DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

Agent-based Modeling for the Multi-objective Optimization of Energy Production Pathways: Integrated Techno-economics and Life Cycle Assessment

Data, Modeling and Analysis

Dr. Jason Quinn
Colorado State University

ENERGY INSTITUTE
COLORADO STATE UNIVERSITY

OUTLINE

- Project Overview
- Approach
- Progress and Outcomes
- Impact
- Summary

OUTLINE

Project Overview

Approach

Progress and Outcomes

Impact

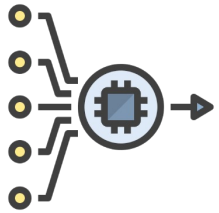
Summary

Project Overview

Project Goal: Provide BETO with an open-source bioenergy tool to evaluate and optimize biofuel-and-bioproduct systems to achieve program and US goals

Problem: Siloing of DOE Sustainability Assessment Models

- ANL – GREET
- NREL – TEA
- INL – Resource Assessment



Solution: Unified and Multipurpose Bioenergy Based Toolset

- Multi-Objective Optimization, Agent Based Modeling, Carbon Costing, TEA/LCA
- High geographic and temporal resolution

Project Timeline

- Length: 36 Months + 18 Month No Cost Extension
- Start Date: April 2020
- Currently: 1st Month of No Cost Extension

Project Overview: Goal Alignment

Sustainable Aviation Fuel Grand Challenge (DOE, DOT, USDA)

- 3 billion gallons SAF per year by 2030
- 35 billion gallons SAF per year by 2050 (or 100% of aviation demand)
- 50% GHG reduction vs 2005 levels

Renewable Fuel Standard (EPA)

- 36 Billion Gallons of Renewable Fuel by 2022
- 50% GHG reduction vs traditional fuel

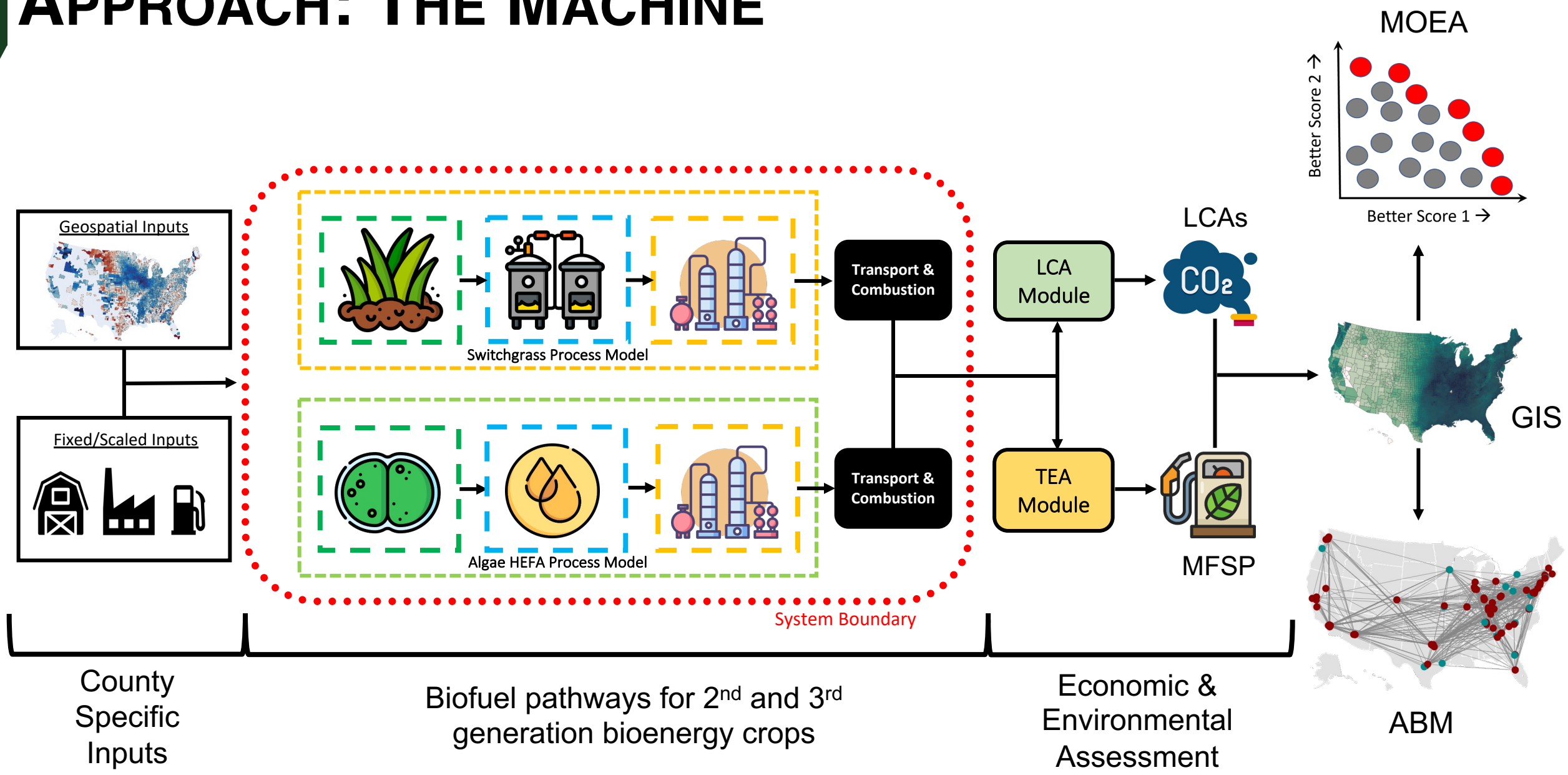
Project Goals

- Provide the DOE with an Open-Source Bioenergy Tool
- Identify optimal fuel pathways to meet US sustainability goals
- Evaluate US SAF production potential (Can we meet 35 bn gallons by 2050?)
- Identify government policies to encourage adoption of bioenergy crops

OUTLINE

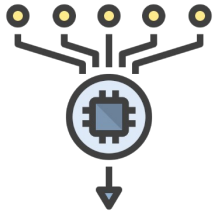
Project Overview | Approach | Progress and Outcomes | Impact | Summary

Approach: The Machine



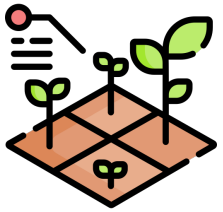
Approach: 200m Resolution GIS Biomass Model

Goal: Determine the land availability and total biomass that can be grown for bioenergy



County-level Outputs

- Land area by land cover
- Crop yield by land cover
- Total biomass grown
- Total biofuel produced
- Mean MFSP
- Mean gCO2eq/gal



Land Exclusions

- Protected areas
- Key Biodiversity Areas
- Steep land grades
- Low crop yields (>$20/gal)

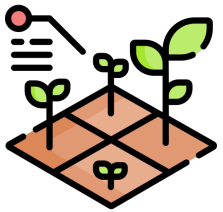
NLCD Land Cover Type	Switchgrass	Miscanthus	Poplar	Algae
Water	No	No	No	No
Perennial Ice/Snow	No	No	No	No
Developed Land	No	No	No	No
Barren Land	No	No	No	Yes
Deciduous Forest	Yes	Yes	Yes	Yes
Evergreen Forest	Yes	Yes	Yes	Yes
Mixed Forest	Yes	Yes	Yes	Yes
Shrubland	Yes	Yes	Yes	Yes
Grassland/Herbaceous	Yes	Yes	Yes	Yes
Pasture/Hay	Yes	Yes	Yes	Yes
Cultivated Crops	Yes	Yes	Yes	Yes
Wetlands	No	No	No	No
Viable Slope	5%	5%	25%	2%
Minimum Yield (Mg/ha)	2.3	2.0	2.4	0.0

