UC Davis Geospatial Bioenergy Systems Model and the BTS2 Scenario

Oak Ridge National Laboratory
30 September 2011

Peter Tittmann, Nathan Parker, Quinn Hart, Colin Murphy, and Bryan Jenkins
UC Davis Energy Institute
University of California, Davis

Outline

- Introduction to Geospatial Bioenergy Systems Model (GBSM)
- National biofuel projections
- BTS2 scenario
- Lessons learned

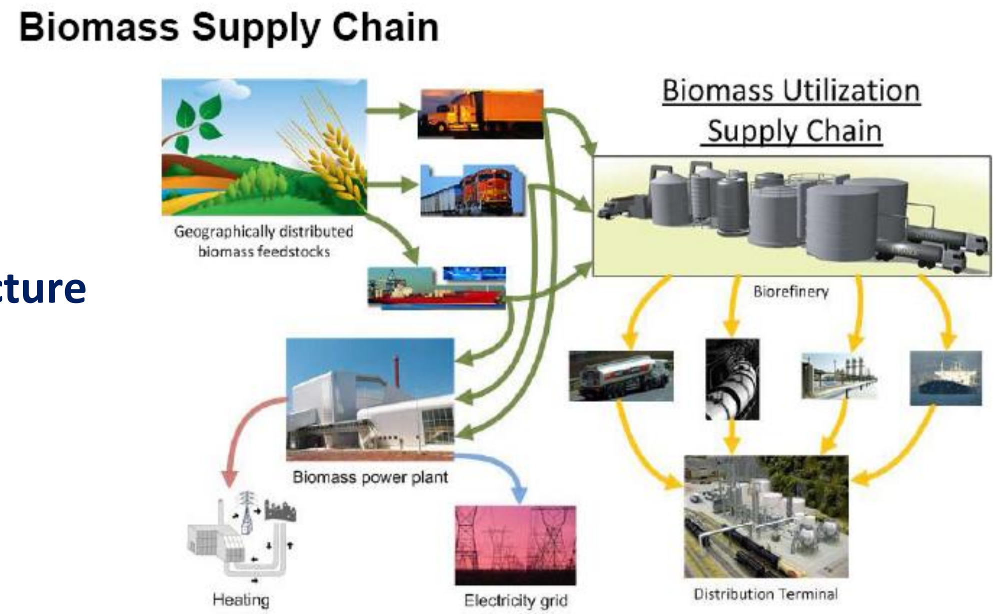
Systems Analysis and Infrastructure Modeling: Motivations

- **Recognized need for more comprehensive and spatially explicit methods for**
  - **assessing resource and infrastructure adequacy, potentials and constraints,**
  - **identifying development opportunities and impacts,**
  - **evaluating policies, incentives, and regulatory approaches**
  - **predicting overall sustainability of future industry under different development scenarios**

- ***"Spatially explicit assessments of impacts have largely been lacking: what are the likely impacts of plans and policies at different scales, and where will they be distributed?"*** *(Phalan, 2009)*

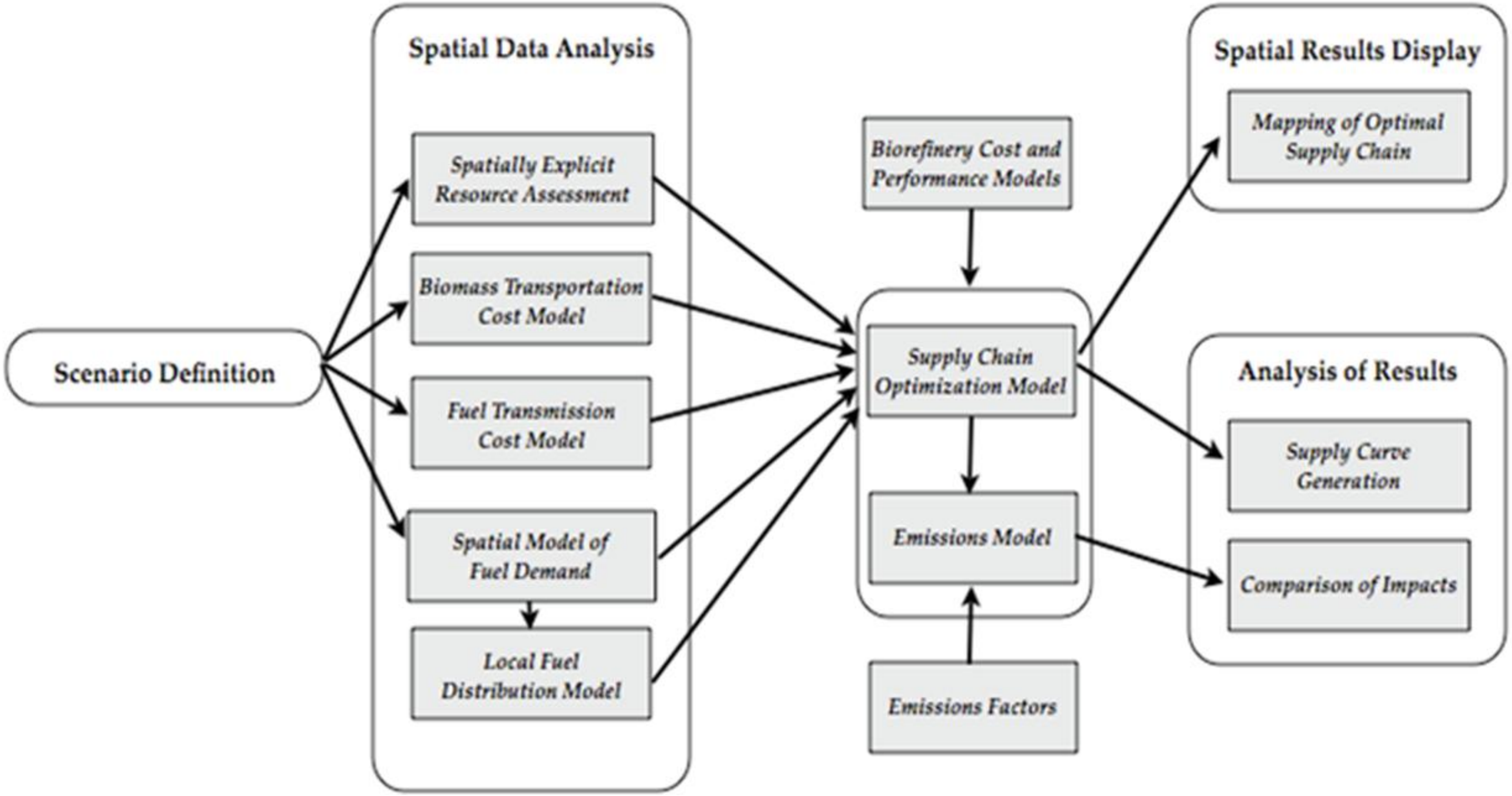
Geospatial Bioenergy Systems Model: Methodology

