DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

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

March 12, 2021
Data Modeling and Analysis

Jason Quinn
Colorado State University

Colorado State University

B&D LLC

NC STATE UNIVERSITY

Project Overview

- *First of a Kind analysis project with bold goals*
- *Project goals: Develop open-source integrated US biofuel model that enables an evaluation from a systems level the ability to meet DOE sustainability goals*

What we are doing:
- Support informed research and commercialization direction based on economic and environmental goals
- Developing an integrated modeling framework

How it is done today:
- Evaluate one technology scenario independent of other technologies
- Technology investment and policy are not typically fully informed

Why this is important:
- Sustainable US energy policy
- Biofuels portion of this picture
- Quantitative or measurable % reduction GHG, Cost, etc. of technology

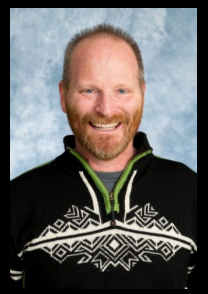
What are the risks:
- Large Scope
- Moving target

1 – Management

CSU Team

PI: Jason Quinn

Co-PI: John Field



Co-PI: Steve Simske

Co-PI: Thomas Bradley

RS I: Evan Sproul

GRA: Jack Smith

B&D LLC

Co-PI: Colin Beal

TL: Nathan Putnam

NCSU Team

Co-PI: Jordan Kern

GRA: Ece Arı Akdemir

UG: Taylor Pack

Advisory Board

Troy Hawkins: ANL

Carlos Quiroz-Arita: SNL

Bill Brandt: ASU

Ryan Davis: NREL

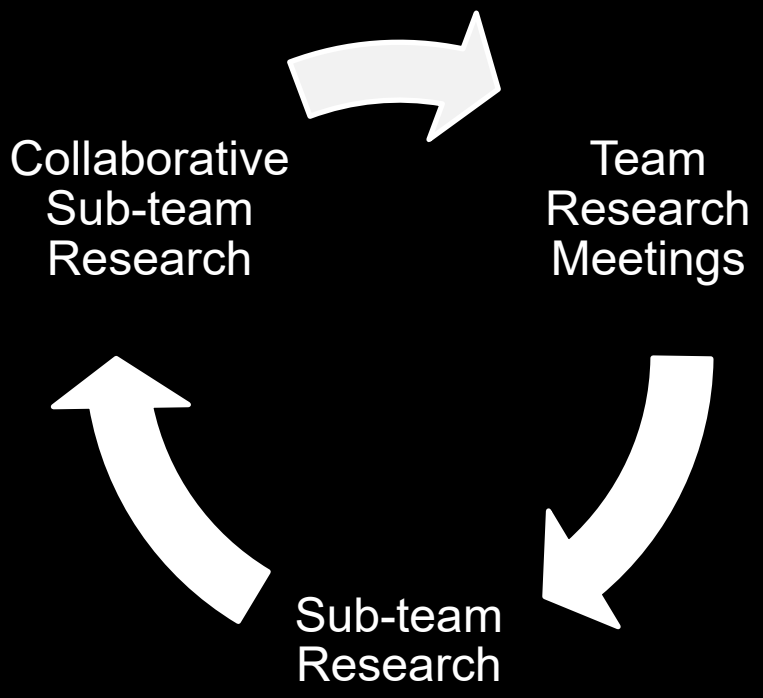
1 – Management

Inclusive Research Environment

The Meeting Details:

- Weekly project meetings
- Quarterly meetings with DOE
- 6 month updates to Advisory board

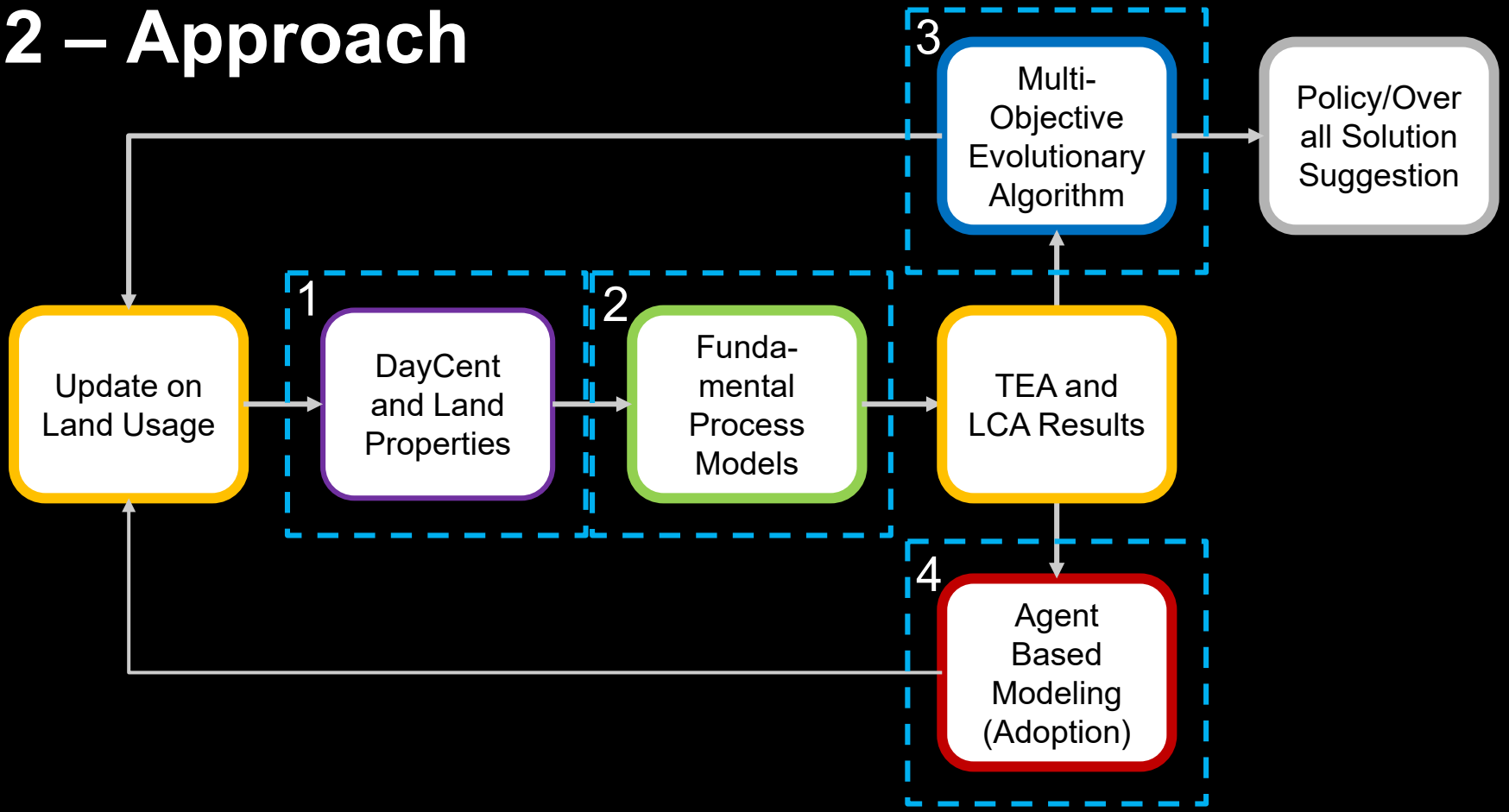
Research Structure



Risk Management:

Communication
Creative Problem Solving

2 – Approach



Agent Based System to Model Adoption
- Farmers
- Biorefinery Investment

Yearly Resolution

Framework for Adaptive Behavior

FOA targets:

- Reducing Consumption Water (10-30%), Energy Consumption (20-60%), GHG Emissions (50-80%), Pollutant Emissions (10-30%)

Program Connections:

- Optimization of the energy bioeconomy
- Defining from a systems level pathways and investments that lead to sustainable bio-economy

2 – Approach

DayCent: Geospatial Agricultural Modeling

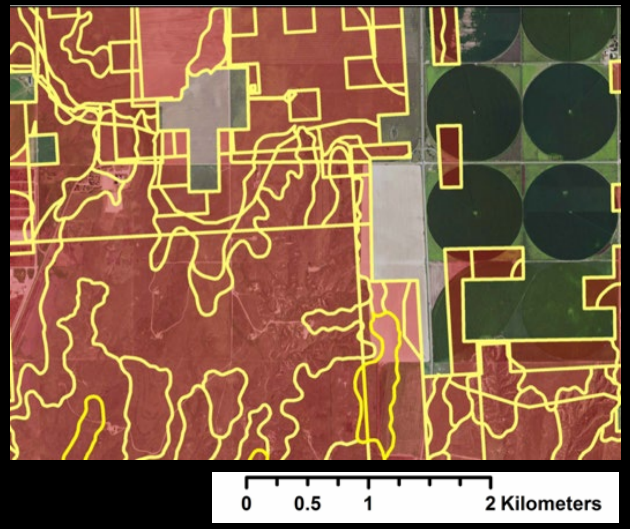
Spatially-resolved data generated from DayCent model

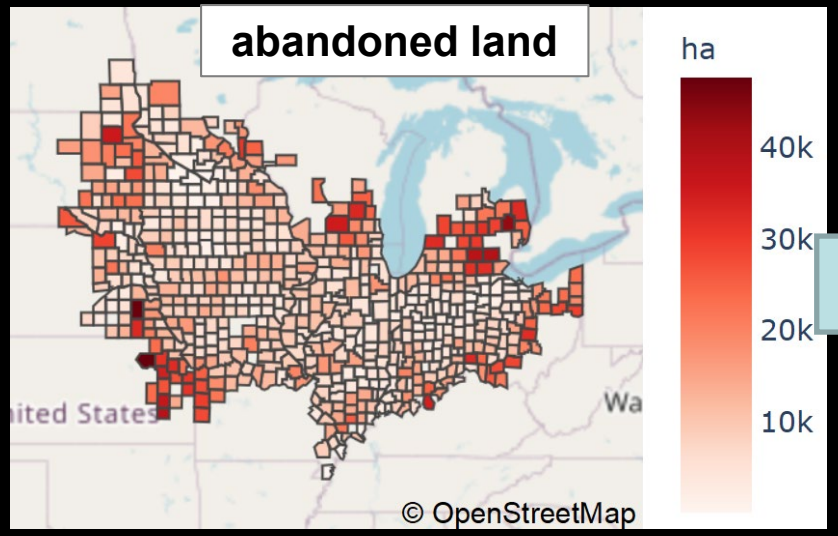
– Process-based simulation of **crop yields**, **soil carbon changes**, other **soil GHG emissions** as affected by soil, climate, and land management

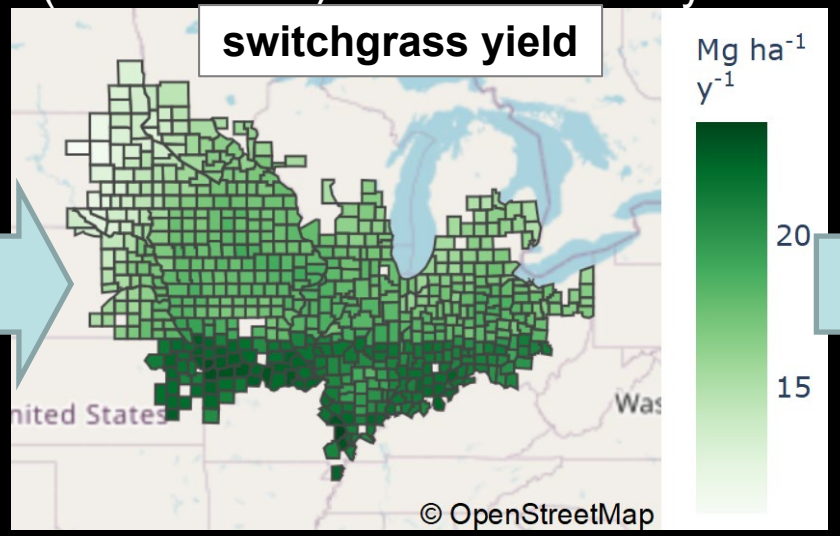
Python-based spatial modeling workflow:

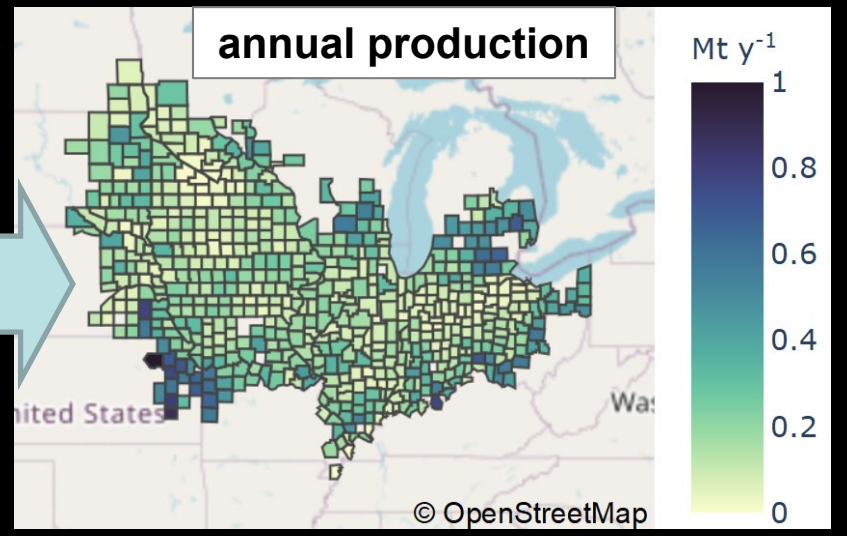
1. Identification of target **land base** (e.g., existing annual cropland, marginal or abandoned land, etc.)
2. Specification of **management scenarios** (e.g., fertilizer application rates, stover removal, etc.) & associated **pseudo field-scale model runs**
3. Automated simulation execution (CSU cluster) and results analysis