Approach: Agent Based Modeling (ABM)

Goal: Understand the impacts of consumer preferences and government policies on bioenergy systems and technology adoption

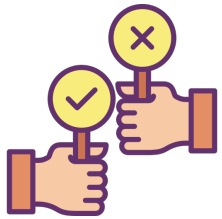
Agent: Each County

Each county is modeled as a farmer with X acres of land



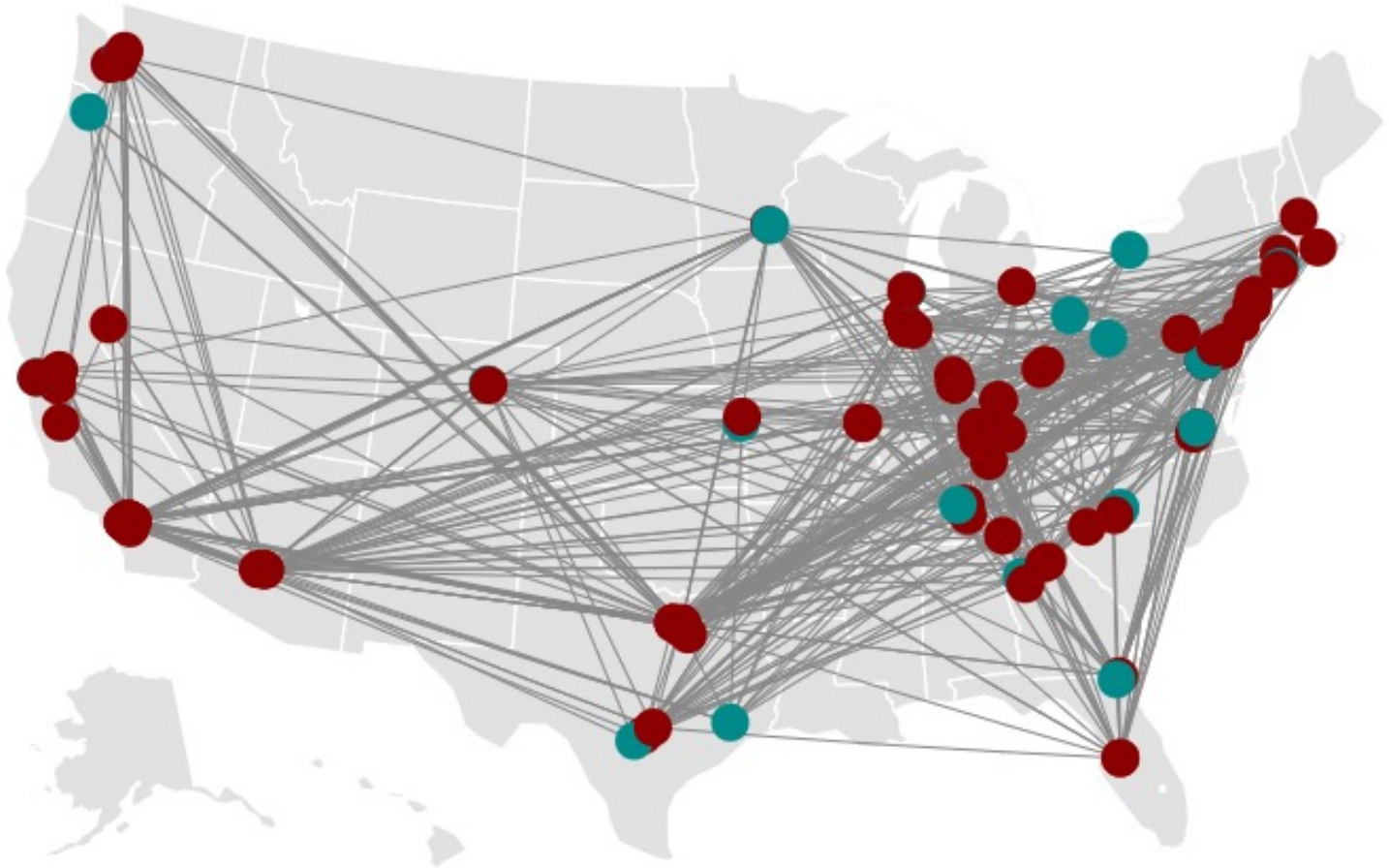
Decision: Which Crops

Each county decides how much area to plant each crop



Variables:

- *Familiarity*
- Profitability
- Environmental Impact

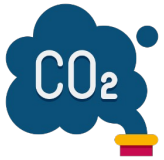


Approach: Multi-Objective Optimization (MOEA)