- **Database development**
  - **Resources**
  - **Technologies**
  - **Infrastructure**
  - **Impacts**
- **Spatial Bioenergy Infrastructure Optimization Model**

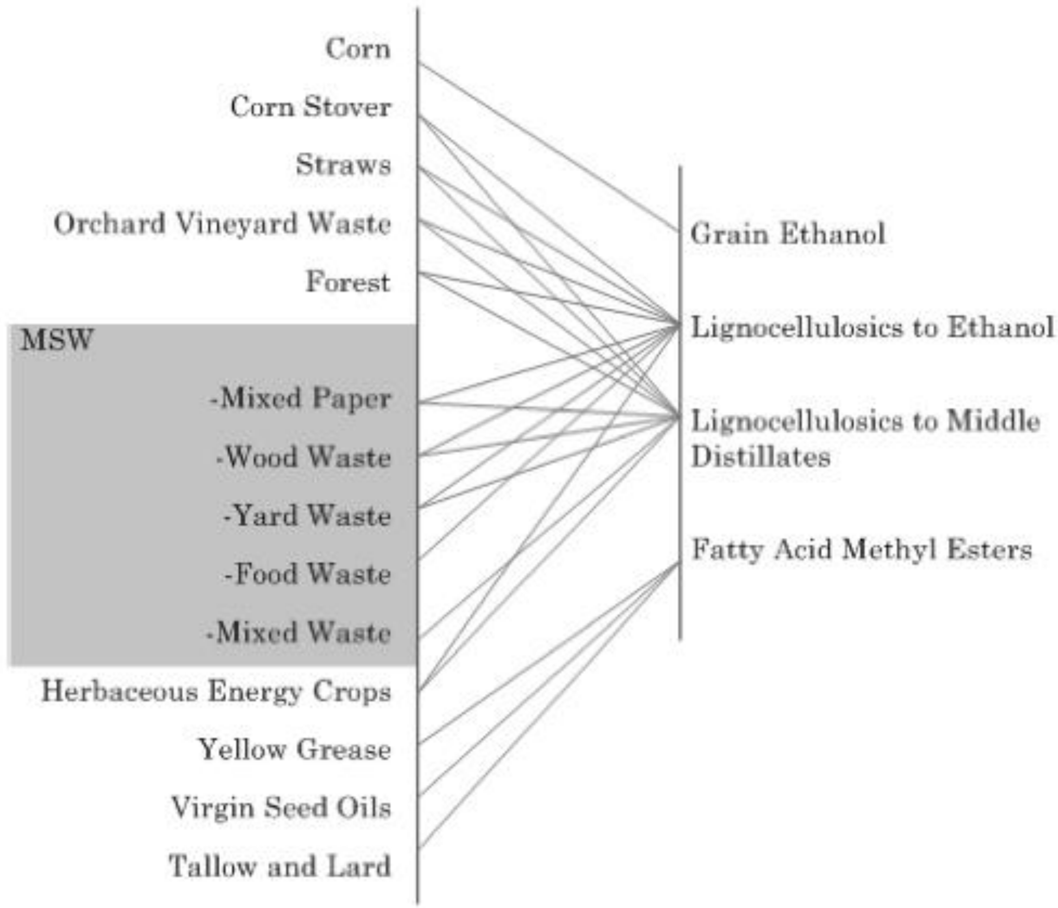


GBSM Design Framework

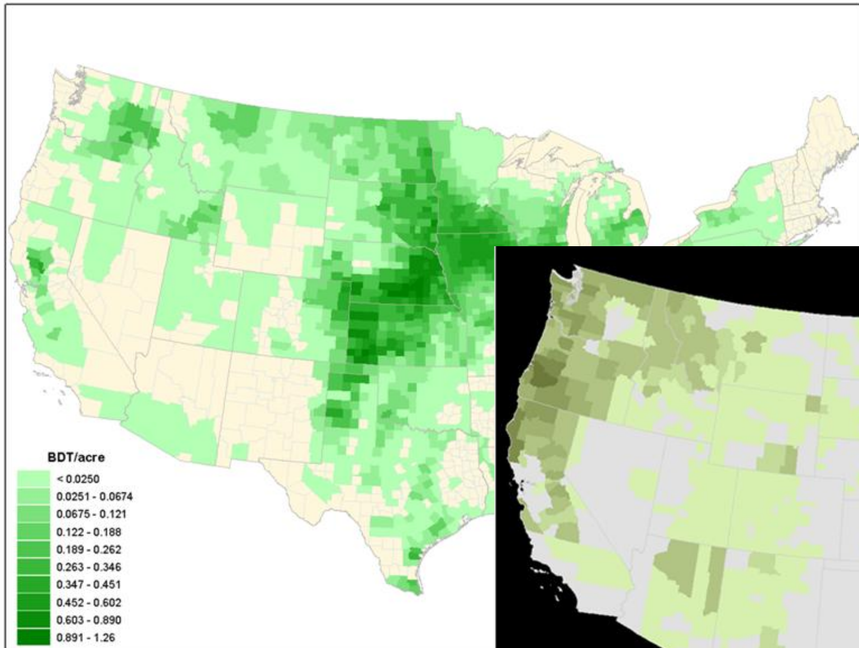
- **Designed to link biofuel supply estimates with costs and impacts addressing spatial constraints and impacts**