pseudo field-scale simulation









2 – Approach
Modular Process Modeling

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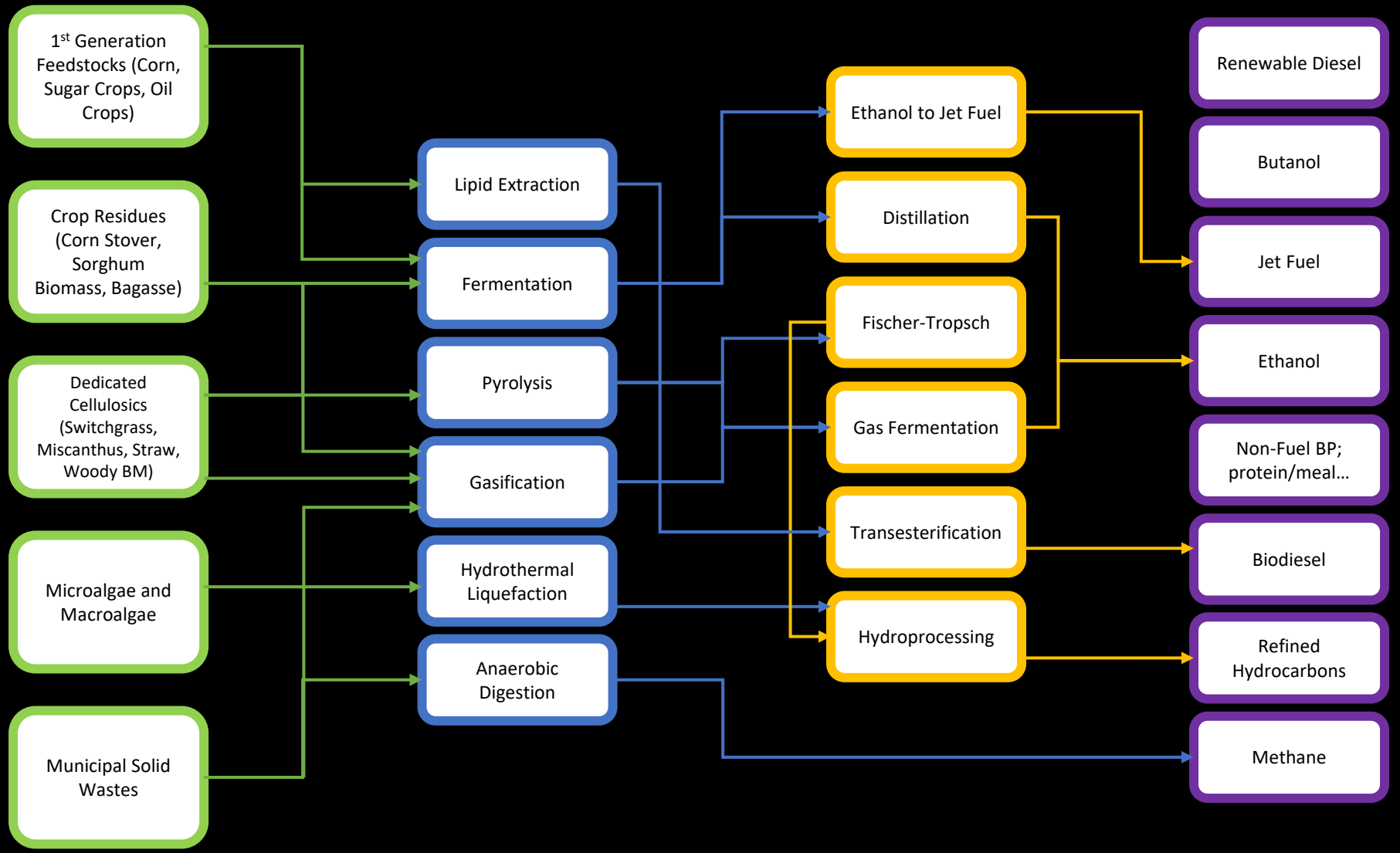
Fundamental Process Models



- Numerous Pathways – Consistent Methodology
- Defines Potential Solution Space (Enables Project)
- LCA and TEA Results
  - MFSP
  - Greenhouse Gas Impact
  - Water Use
  - Criteria Pollutants
- Consumes Rich Spatial Data (DayCent)
- Feeds Optimization Algorithm

2 – Approach
Modular Process Modeling

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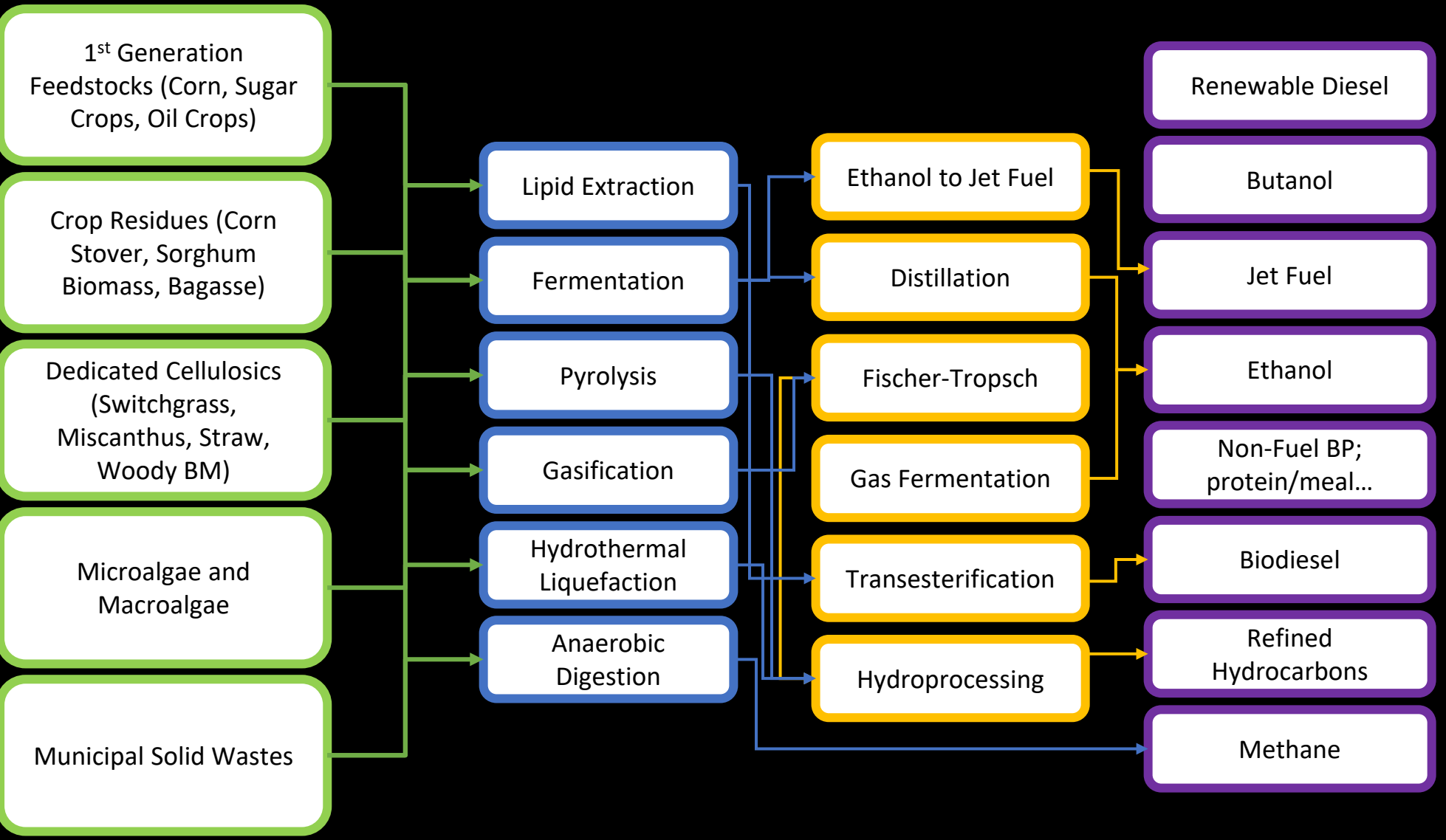
Fundamental Process Models