Goal: Understand tradeoffs between achieving multiple DEO goals

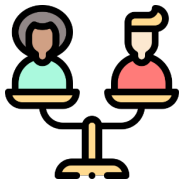
Energy Demand

Fuel Cost

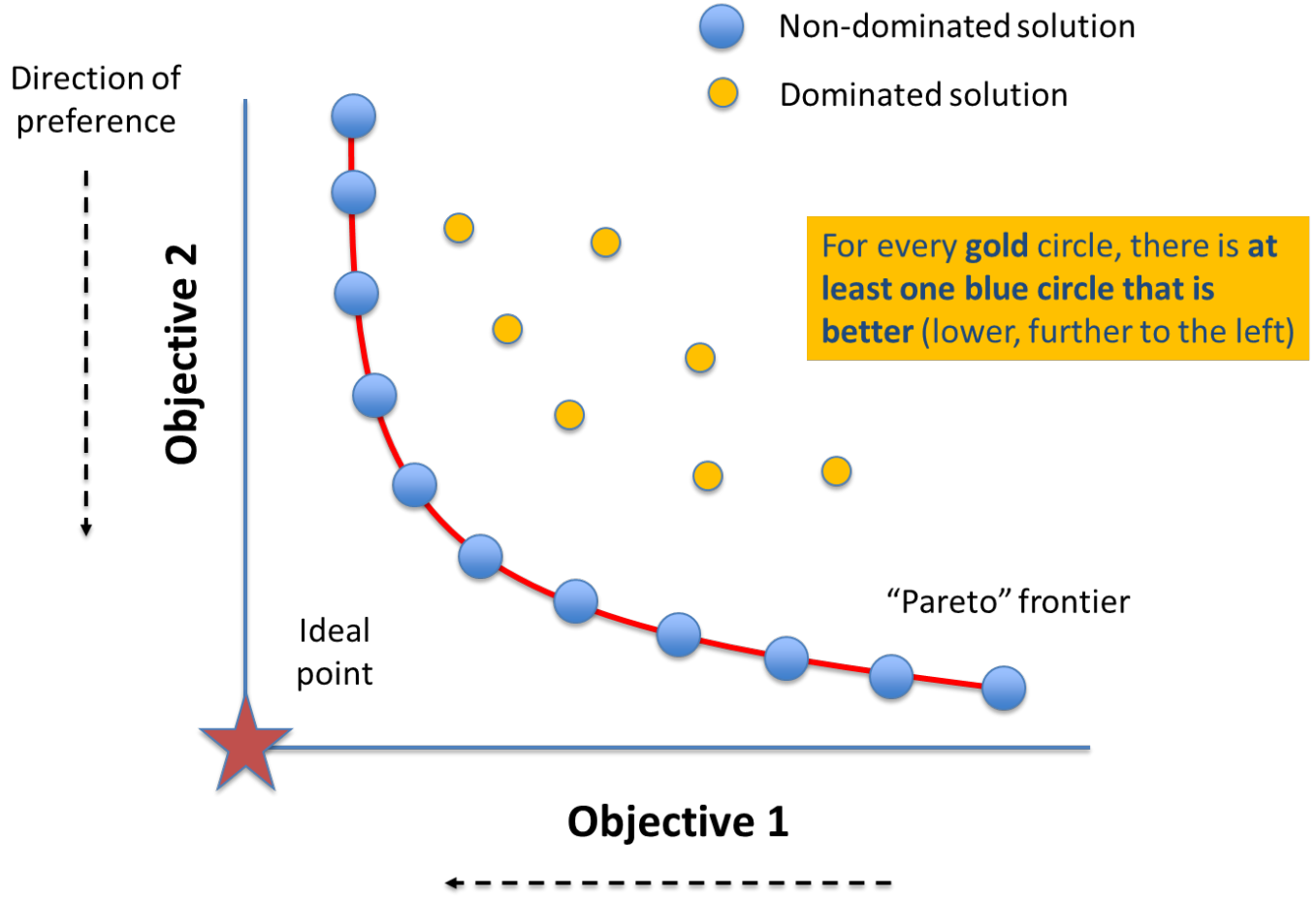


GHG Intensity

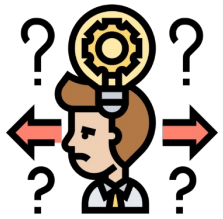
Supply Chain Reliability



System Equity



Approach: Project Risks and Mitigation



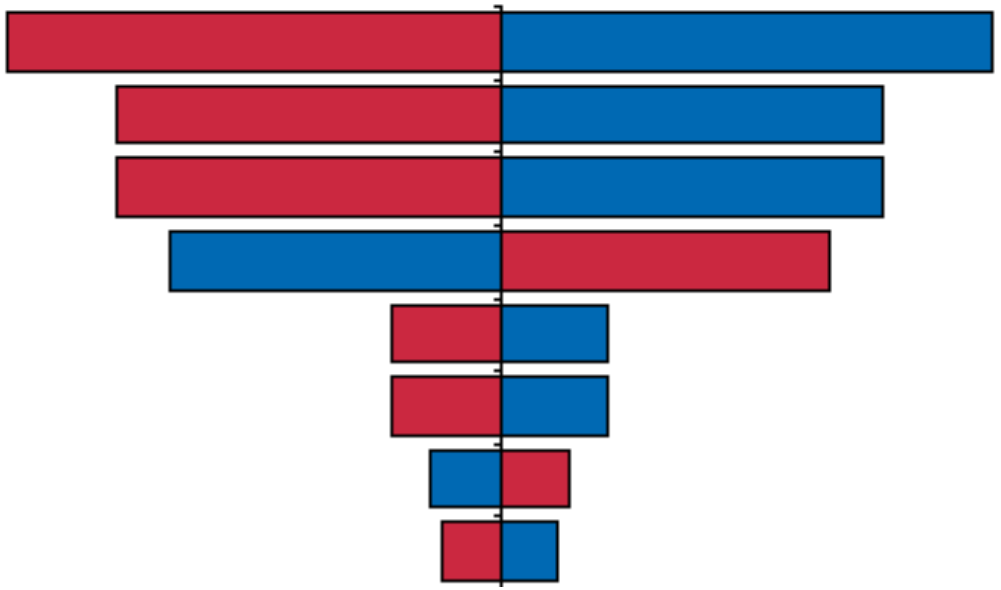
Model Uncertainty

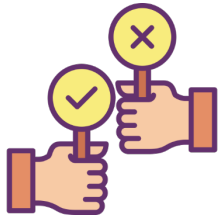
- Sensitivity Analysis
- Optimization of Results

Integration of Models

- Leveraging existing sub-process models
- Using identical inputs for all models

Model Sensitivity Analysis





Go/No Go Decisions (18M/36M)

- 18M: Multiple biofuel production pathways with TRACI 2.1 impact categories
- 36M: Recommendations to DOE for pathways and performance targets

Approach: Diversity, Equity, and Inclusion

Evaluation of System Equity

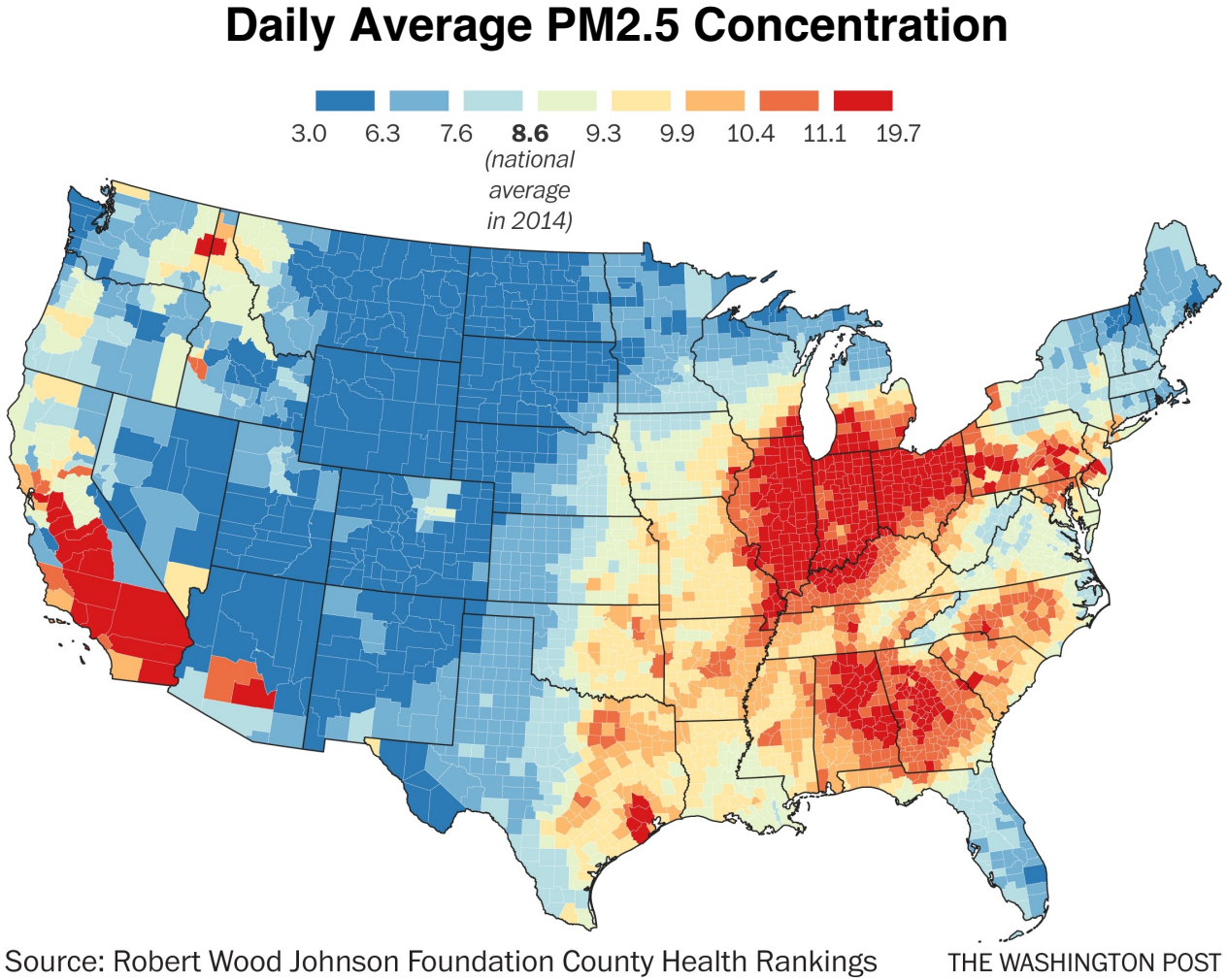
Multi-objective optimization will analyze tradeoffs of equitable vs non-equitable bioenergy systems