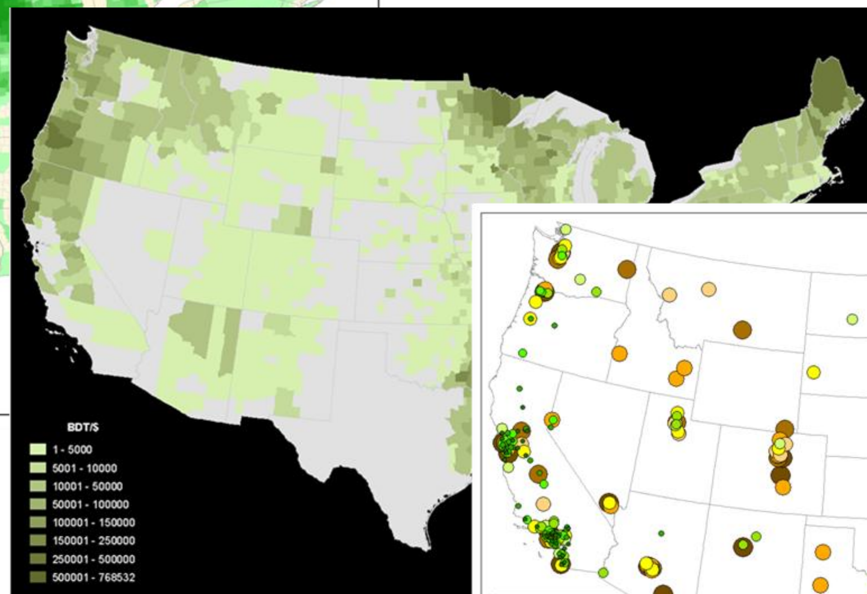
Feedstock conversion pathways



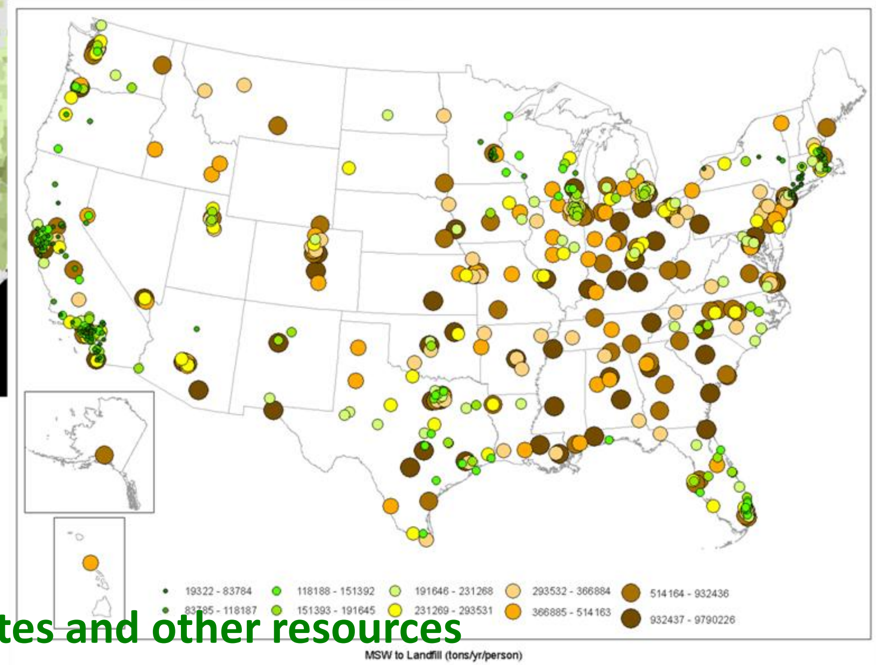
Spatial Resource Analysis



Agricultural and energy crops

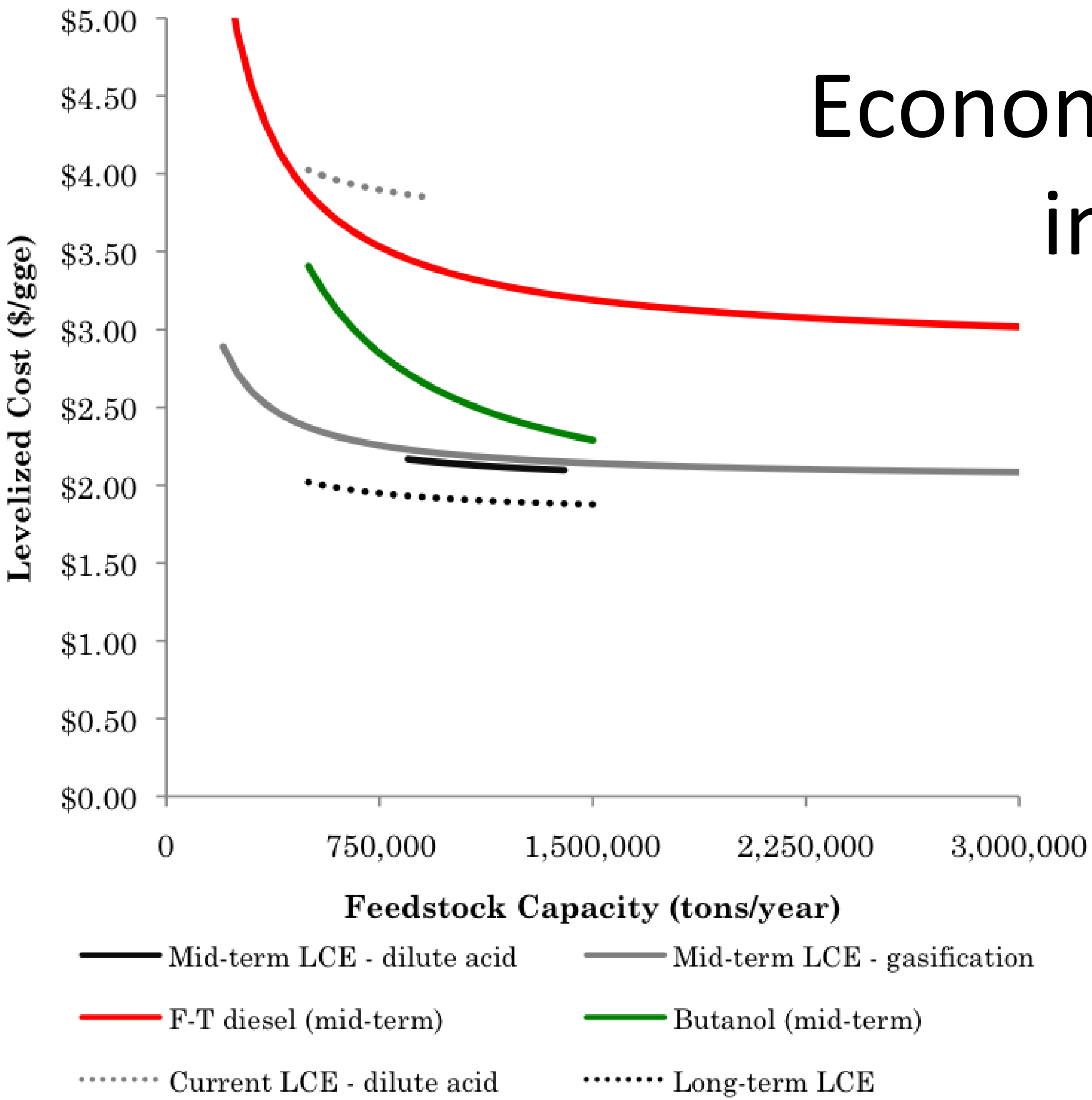


Forest biomass



Urban wastes and other resources

Economies of Scale in biorefining



Model Formulation

- **Optimizes the location, size, resource allocation and products for biorefineries.**
- **Maximizes industry profit given product prices, technology and resource costs.**
- **Mixed integer linear program**