Numerous Pathways – Consistent Methodology

Defines Potential Solution Space (Enables Project)

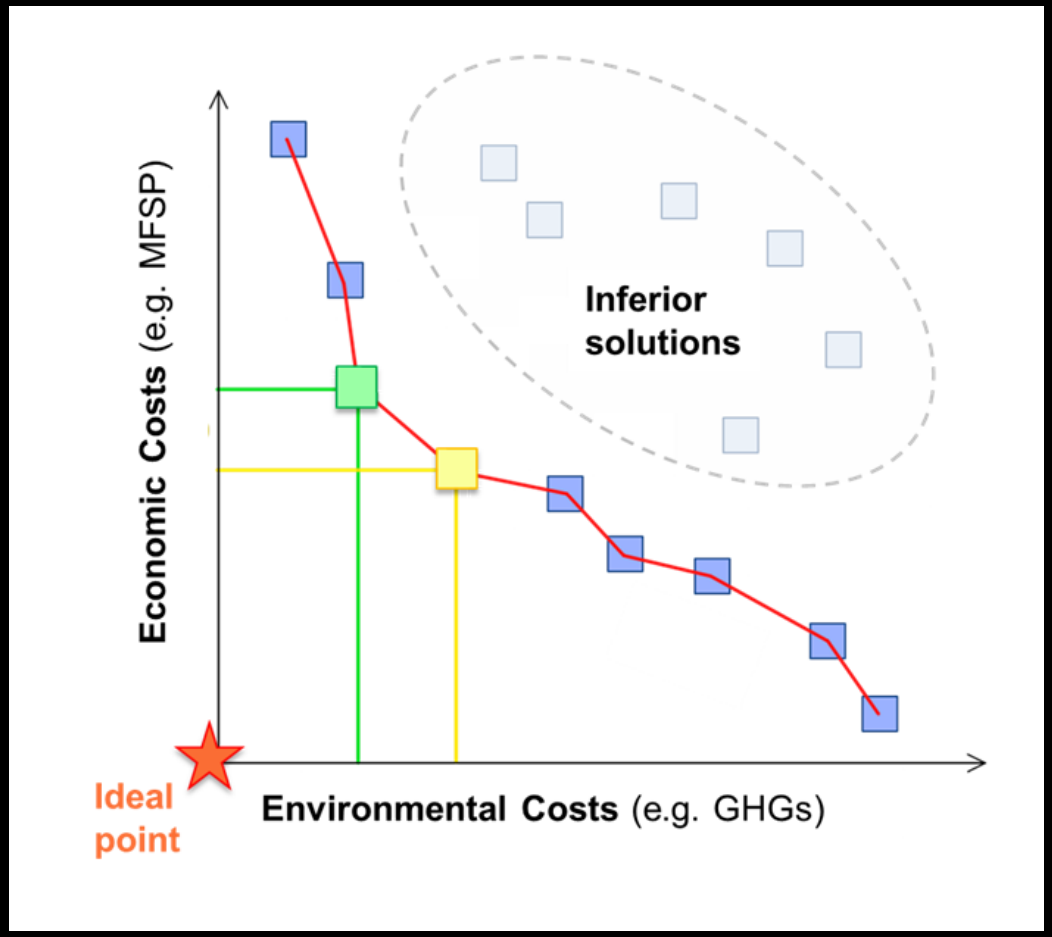
LCA and TEA Results
- MFSP
- Greenhouse Gas Impact
- Water Use
- Criteria Pollutants

Consumes Spatial Data (DayCent)

Feeds Optimization Algorithm

2 – Approach
Multi-objective Optimization

Embed LCA/TEA within Multi-objective optimization of Biofuel Supply Chain (farm to fuel)



= 1 Viable Supply Chain Network

Optimize County-to-Hub Supply Chain Network

Decision variables:

- County level cultivation choices (feedstock, volume)
- Flow of biomass between preprocessing hubs and biorefineries
- Biorefinery design, size and location
- End product choice

Constraints:

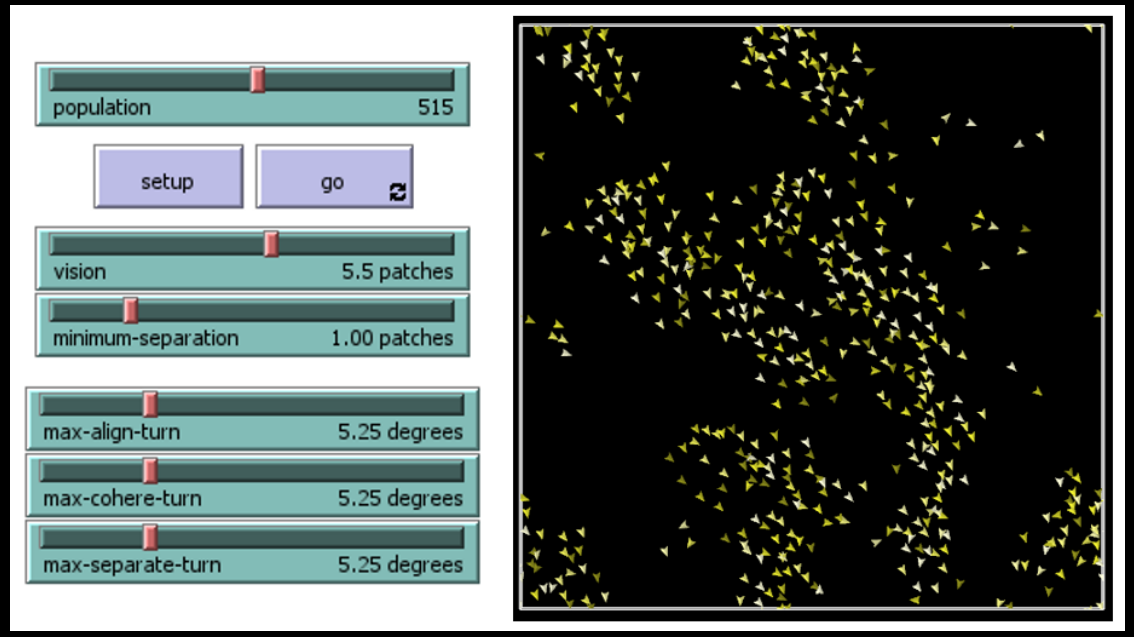
- Production quotas, resource usage (land, water), supply vulnerability (weather)

Navigating Tradeoffs in Cost and Greenhouse Gas Emissions (what if there's no silver bullet?)