Localized Impact Assessment

Multi-objective optimization will evaluate tradeoffs between localized vs dispersed acidification and eutrophication impacts

Air Quality Assessment

Evaluation of air quality metrics (ex. PM2.5) to understand impact of increased bioenergy production



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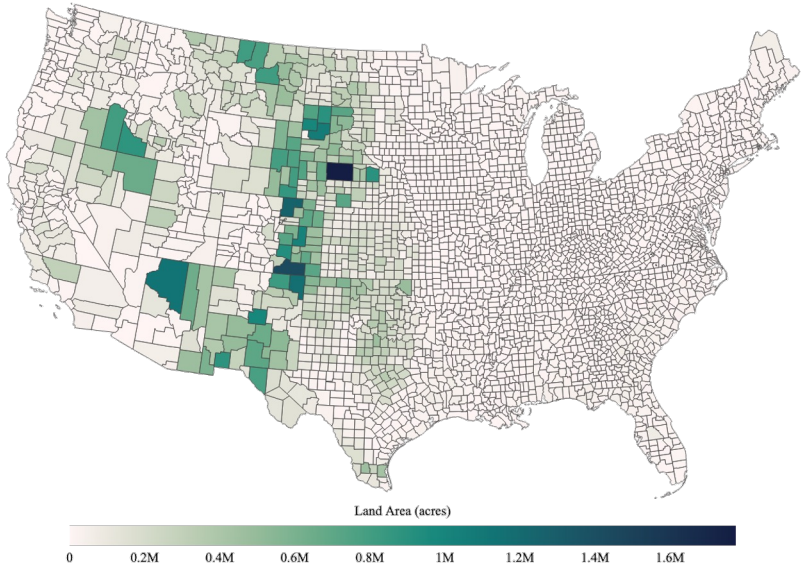
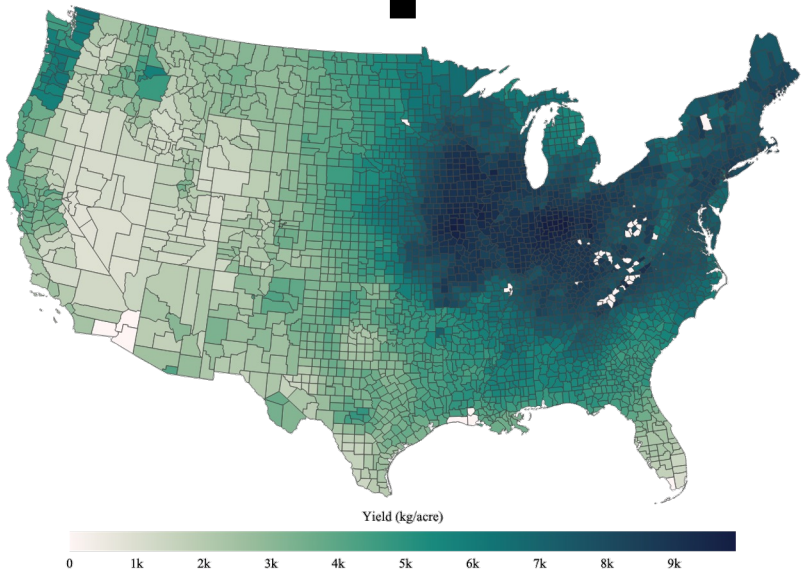
PROGRESS: GIS EXAMPLE (MISCANTHUS + GRASSLAND)