$$Profit = \sum_{jkt} fuelprice \cdot gge_t \cdot T_{jkt} + \sum_{jt} cop_t \cdot Yb_{jt} - Cost \qquad (1)$$

where

$$Cost = \sum_{ijfp} [PC_{ifp} + DC_{ijf}] \cdot F_{ijfp} + \sum_{jt} a_t \cdot X_{jt} + \sum_{jt} b_t \cdot Yf_{jft} + \sum_{jkt} TC_{jk} \cdot T_{jkt} \qquad (2)$$

$$\sum_{j} F_{ijfp} \leq Supply_{ifp} \qquad (3)$$

$$\sum_{ip} F_{ijfp} = \sum_{t} Yf_{jft} \qquad (4)$$

$$Yb_{jt} = \sum_{f} \eta_{ft} \cdot Yf_{jft} \qquad (5)$$

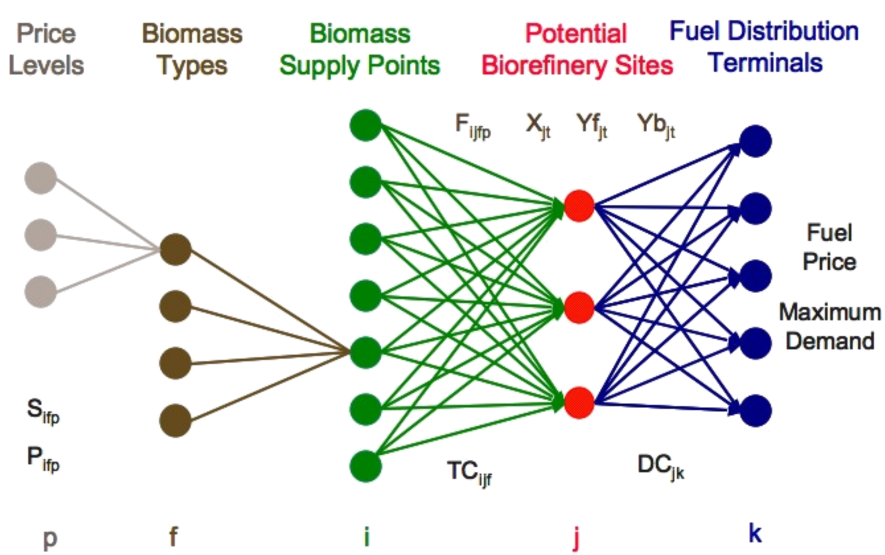
$$\sum_{k} T_{jkt} \leq Yb_{jt} \qquad (6)$$

$$\sum_{f} Yf_{jft} \leq M_t \cdot X_{jt} \qquad (7)$$

$$\sum_{jt} T_{jkt} \leq 1.05 \cdot vmt_k \cdot \sum_{jt} Yb_{jt} \qquad \forall e \subset t \qquad (8a)$$

$$\sum_{jt} T_{jkt} \leq \phi_e \cdot vmt_k \cdot NationalDemand \qquad \forall e \subset t \qquad (8b)$$

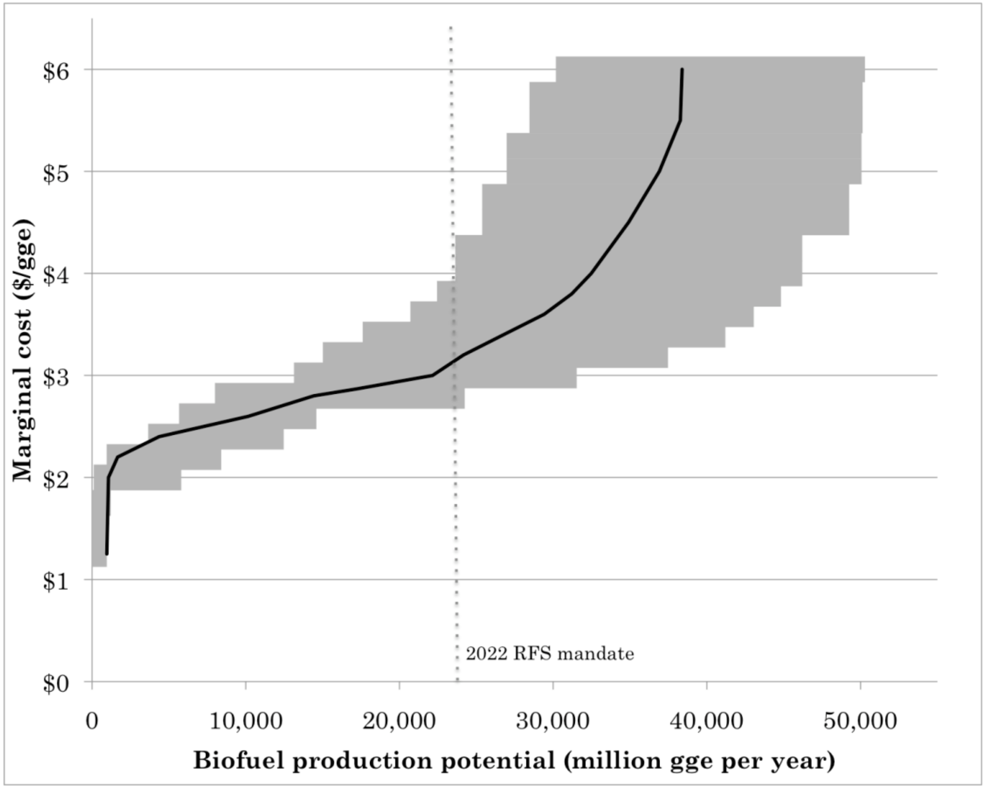
$$F_{ijfp}, Yf_{jft}, Yb_{jt}, T_{jkt} \geq 0 \qquad (9)$$



