Spatially Varying Costs of GHG Abatement with Alternative Cellulosic Feedstocks for Sustainable Biofuels

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Introduction

- Cellulosic feedstocks (e.g., corn stover and perennial crops) offer a promising source for scaling up sustainable aviation fuel (SAF) production with less conflict with food crops compared to using food crops for biofuels because they are high yielding and can be grown productively on low quality land.
- The breakeven price and carbon intensity of cellulosic feedstock-to-SAF pathways are likely to differ across feedstocks and across spatial locations due to differences in feedstock attributes, productivity, opportunity costs of land for feedstock production, soil carbon effects and feedstock composition.
- The choice of preferred feedstock at each location will depend on various features of these feedstocks and their interaction with incentives provided by policy.

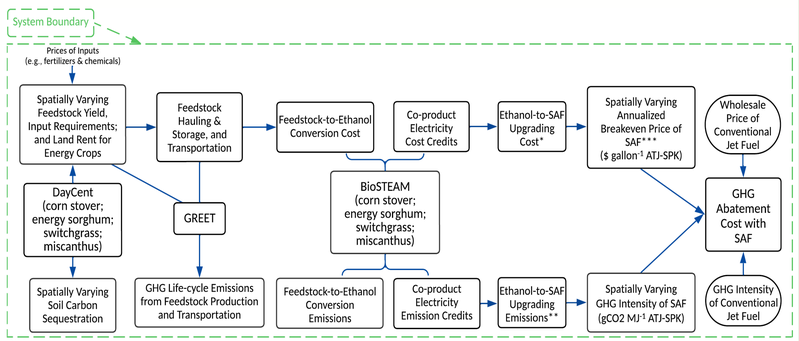
Objective

- This study integrates feedstock to fuel supply chain economics and life-cycle carbon accounting using the same system boundary to identify the feedstocks that will be preferred for SAF production by location according to four criteria:
  - ➢ biofuel production per unit land;
  - ➢ GHG intensity per unit biofuel;
  - ➢ breakeven price per unit biofuel; or
  - ➢ cost of abatement per ton of GHG abated relative to conventional jet fuel.

Methodology

- We develop an assessment framework that integrates feedstock production economics and biogeochemical effects with techno-economic analysis (TEA) and life-cycle analysis (LCA) to estimate
  - ➢ the spatially varying yields, GHG intensity, breakeven prices, and GHG abatement costs of Alcohol-to-Jet (ATJ) derived SAFs from four feedstocks (corn stover, miscanthus, switchgrass, and energy sorghum) at the 4 km resolution of the US. rainfed region.
- Spatial heterogeneity in feedstock production and soil carbon effects are simulated using a biogeochemical model DayCent (Daily CENTURY)[1]
- Biorefinery processes are simulated using a refinery scale model BioSTEAM (Biorefinery Simulation and Techno-Economic Analysis Modules)[2]

The System Boundary for SAF TEA and LCA



Note:
DayCent: Daily CENTURY model; GREET: Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model; BioSTEAM: Biorefinery Simulation and Techno-Economic Analysis Modules; SAF: Sustainable Aviation Fuel; AJT-SPK: alcohol-to-jet synthetic paraffinic kerosene.
* Determined by Geleynse et al. [3]; ** Determined by the GREET Aviation Module [4];*** A life span of 10 years for switchgrass and 15 years for miscanthus.

Figure 1. The system boundary for feedstock-to-SAF pathways

Results and Conclusions

- While miscanthus and energy sorghum-based SAF dominate much of the rainfed region in terms of highest biomass yields per unit land, corn stover leads to the lowest breakeven price of SAF per gallon and switchgrass-based SAF is dominant for its lowest carbon intensity.
- The cost of abating GHG emissions with SAF ranges from \$181 Mg^{-1} CO_2e to more than \$444 Mg^{-1} CO_2e and is lowest with miscanthus in the Midwest, switchgrass in the south, and energy sorghum in a relatively small region in the Great Plains.
- While corn stover-based SAF has the lowest breakeven price, it has the highest cost of abatement due to its relatively high GHG intensity.

References

(1) Del Grosso, S.; Parton, W.; Keough, C.; Reyes-Fox, M. *Special features of the DayCent modeling package and additional procedures for parameterization, calibration, validation, and applications*. In Methods of Introducing System Models into Agricultural Research; Lal, R., Ma, L., Eds.; American Society of Agronomy, Inc.; Crop Science Society of America, Inc.; Soil Science Society of America, Inc.: Madison, WI, **2011**, 155−176.

(2) Cortes-Peña, Y.; Kumar, D.; Singh, V.; Guest, J. S. BioSTEAM: A Fast and Flexible Platform for the Design, Simulation, and Techno-Economic Analysis of Biorefineries under Uncertainty. *ACS Sustain. Chem. Eng.* **2020**, *8*, 3302–3310.

(3) Geleynse, S., Brandt, K., Garcia-Perez, M., Wolcott, M., Zhang, X. The Alcohol-to-Jet Conversion Pathway for Drop-In Biofuels: Techno-Economic Evaluation. *ChemSusChem* **2018**, *11*, 3728–3741.

(4) Wang, M.; Elgowainy, A.; Lee, U.; Baek, K.; Bafana, A.; Benavides, P.; Burnham, A.; Cai, H.; Capello, V.; Chen, P.; Gan, Y.; Gracida-Alvarez, U.; Hawkins, T.; Iyer, R.; Kelly, J.; Kim, T.; Kumar, S.; Kwon, H.; Lee, K.; Zaimes, G. *Summary of Expansions and Updates in GREET ® 2022*; Argonne National Laboratory, Argonne, IL, **2022**. https://www.osti.gov/biblio/1891644 (accessed 2024-01-05).

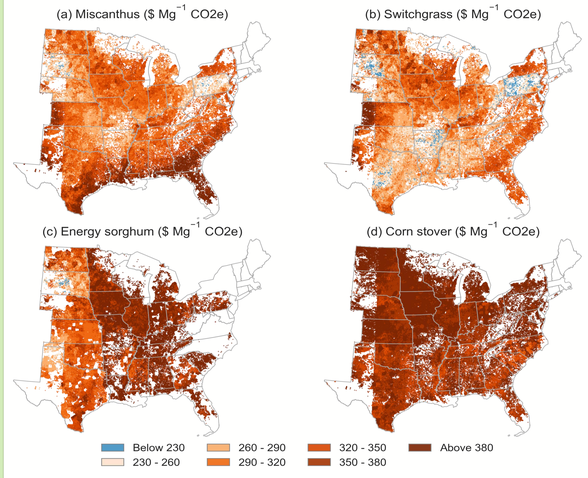


Figure 2. Spatial distribution of feedstock-specific annualized GHG abatement cost of SAF

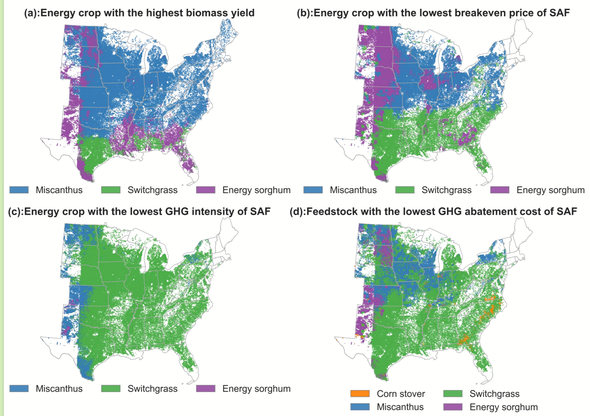


Figure 3. Optimal choice of feedstock for SAF production by location based on objective

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