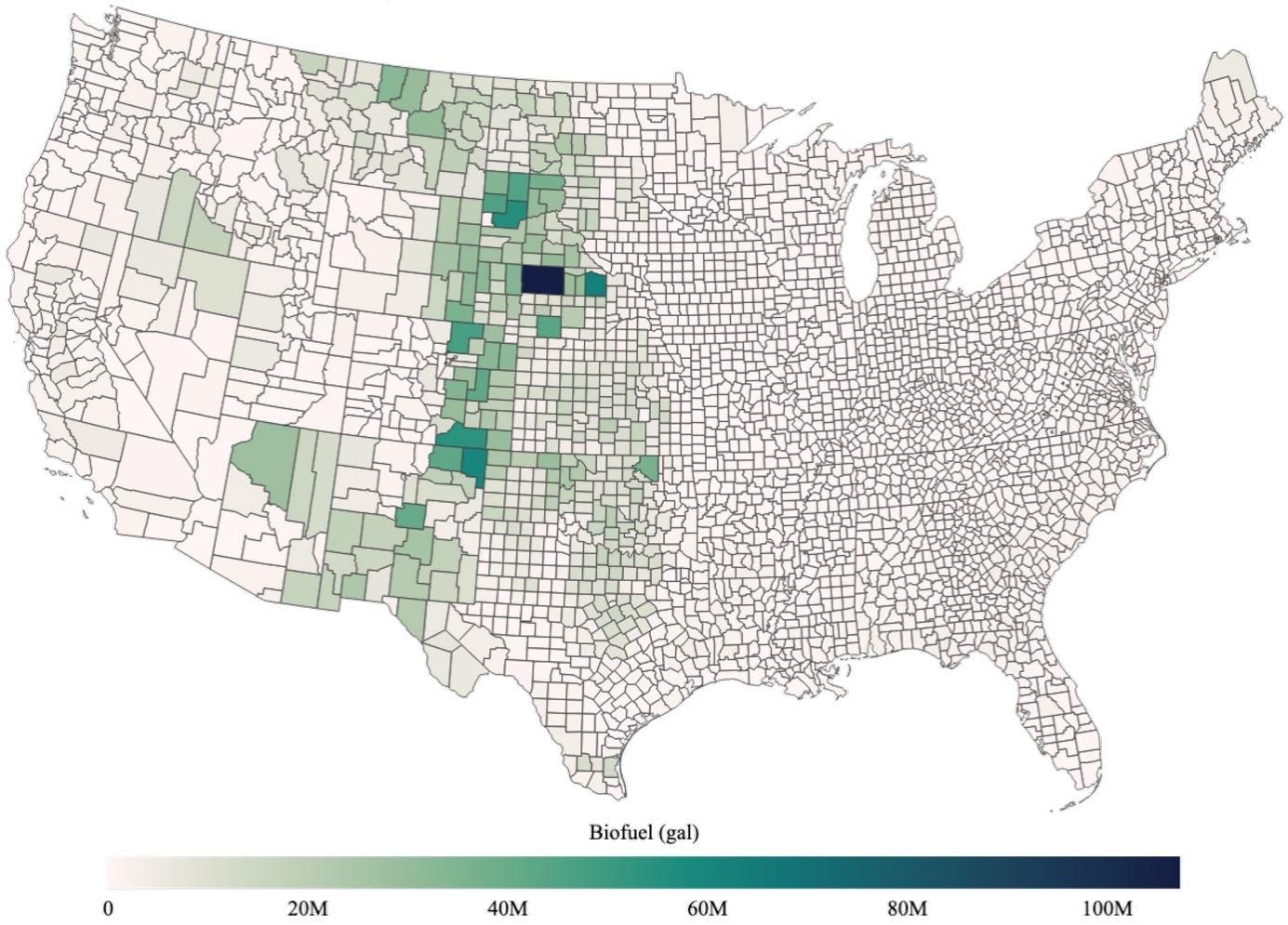
Available Land



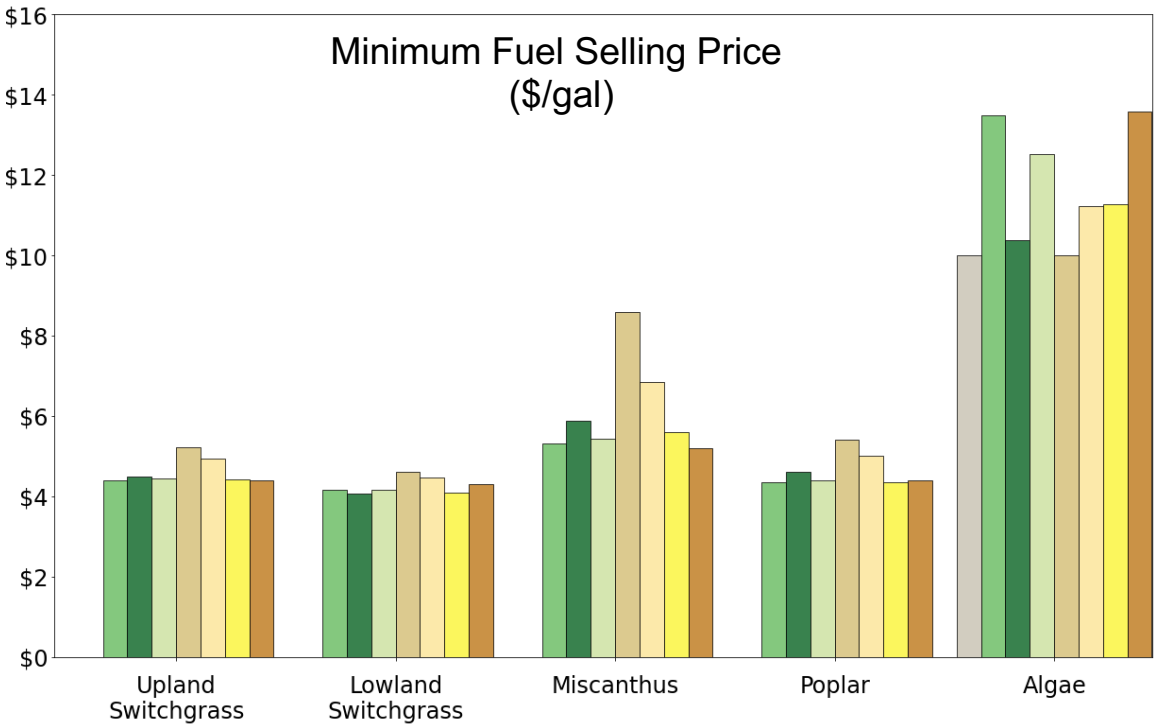
Crop Productivity

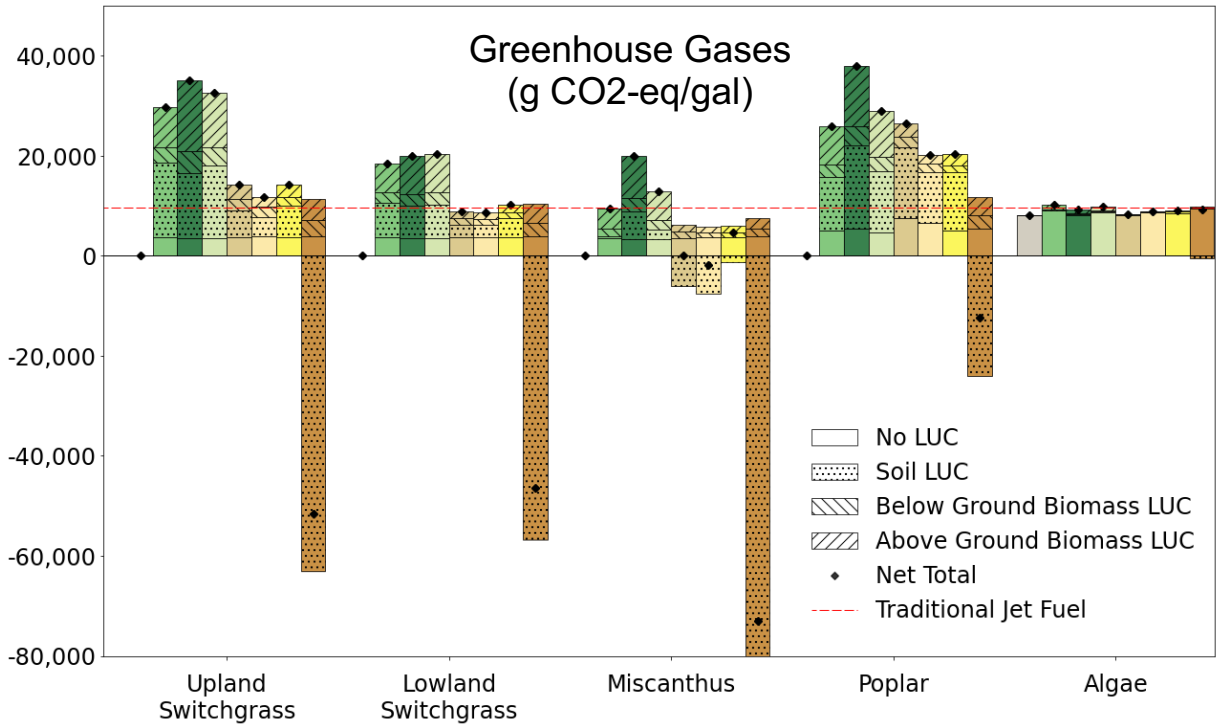


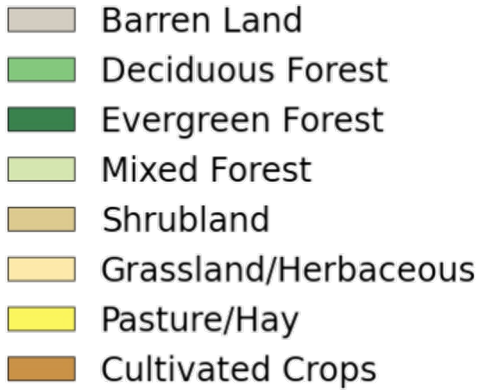
County Level SAF Production Potential



PROGRESS: GIS NATIONALLY AGGREGATED RESULTS







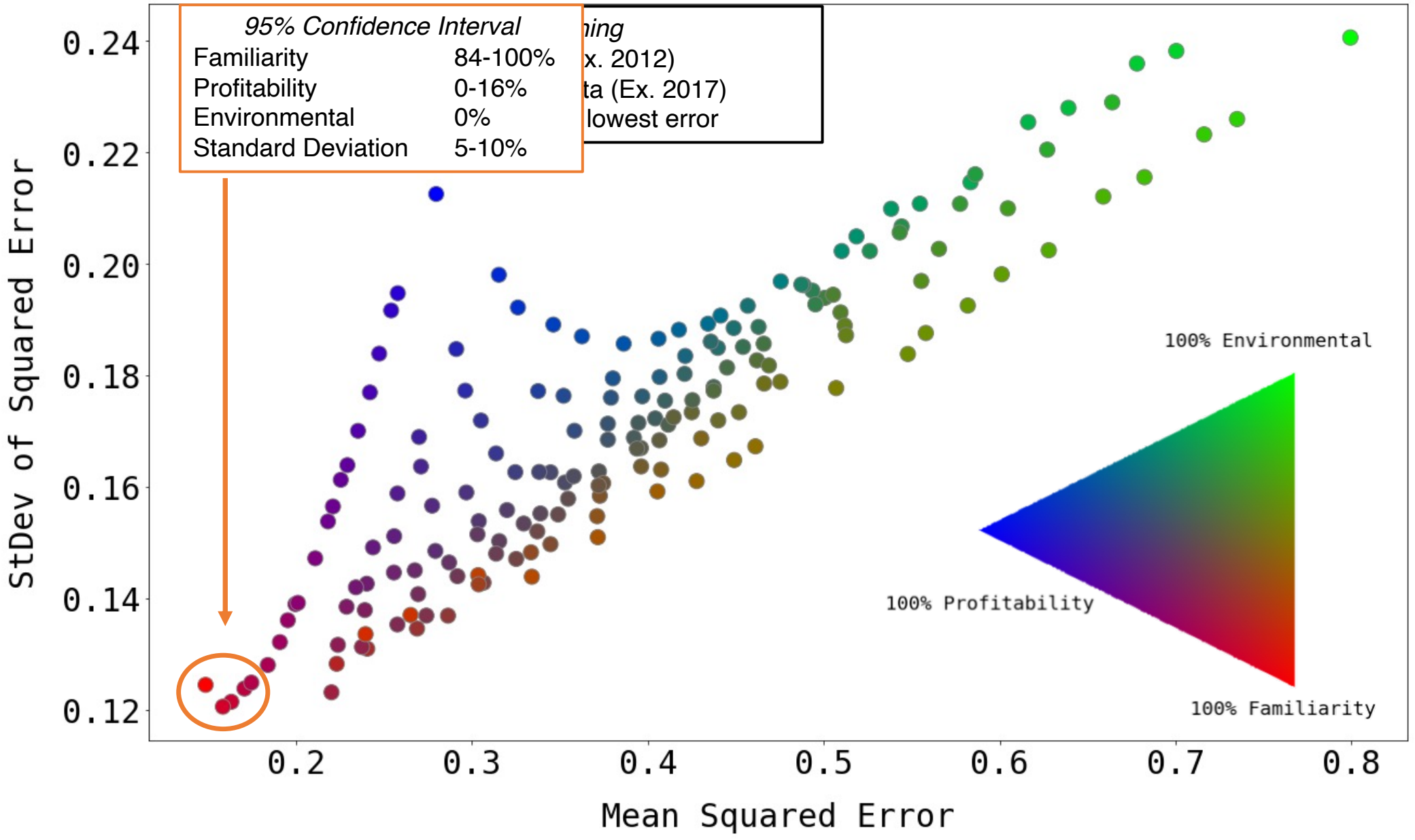
Economic Takeaways

- 2nd gen. bioenergy crops MFSP <$10/gal
- Algae MFSP >$10/gal
- Switchgrass is most cost effective

Environmental Takeaways

- 2nd gen. bioenergy crops perform well
- Algae GHGs ≈ Traditional Jet Fuel
- Cropland conversion sequesters carbon
- Forest land use change is non-starter