Scenario Definition

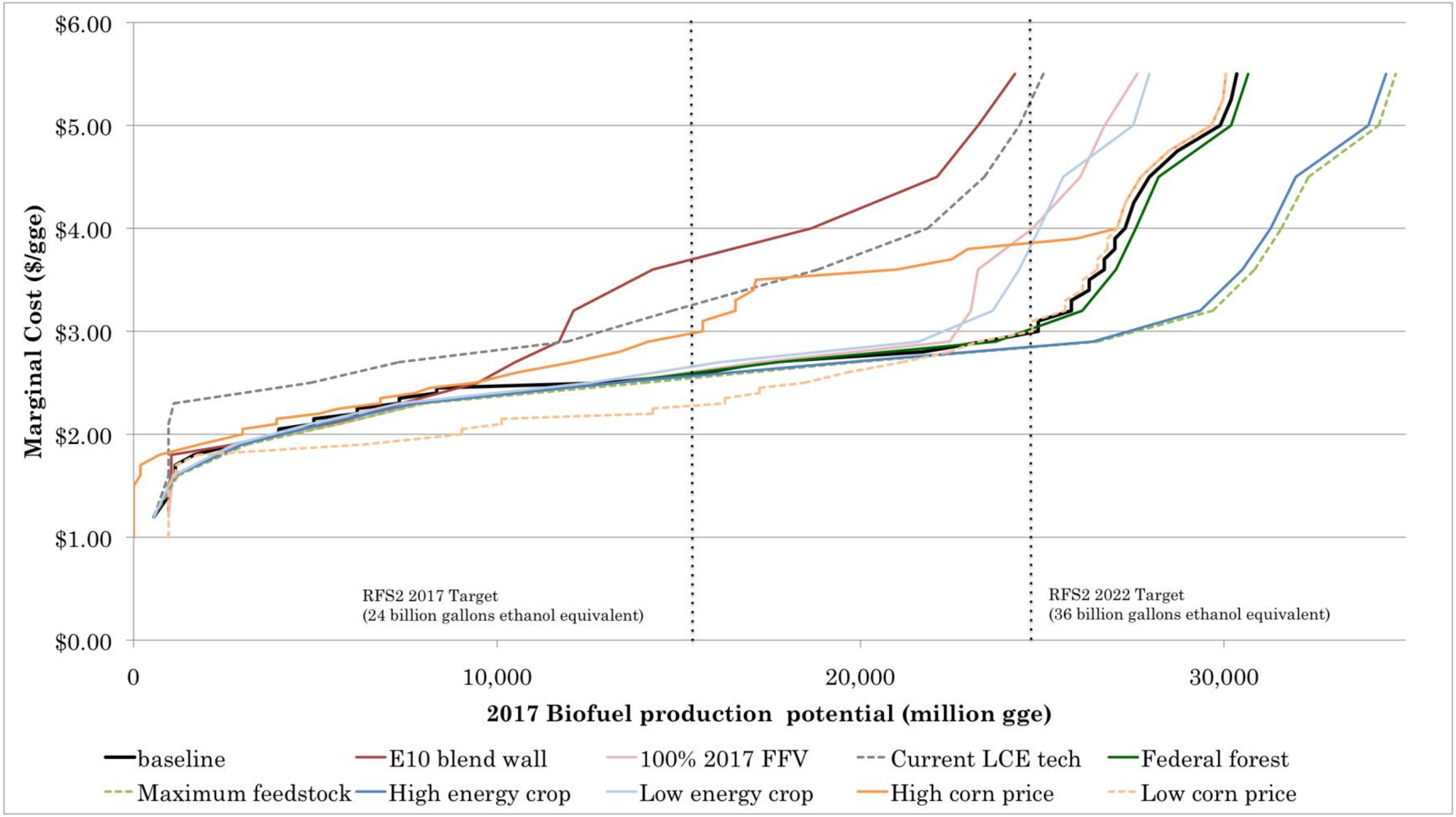
	Baseline	High Feedstock	Low Feedstock
Parameter			
Cropland - Idle (% of 2007 acres)	50%	50%	**25%**
Cropland - Pasture (% of 2007 acres)	50%	50%	**25%**
Pastureland (% of 2007 acres)	0%	**5%**	0%
Switchgrass yields	2010 upland from ORNL	**2010 lowland from ORNL**	2010 upland from ORNL
Allow Forest biomass from federal lands	no	**yes**	no
Ag. Residues	2018 projection (38% harvest eff)	**2018 projection (70% harvest eff)**	**10 yr historical**
Pulpwood	BTS 2018	**BTS 2018 (-20% prices)**	**BTS 2018 (+20% prices)**
MSW - food (% recoverable of currently landfilled)	25%	**50%**	**0%**
MSW - yard (% recoverable of currently landfilled)	33.00%	**75%**	**0%**
MSW - wood/c&d (% recoverable of currently landfilled)	25%	**50%**	25%
MSW - paper (% recoverable of currently landfilled)	25%	**50%**	**0%**
MSW - mixed (% recoverable of currently landfilled)	33%	**75%**	**0%**
Cellulosic Ethanol (technology performance)	middle	middle	middle
Cellulosic Butanol	not included	not included	not included
Cellulosic FT diesel (BTL) (technology performance)	middle	middle	middle
Ethanol demand limitation	E10	E10	E10
F-T diesel demand limitation	50% of diesel	50% of diesel	50% of diesel
Price of Carbon ($/ton CO2)	$0/ton	$0/ton	$0/ton

