that promotes flexibility through the modular separation of data (domain of application) vs. analysis (reusable model structure and estimation routines).

Having state-level results and including economic equity considerations help connect large-scale model results to industry stakeholders and specific communities.

- Census Divisions (the spatial units in the previous version of BioTrans) were not spatial units that industry stakeholders or policymaking agencies naturally think about.
- Combining information from Billion Ton study + BioTrans + CEJST helps **identify opportunities to increase the economic benefits from biofuel production realized by disadvantaged communities**.
  - Substantial overlap between potential suppliers of low-cost bioenergy feedstocks and economically disadvantaged populations.
  - High unemployment counties with significant potential biomass supply are attractive locations for workforce development programs in bioenergy feedstock growing/processing activities.
  - Bioenergy feedstocks can help diversify/mitigate the risk of agricultural value loss due to natural hazards in some areas.

Summary

- This project contributes to understanding and enhancing socioeconomic and environmental benefits of bioenergy through economic and policy analysis.
- A market equilibrium model (BioTrans) is used to explore potential synergies or competition for biomass across transportation segments (focusing on aviation and marine) under alternative futures (2020–2050).
- Insights from no-policy baseline scenarios combining different oil price levels and a constraint on aviation emissions:
  - Based on market prices alone, the mix of biofuels that maximizes the value of biomass use in transportation sector primes substitution of petroleum-based diesel rather than jet fuel.
  - Scenarios that require substantial growth in aviation and marine fuel production reveal instances of resource supply constraints (FOGs), strong competition from non-transportation uses (forest residues), and a central role for dedicated energy crops.
- Linking county-level info on feedstock supply from model solution to CEJST metrics allows exploring economic equity implications of model scenarios.
- Work is ongoing to introduce biofuel-related policies and incentives (federal and state level) into the model and examine their effects on biofuel mix and transportation fuel prices.
- *Project impact will be realized by delivering a nimble, transparent tool for scenario analysis that can evaluate combinations of technoeconomic, market, and policy levers of interest for policymakers and industry stakeholders*.

Quad Chart Overview

Timeline

- *Project start date: October 2021*
- *Project end date: September 2024*

	FY22 Costed	Total Award
DOE Funding	*FY22 costed: $185K*	*FY22 budget authority: $250K* *FY23 budget authority: $250K*
Project Cost Share *	NA	NA

TRL at Project Start: NA
TRL at Project End: NA

Project Goal

The goal of this project is to develop a tool to model the effects of market conditions and policy incentives on rates on biofuel use in "hard-to-decarbonize" transportation sectors. It will consider economic efficiency aspects as well as emissions reductions and also consider potential energy justice implications of biofuel feedstocks/mixes chosen.

End of Project Milestone

By 09/30/2024, publish model and results from a collection of scenarios contrasting the effects on biofuel volumes used, biofuel mix, biofuel prices, DEI implications of different state, national, and international –level policies/incentives.

Funding Mechanism

Lab call

Project Partners*

- UC Davis (subcontract starting FY23Q2)

*Only fill out if applicable.

Additional Slides

Acronyms

- AEO – Annual Energy Outlook
- BTC – Biodiesel Tax Credit
- CEJST – Climate and Economic Justice Screening Tool
- CORSIA – Carbon Offsetting and Reduction Scheme for International Aviation
- EV – Electric vehicle
- GAMS – General Algebraic Modeling System
- GREET – Greenhouse gases, Regulated Emissions, and Energy use in Transportation
- HEFA – Hydrotreated esters and fatty acids
- HFO – High-sulfur fuel oil
- IRA – Inflation Reduction Act
- LCFS – Low Carbon Fuel Standard
- LDV – Light-duty vehicle
- MSW – Municipal solid waste
- RFS – Renewable Fuel Standard
- SAF – Sustainable aviation fuel
- VLSFO – Very low sulfur fuel oil