PROGRESS: AGENT BASED MODELING WEIGHTING

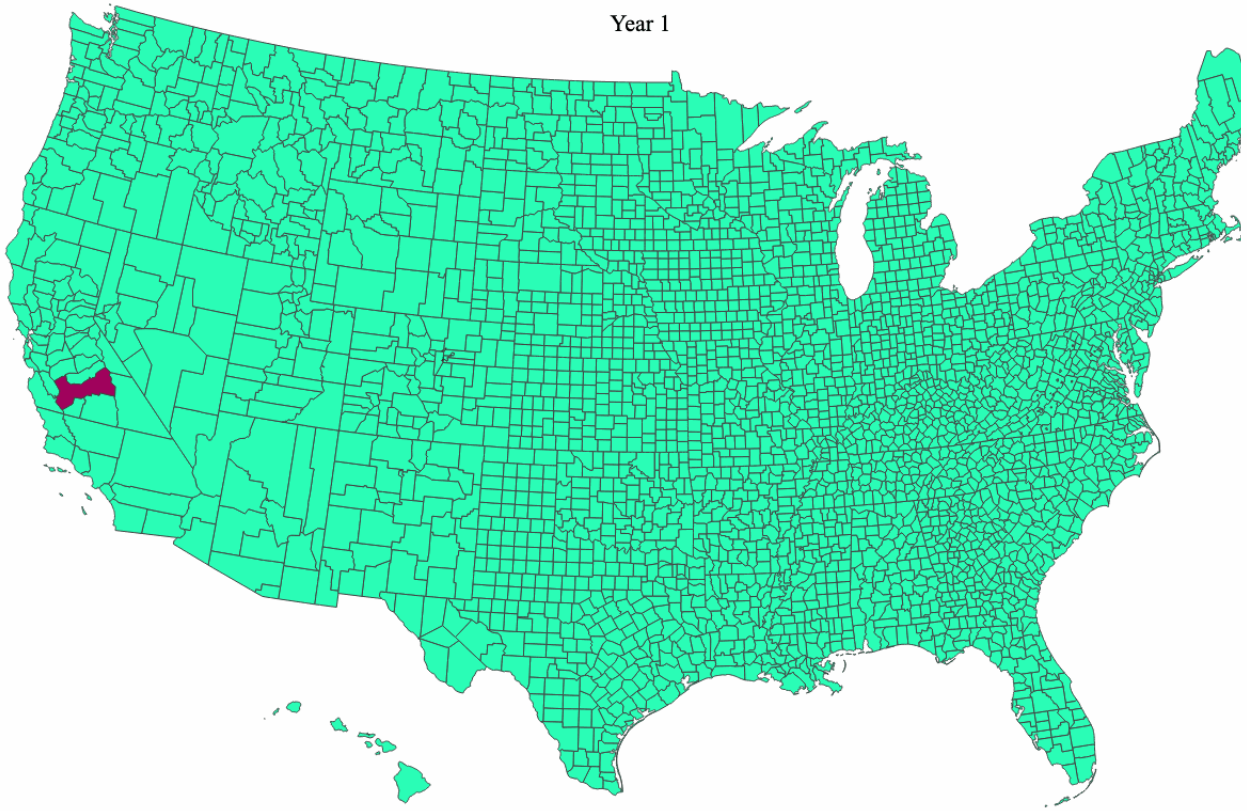


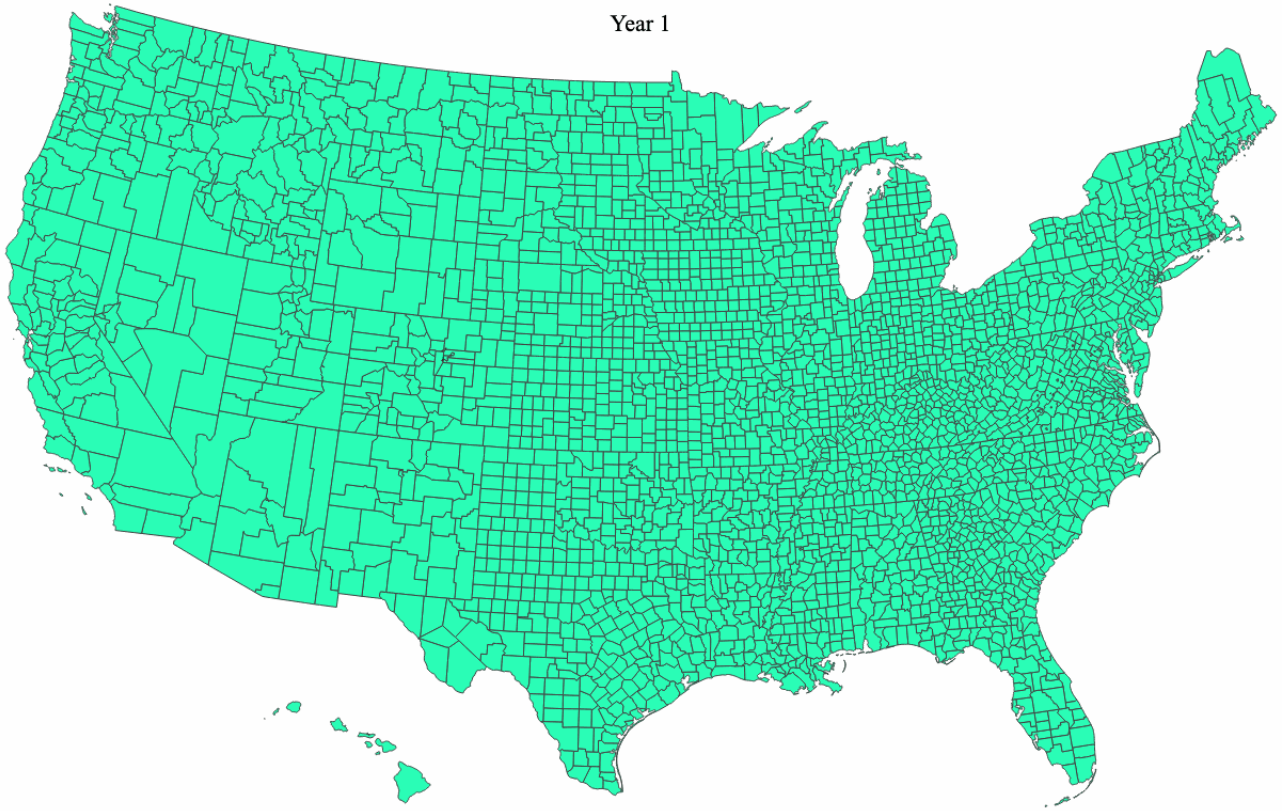
Progress: Agent Based Modeling Example

Year 1

Inverse Square Familiarity

100-mile Radius Ave. Familiarity

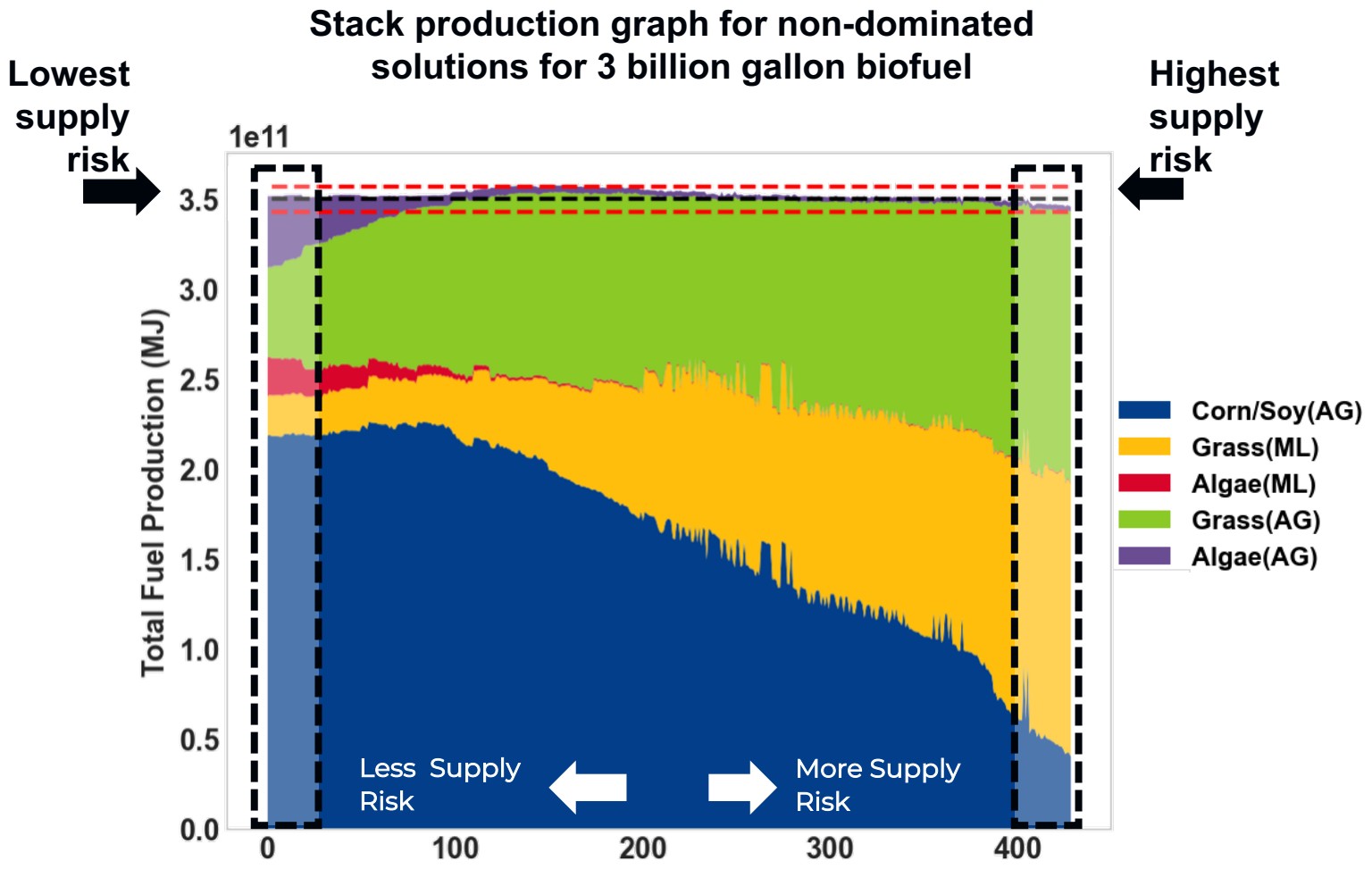




Corn Soy Miscanthus

PROGRESS: MULTI-OBJECTIVE OPTIMIZATION

- Non-dominated solutions sorted by maximum quota shortfall
- **Left side** = lowest risk
- **Right side** = highest risk
- Takeaways:
  - To minimize supply risk, **increase algae production**
  - Algae cultivation (an engineered process) much less vulnerable to hydro meteorological stress
  - The lowest shortfall produces the least amount of energy.