Biofuels could supply 6.5% to 22% of total U.S. vehicle fuel demand in 2018

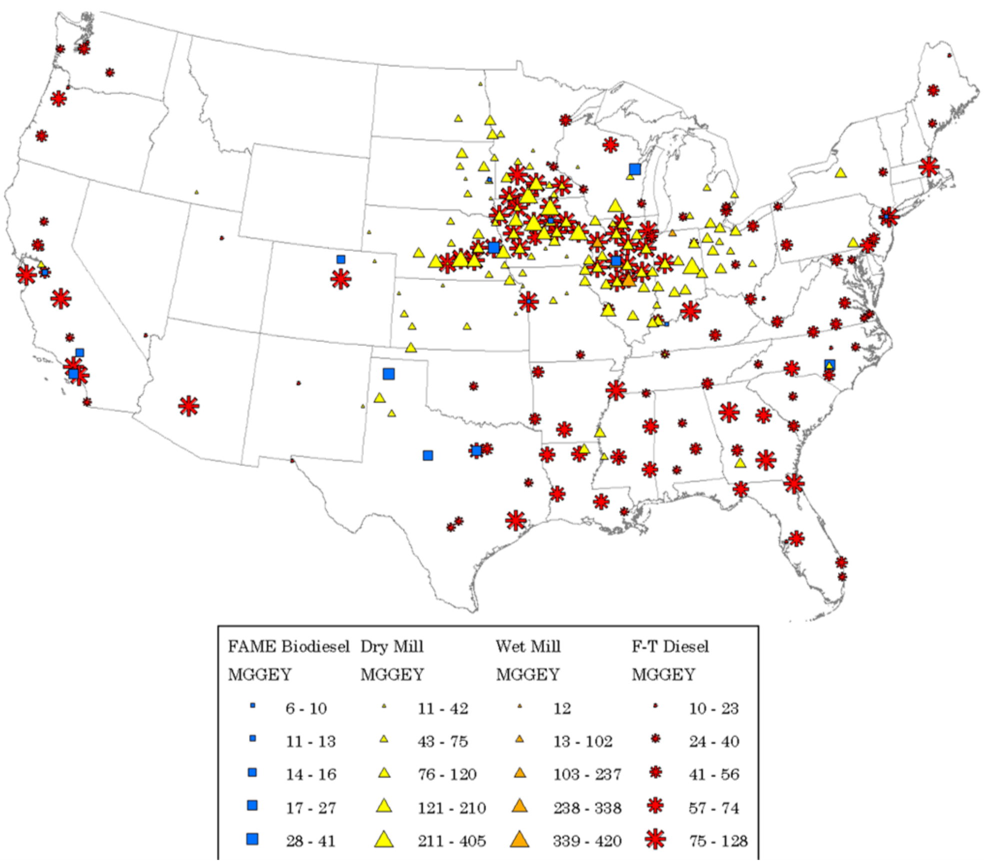


- Estimates for total sustainably available biofuels vary widely.
- **At $3/gge-$4/gge**
  - 2-10% from wastes and residues
  - 0-7% from energy crops and pulpwood
  - 1-5.5% from corn and soy

Sensitivity Analysis

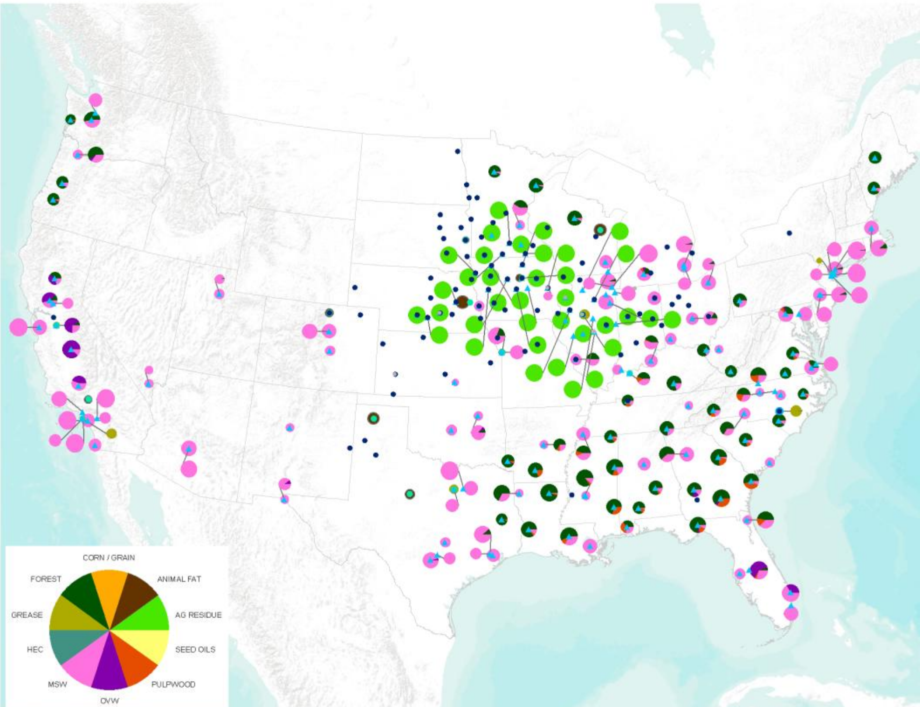


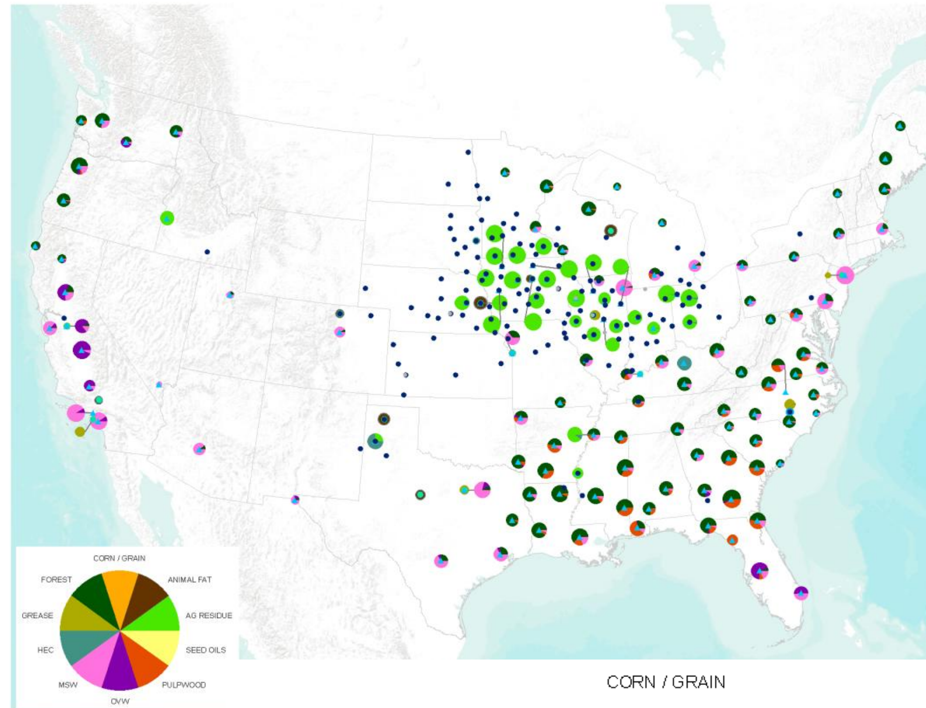
A simulated industry to meet the RFS



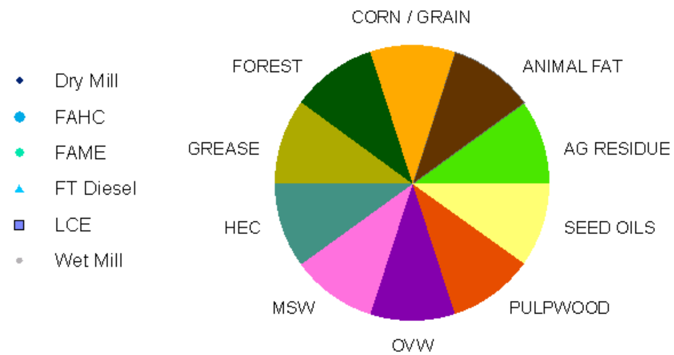
- **To achieve federal mandated volumes:**
  - **200 to 250 commercial scale cellulosic biorefineries needed, costing $100-360 Billion.**
  - **Corn ethanol and cellulosic biofuels from MSW and forest residues are the low cost pathways**