Better understand design choices that lead to:

Higher cost + lower emission **vs** Lower cost + higher emission

2 – Approach
Agent Based Modeling



Agents in US Bioeconomy

Framework Capacity:

- Farmer/Biorefinery/Consumer Interaction and Behavior
- Predict Pathway Adoption Rates and Mechanisms
- Identification of Levers in Industry
- Informs Behavior of Proposed Policy

Characteristics:

- Yearly Time-Steps (Analysis of Intermediate States)
- Preserves Heterogeneity
- Potential to Model Adaptive Behavior

2 – Approach
Future Work

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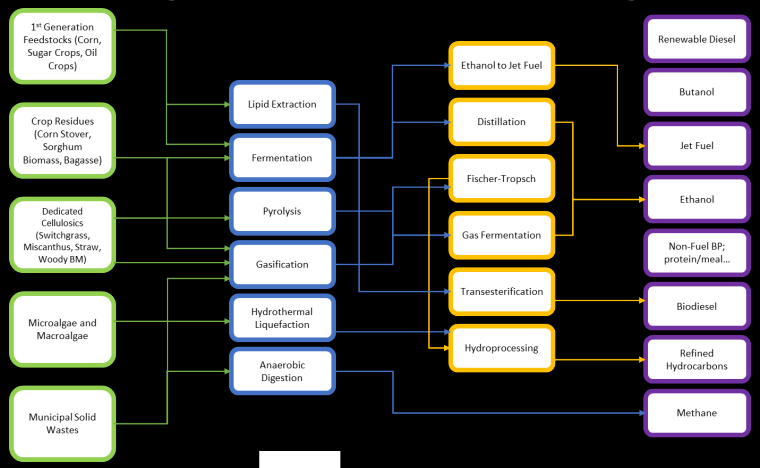
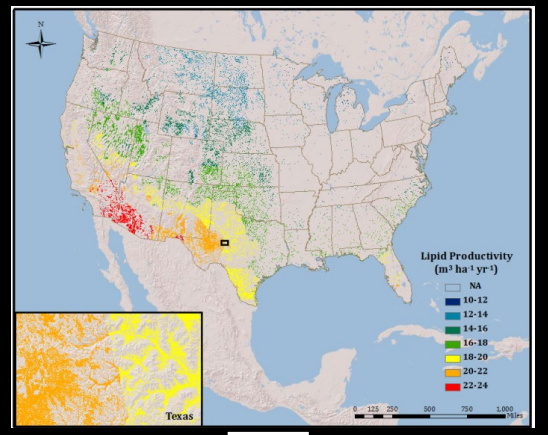
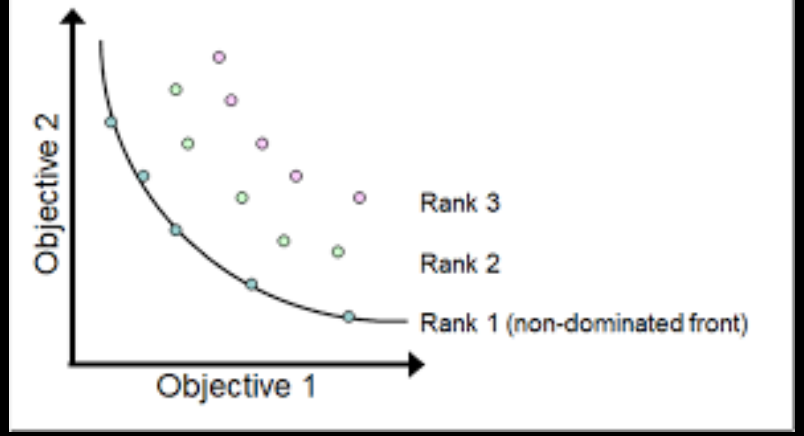
Expanding Process Modeling Pathways