Responses to Previous Reviewers' Comments

- Reviewer comments:
  - It would be helpful as the model matures for the analysis responsiveness to be faster/more nimble so that the modeling team can respond to policy questions more rapidly.
  - There appears to be too much focus on ethanol in lieu of more relevant long-term analysis; focus on octane standard seems a bit outdated compared to this model's potential to evaluate SAFs and bio-based materials.
- Response:
  - We agree with the importance/value of being nimble, in keeping with changing technological options and evolving programmatic priorities. The content of the model and questions of analysis have evolved over time to stay in synch with the priorities in the BETO Multiyear Program Plan. Aviation and marine fuels are gaining increasing relevance for BETO and we are in the process of redirecting our analysis toward them, in connection with the larger DOE/EERE research community and DOT/MARAD. We do believe it is important to continue including LDV ethanol/biofuel use in the model as it remains a large biomass use over the intermediate term (transitional period) and may influence biomass volume availability and cost for other sectors. Our goal is for the project to offer tools to assess bioenergy market outcomes in a variety of scenarios, including alternative policy incentives/policy designs, and have a framework that is sufficiently flexible to be able to look at many potential policies without requiring extensive modifications of model structure. We note that, operationally, we promote the flexibility of our tools and approaches through the modular separation of data (domain of application) vs. analysis (the re-usable model structure and estimation routines) and through a well-documented/replicable code and workflow.
- No Go/No-Go Review has taken place for this project yet.

Milestones table

Milestone Name/Description	End Date	Type
Data gathering: Data will be gathered from 1) EIA, 2) agencies/entities focused on the aviation and marine sector, 3) peer-reviewed literature. Target data are state (or sub-state depending on data availability) level production and consumption of jet fuel and SAF, installed and planned capacity for SAF production, TEA and LCA data of SAF and marine fuel pathways, supply of biomass and waste feedstocks used in the SAF/marine fuel production pathways.	12/31/2021	Quarterly
Model development for inclusion of SAF feedstocks, conversion process, and end markets: Modify structure of BioTrans including transition to new spatial units and depiction of initial set of feedstocks, processes and end use markets for SAF and marine biofuels. Using the resulting version of the model, conduct initial scenario analysis exploring 1) biofuel mix used for SAF production under various market conditions, 2) biofuel mix when SAF and marine fuel demands are considered together to identify potential synergies and competition, 3) explore model solution subject to a constraint consistent with IATA-IMO's aspirational goals of 50% reduction by 2050.	03/31/2022	Quarterly
DEI metrics memo: Develop initial set of DEI metrics by linking the model results for which spatial resolution is sufficiently high (at least county-level) to income and demographic data from the US Census and/or information from EPA's EJSCREEN tool.	06/30/2022	Quarterly
Model description with discussion of initial market scenarios and DEI metrics: Prepare a technical report that describes the new version of the model and discusses the results from modeling done during FY22Q2 (scenarios exploring biofuel mix considering SAF demand only and SAF plus marine fuel demand with or without ICAO-IMAO 2050 decarbonization targets) and FY22Q3 (pilot examples of application of DEI metrics to scenario results). The technical report will include as appendix detailed documentation of the new version of BioTrans. The information in the technical report will also be converted into a manuscript for publication in a peer-reviewed journal.	09/30/2022	Annual SMART
BioTrans model development: Add new features and detail to the model: 1) depicting international trade of biofuels, 2) reviewing lifecycle emission assumptions for biofuel pathways using GREET's aviation module, 3) implementing workflow to run BioTrans in one of ORNL's HPC assets to enable more extensive sensitivity and scenario analysis capabilities	12/09/2022	Progress measure

BioTrans model

- Partial equilibrium model
  - Depicts transportation fuel markets and their supporting fuel supply chains; it does not capture indirect effects of fuel/biofuel production activities through the entire economy.
- Intertemporal optimization: perfect foresight (i.e., single model run to solve entire modeling period) or limited foresight (rolling solution windows for subsets of periods)
  - Connections across periods are captured through an equation of motion for biorefinery capacity
- Modeling period: 2020–2050; temporal units: years
- Spatial scope: Unites States; spatial units: U.S. states
- Material balance equation for each combination of commodity, state, and year
  - Sources: internal supply, imports, output from an intermediate conversion process at upstream stage of supply chain
  - Sinks: internal demand, exports, input to an intermediate conversion process in downstream stage of supply chain
- Elastic supply and demand curves
  - Nonlinear biomass feedstock supply curves (functional form captures nonlinear increase in supply cost at feedstock levels close to 100% resource availability)
  - Linear petroleum product supply curves
  - Nonlinear transportation fuel demand curves (constant elasticity functional form)
- Objective function: Maximization of social surplus