Layout of the industry depends on biomass resource availability



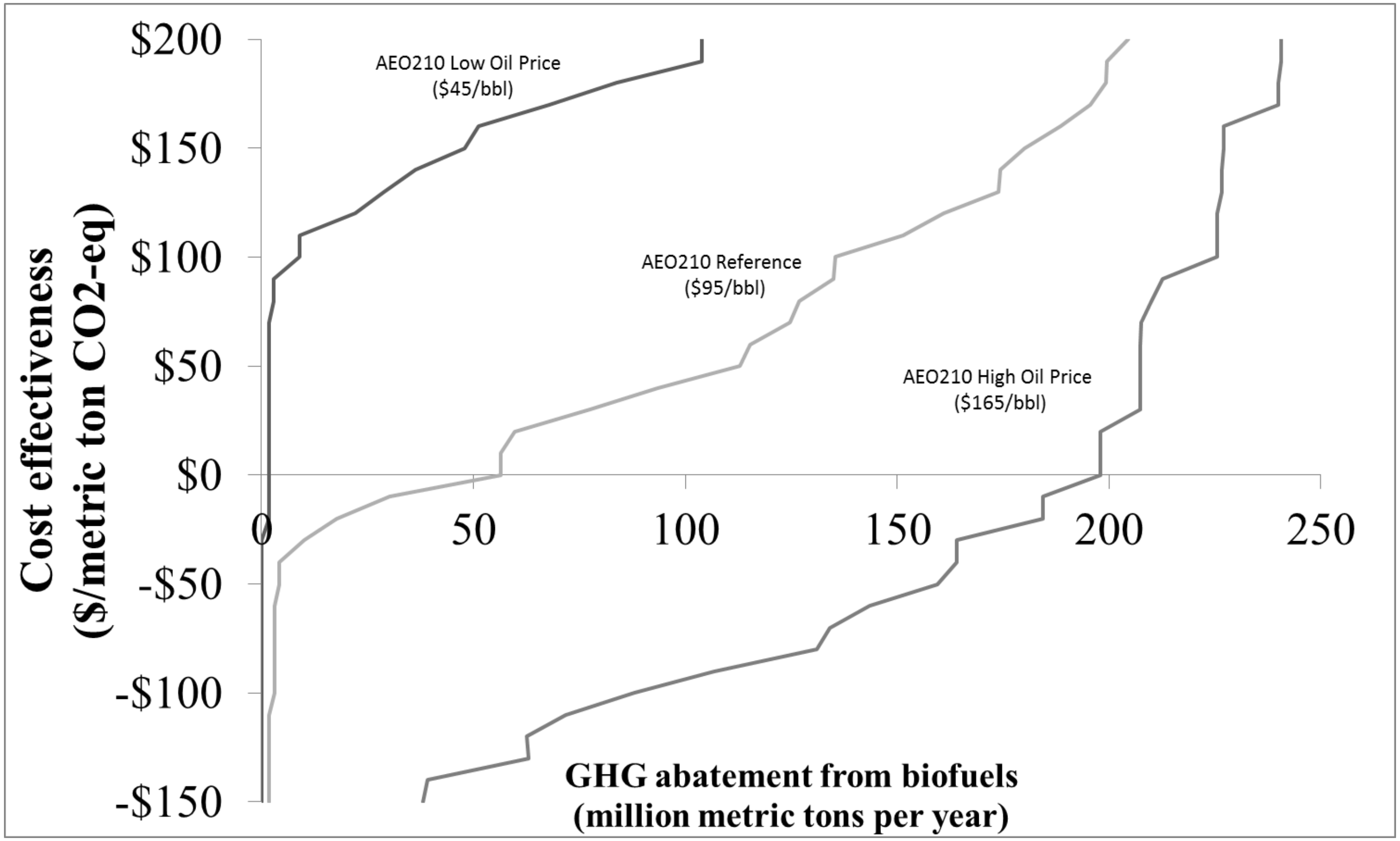


Maps of the biorefineries to meet the 2018 RFS2 mandate under high (left) and low (right) feedstock scenarios.



Carbon impacts: GBSM cost effectiveness of GHG abatement

The biofuel supply curve projected by the GBSM is used to calculate the cost of GHG abatement for each biofuel pathway which are combined to give an abatement curve for biofuels.