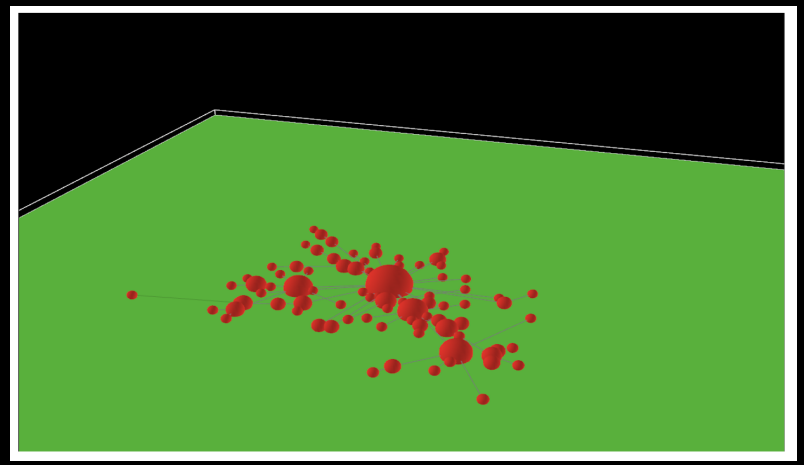
Continued Geospatial Modeling



US Policy



Multi-objective Optimization



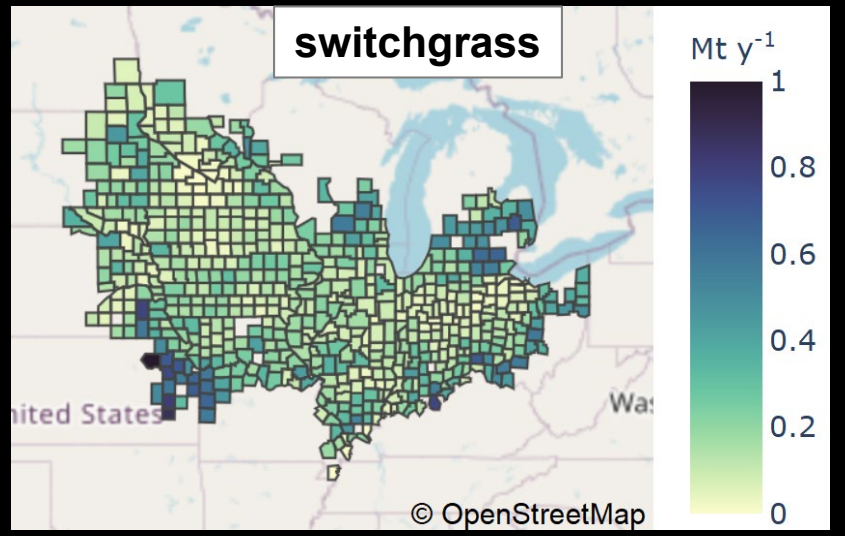
Agent Based Modeling

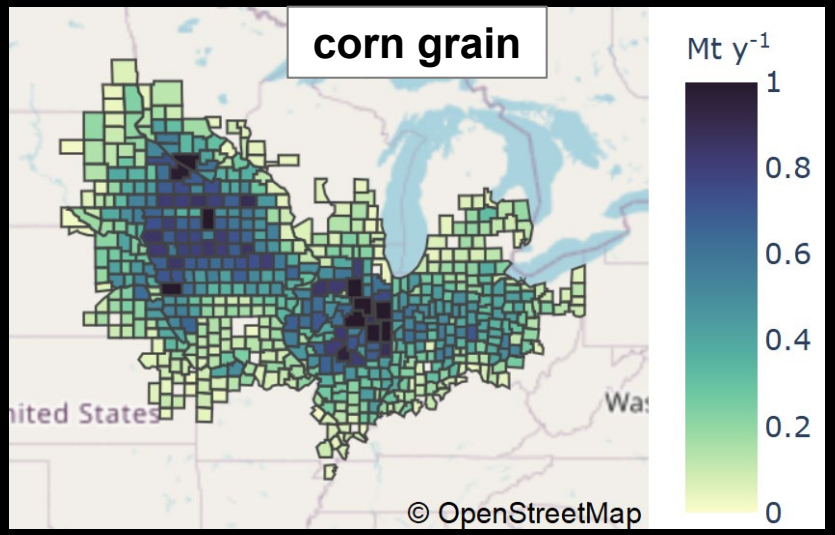
3 – Impact

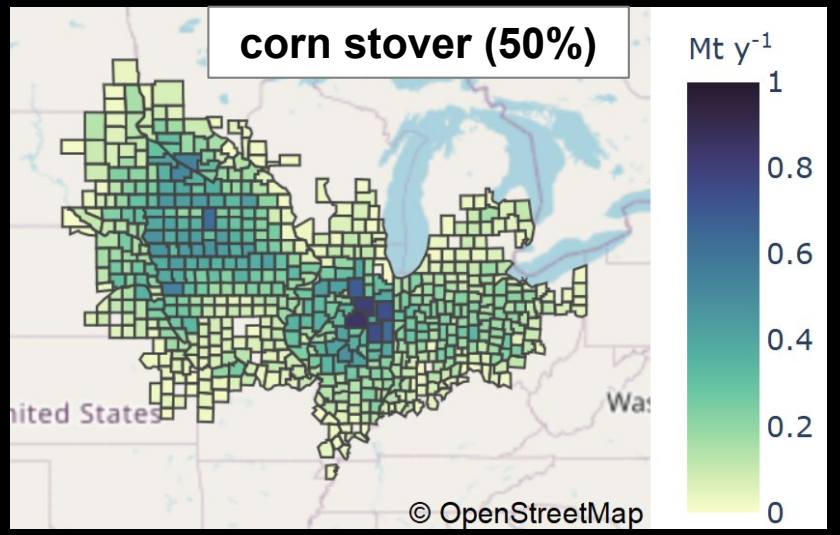
- *Goal of the project is IMPACT*
  - *Identifying technologies and pathways that meet DOE sustainability targets*
  - *Identify performance (R&D) targets for DOE and Industry*
- *System level assessment*
  - *Not individual technologies*
- *Department of Energy is Dynamic*
  - *Modeling work is intended to be re-active and adjustable*
    - *Current administration is focusing on the environment*
    - *Future of biofuels (heavy fuels and jet)*
- *Generation of open-source toolset*

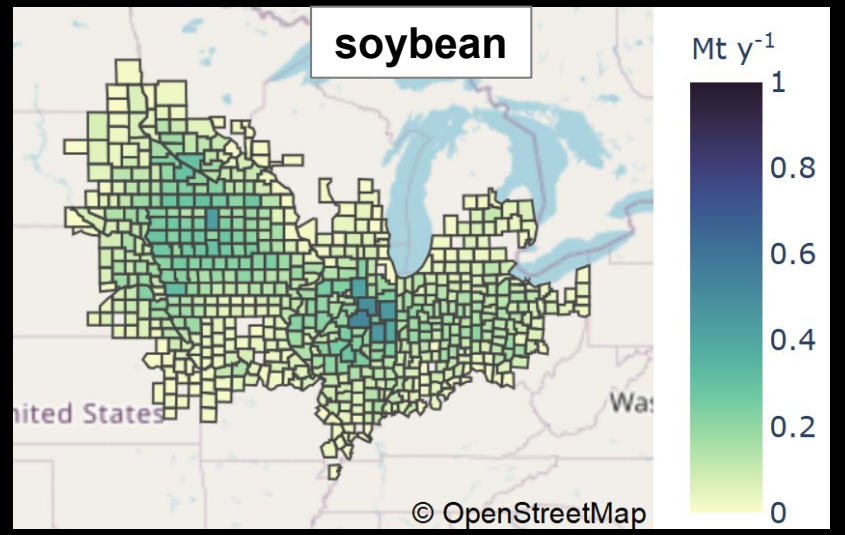
4 – Progress and Outcomes
DayCent: Geospatial Agricultural Modeling

- Completed curation of modeling results for current-day **corn–soybean** cultivation in US Corn Belt, incl. **stover harvest**
  - Highest density of production in Iowa, Illinois
  - Quantified soil carbon penalty of different rates of stover harvest rates
- Preliminary results for **switchgrass** cultivation on **abandoned cropland** across same region
  - Abandoned land down-scaled from historical county land use records
  - Different spatial pattern, with abandoned land most concentrated at periphery of the Corn Belt
  - Ongoing modeling effort to capture baseline for business-as-usual management of abandoned lands



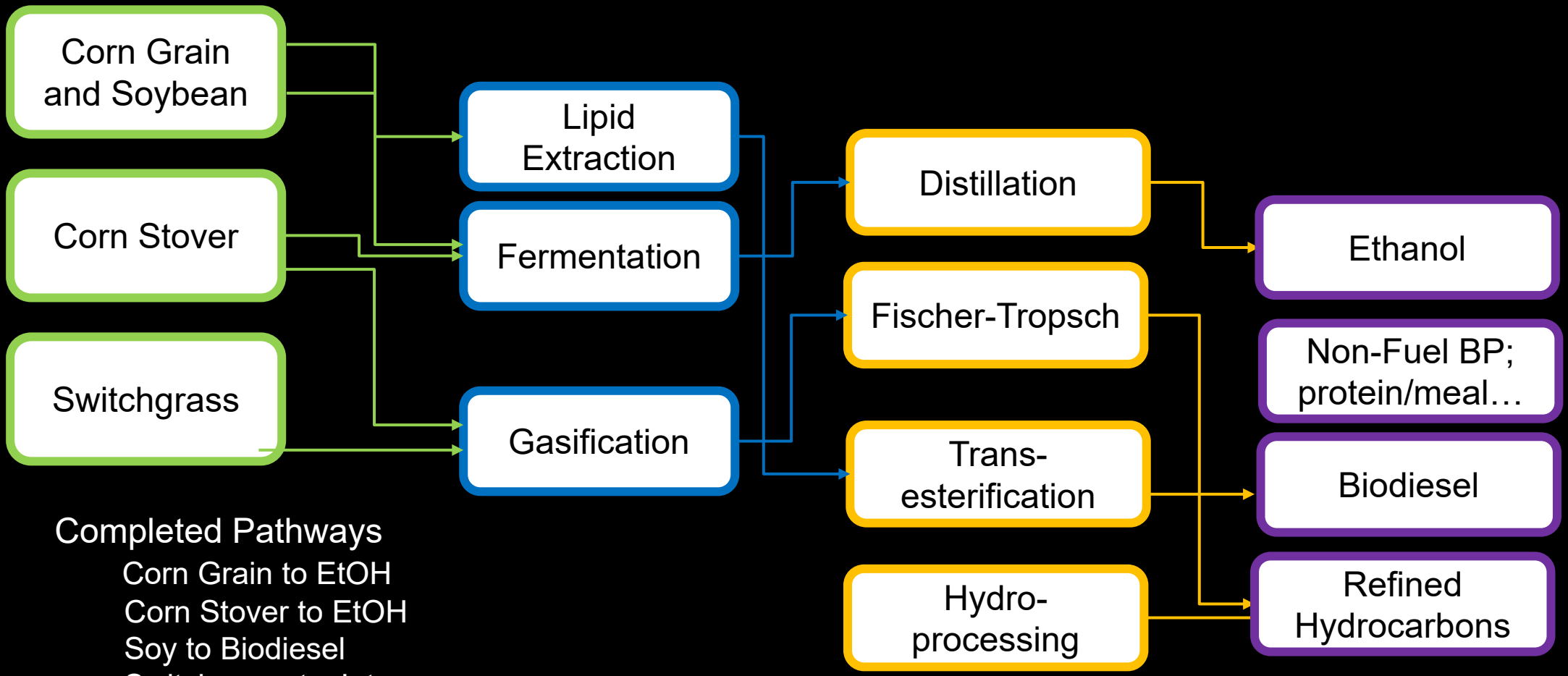






4 – Progress and Outcomes
Process Modeling

Process Modeling



Completed Pathways

- Corn Grain to EtOH
- Corn Stover to EtOH
- Soy to Biodiesel
- Switchgrass to Jet
- Corn Stover to Jet