CEJST metrics definitions

- **Economically disadvantaged communities**:
  - Census tracts above the 65th percentile for low income and having 80% or more adults not enrolled in higher education
- **High unemployment communities**:
  - Census tracts that are above the 90th percentile for unemployment, have low high school attainment, and a high percent of residents that are not higher education students
- **Communities with high expected agricultural loss rate**:
  - Census tracts that are at or above the 90th percentile for expected agricultural loss rate, have low income, and have a high percent of residents that are not higher education students.
    - This is one of the metrics in the CEJST to identify communities with high climate change risk. The expected agricultural value loss data source used in the CEJST is FEMA's National Risk Index. It measures expected agricultural value lost due to 18 natural hazards that have some link to climate change.

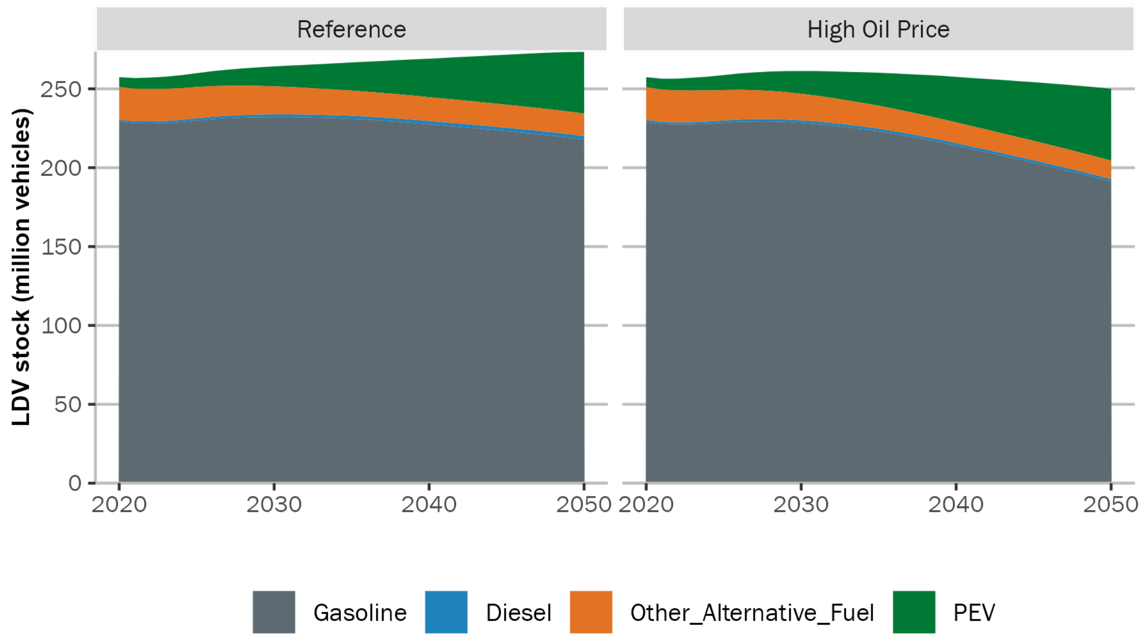
Ethanol supply-demand balance

- Ethanol material balance equation:

Domestic Corn Ethanol Production	+	Sugarcane Ethanol Imports	=	Domestic Fuel Blend Demand	+	Ethanol Industrial Demand	+	Corn Ethanol Export Demand
High Oil Price Scenario 2020: **13,484** million gallons		High Oil Price Scenario 2020: **537** million gallons		High Oil Price Scenario 2020: **11,959** million gallons		High Oil Price Scenario 2020: **782** million gallons		High Oil Price Scenario 2020: **1,280** million gallons
High Oil Price Scenario 2050: **12,962** million gallons		High Oil Price Scenario 2050: **108** million gallons		High Oil Price Scenario 2050: **11,014** million gallons		High Oil Price Scenario 2050: **776** million gallons		High Oil Price Scenario 2050: **1,280** million gallons

- E10 reference demand derived from AEO2021 High Oil Price case is 10% lower in 2050 than 2020; similar to the decrease in the model solution.
- The number of gasoline-powered LDVs barely changes by 2050 in the AEO2021 reference scenario; it decreases by 17% in the High Oil Price case.

U.S. light-duty vehicle stock by vehicle category (AEO2021)



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