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IMPACT

Toolset evaluates feasibility of DOE Goals

- Identifies optimal paths to meet DOE sustainability goals

Toolset evaluates impact of tech advancement

- Identifies necessary tech advances to become competitive

MOEA evaluates system-level vulnerabilities

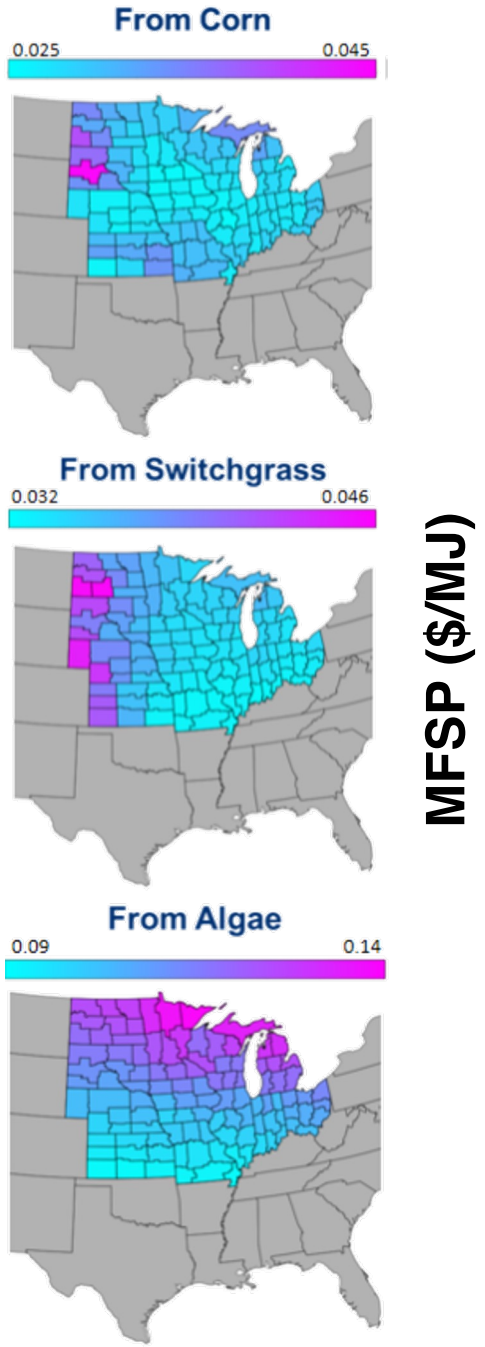
- Identifies supply chain risks and climate induced shortfalls

ABM evaluates the likelihood of tech adoption

- Agent level decisions highlight policy/incentive impacts

Publications

- 1 article in review at Journal of Cleaner Production
- 1 article in preparation for Nature Sustainability
- 4 articles to be submitted during no cost extension



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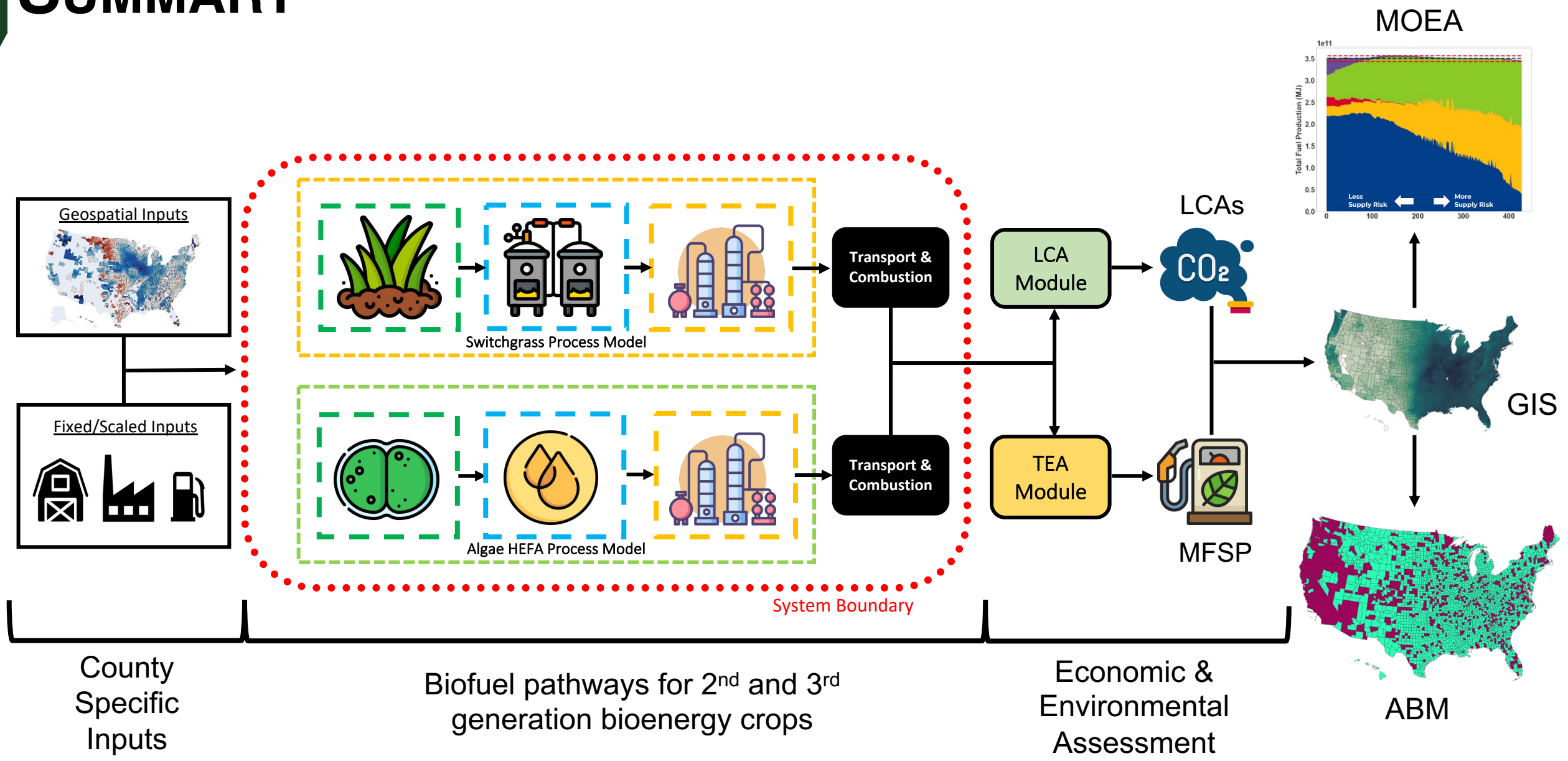
SUMMARY


MOEA
Total Fuel Production (MJ)
Less Supply Risk
More Supply Risk
Geospatial Inputs
Fixed/Scaled Inputs
Switchgrass Process Model
Algae HEFA Process Model
Transport & Combustion
Transport & Combustion
LCA Module
TEA Module
LCAs
CO_2
MFSP
GIS
ABM
System Boundary
County Specific Inputs
Biofuel pathways for 2nd and 3rd generation bioenergy crops
Economic & Environmental Assessment

QUAD CHART

Timeline

- *Project start date: April 2020*
- *Project end date: August 2024*

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022) $254,240.30*	*$1.25 million*
Project Cost Share *	*$11,074.14*	*$250,000*

Project Goal

Develop a toolset capable of identifying promising production pathways as well as performance targets for bio-based energy and co-product systems incorporating high geospatial and temporal resolution.

End of Project Milestone

Recommendations to DOE in terms of pathways and performance targets to meet the FOA objectives. In addition, an open source tool set will be developed and disseminated.

Funding Mechanism

DE-FOA-0002029

TRL at Project Start: 3
TRL at Project End: 5

Project Partners*

- North Carolina State
- B&D Engineering and Consulting LLC