Flexible Structure – Facilitates Added Pathway Steps

4 – Progress and Outcomes
Multi-objective Optimization

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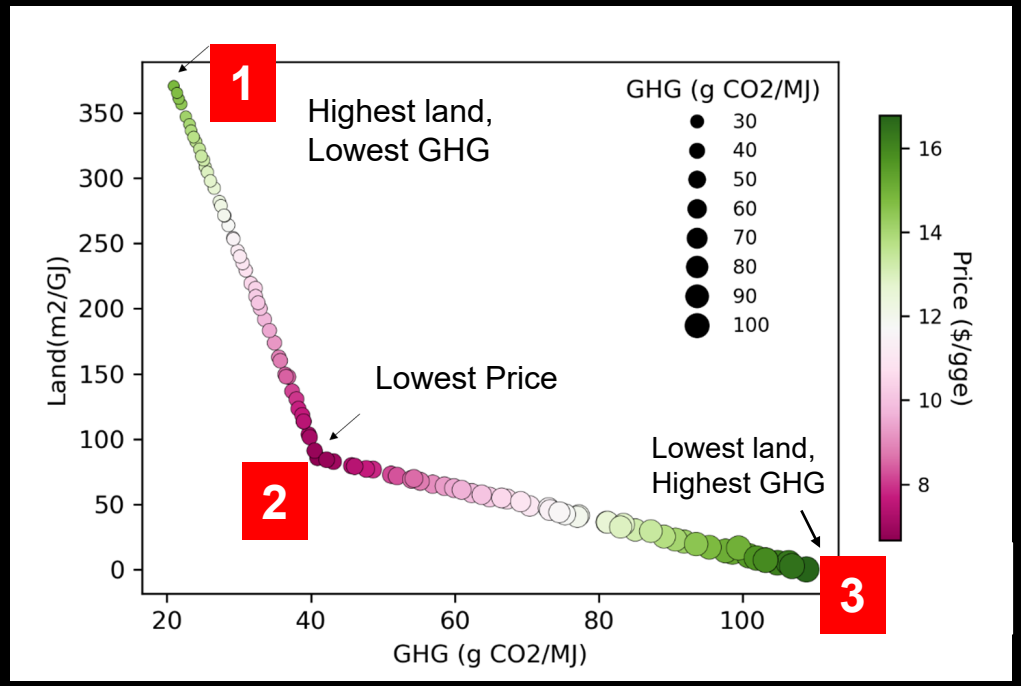
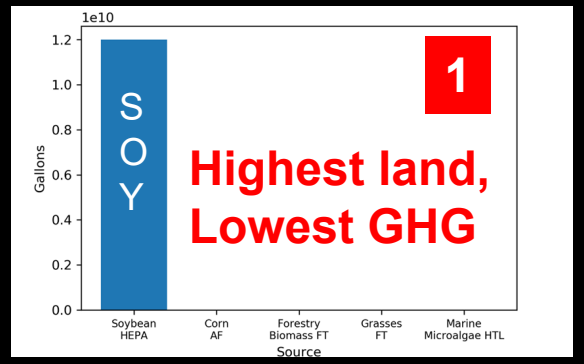
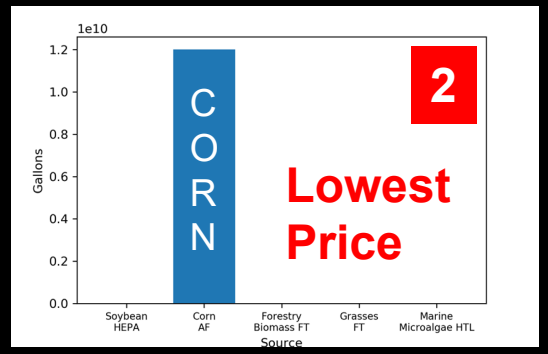
Multi-objective optimization of Biofuel Supply Chain (farm to fuel)

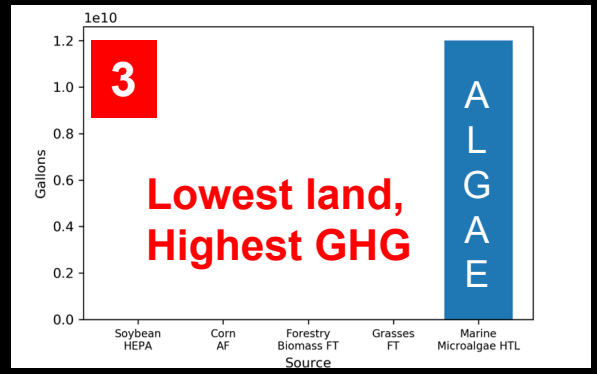
Initial proof-of-concept for 5 national jet fuel pathways: Balance cost, GHGs, and land use, produce 12M gallons

Source	Cost ($/gge)	Post-Combustion GHG (g CO2e/MJ)	Arable Land (m2/GJ/yr)	Nitrogen (g/GJ)
Soybean HEFA	$14.85	20.94	370.75	102.08
Corn AF	$6.66	40.92	85.52	1,186.38
Forestry Biomass FT	$7.11	70.88	99.64	354.82
Grasses FT	$8.24	41.87	128.17	1,512.40
Marine Microalgae HTL	$16.79	108.90	0.00	226.60





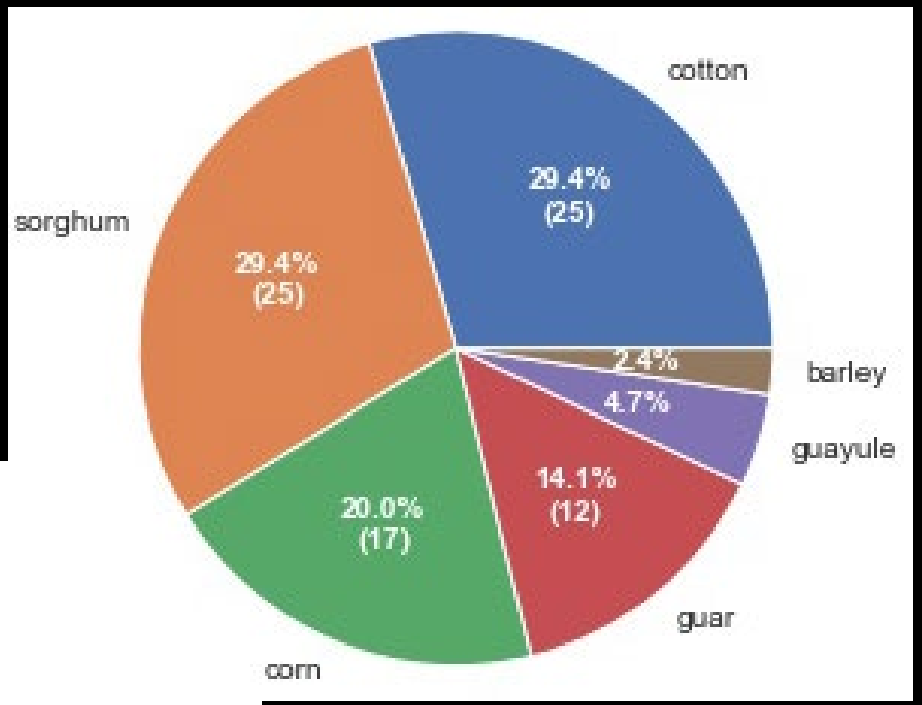


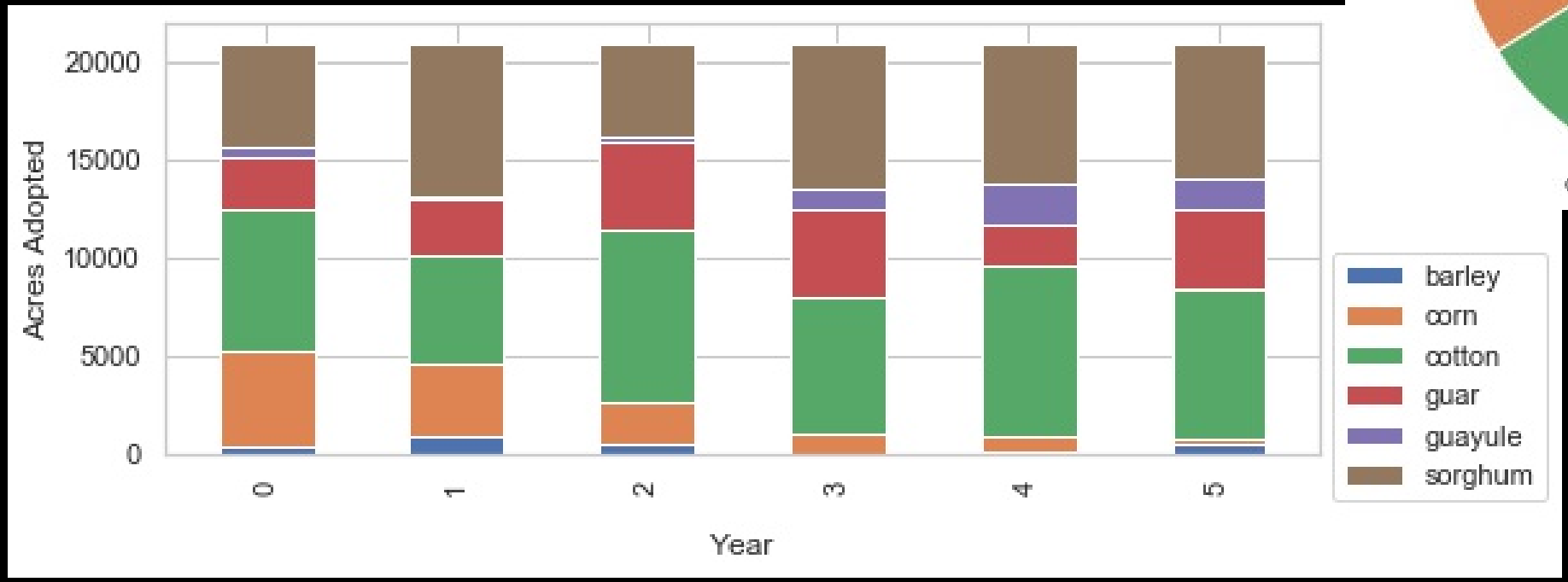


4 – Progress and Outcomes
Agent Based Modeling

Scenarios:

1) Only profitability
2) Only familiarity
3) Only environmental
4) **Equal weighting**
5) Random weighting

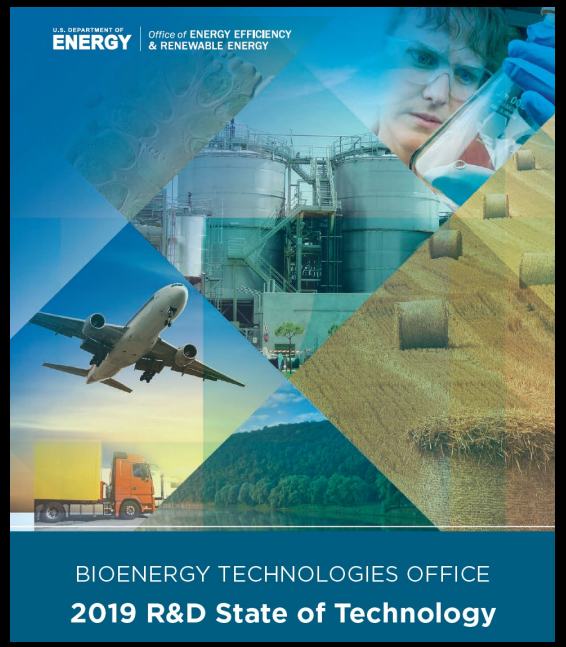




4 – Progress and Outcomes
Future Direction

Near Term

Compliment and Add to the DOE



Note future potential

- >1 billion tons biomass in 2040
- ~35% from dedicated energy crops

Identify promising case studies

Long Term

Integrated Assessment Model

- Dynamic assessment tool
- Holistic tool set that investigates non-trivial trade-offs
- Enables informed policy decisions
- Leverages multiple optimization techniques

Open-source model for the community

4 – Progress and Outcomes

1	**Development of modular engineering process models**
2.0	Development of concurrent and spatially explicit sustainability models
3.0	External Review
Go/No-go	Modeling of 6 production pathways with results quantifying water consumption, energy consumption, greenhouse gas emissions, and pollutant emissions for fuel products on the metrics of MJ MJ-1, g-CO2-eq MJ-1, and g MJ-1, respectively
4.0	Development of modular engineering process models
5.0	Optimization and evaluation of favorable configurations
6.0	External review

Progress:

- On schedule with process modeling
- Ahead of Schedule on optimization work

Summary

- *Demonstrated capabilities*
- *Adapting to Directions of the DOE*
- *Established an effective working team*
- *Technical achievements*
  - *Modular Process modeling*
  - *Demonstrated proof of concept on MOO and ABM*
  - *Geospatial data modeling and integration*
- *Defining near term directions with the DOE*

Quad Chart Overview

BETO FY19 Multi-Topic FOA, AOI 10: Reducing Water, Energy, and Emissions in Bioenergy.

Timeline

- 10/01/2019
- 09/30/2021

	FY20 Costed	Total Award
DOE Funding	(10/01/2019 – 9/30/2020) $15,703.51	$1,000,000
Project Cost Share	$250,000	

Project Partners*

- North Carolina State University
- B&D Consulting

Project Goal

Develop an open-source sustainability model that supports the strategic investment of research by the DOE to achieve renewable fuel goals.

End of Project Milestone

- Develop an open source bioenergy tool to support strategic investments by DOE.
- Identify optimum bioenergy pathways through Agent Based Modeling (ABM) and multi-objective optimization to meet sustainability goals: reduction in water consumption, energy consumption, greenhouse gas emissions, and/or pollutant emissions.
- Couple economic modeling and life cycle assessment to understand the impact of carbon accounting on technology investments.

Funding Mechanism

DE-FOA-0002029

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