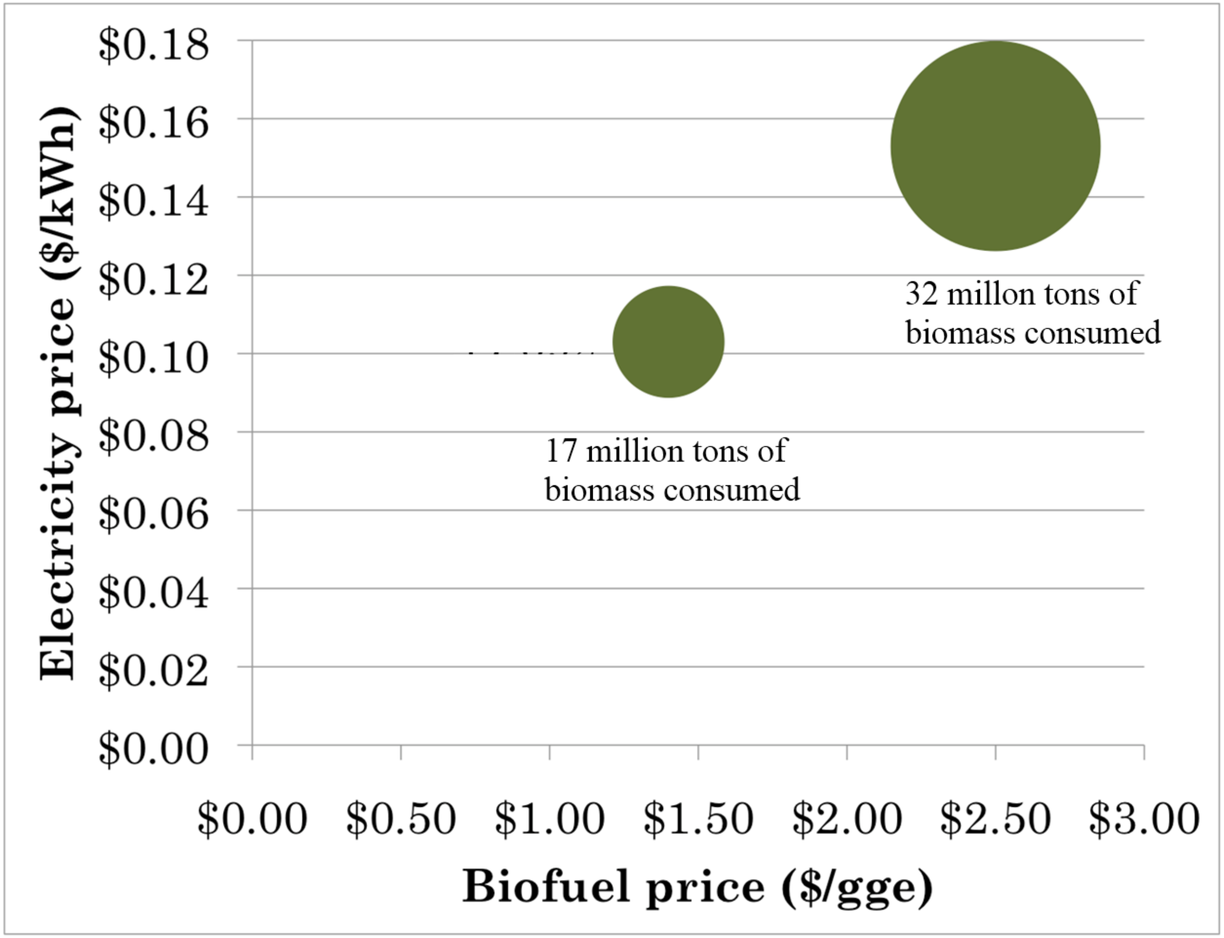


$$CE = \frac{Price_{biofuel} - Price_{gasoline}}{CI_{gasoline} - CI_{biofuel}}$$

Modeling competition among energy sectors

- California case study for biofuels and electricity

Electricity price needed for biomass power plants to meet 20% share of California RPS in competition with biofuels.

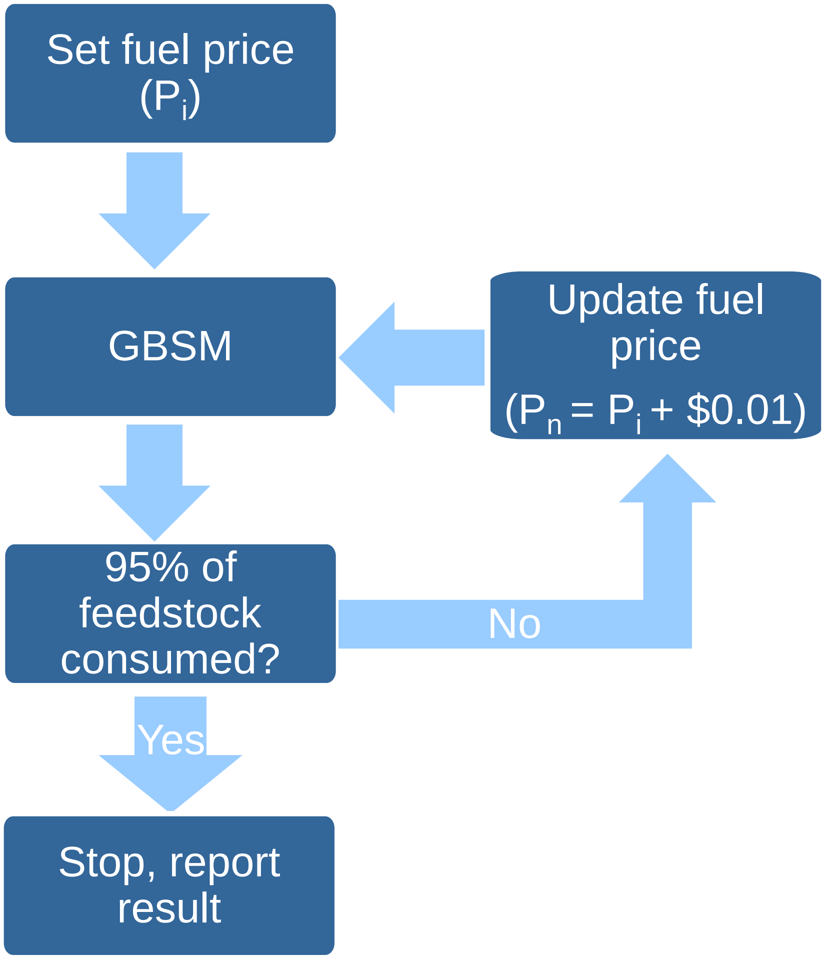


Social and Environmental Impacts

- Classification under land use, feedstock, and technology/scale effects with interactions

- **Land use**
  - *Land tenure and labor rights*
  - *GHG balance*
  - *Biodiversity*
- **Feedstock**
  - *Food security*
  - *Soil resources*
  - *Air and water resources*
  - *Human health*
  - *Invasive species*
- **Technology/scale**
  - *Rebound effects*
  - *Efficiency*
  - *Energy security*
  - *Air and water resources*
  - *Scale*

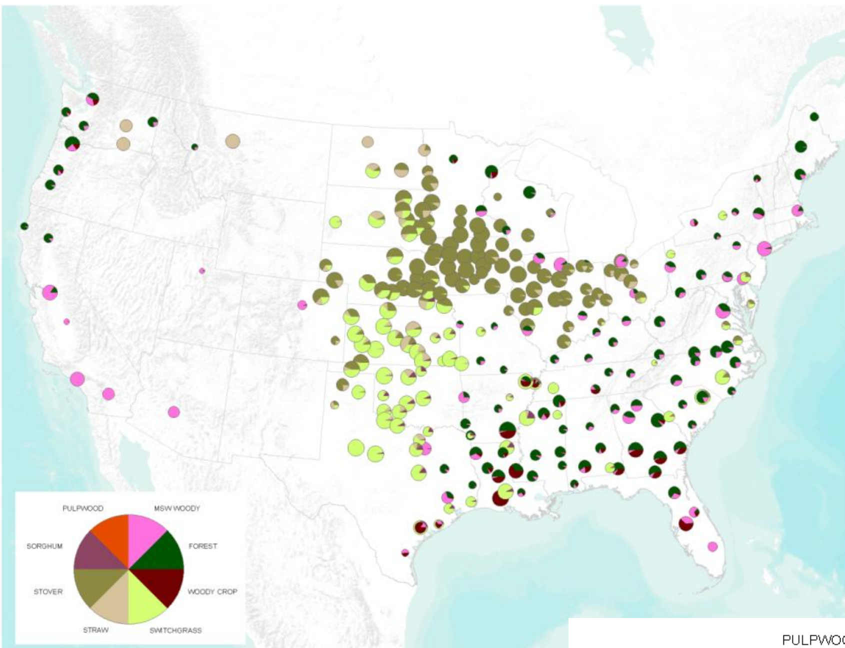
Modifications to use BTS2 data



- **Feedstock supply is limited to one price point.**
- **Model is looped to find biofuel price where most of the feedstock is consumed.**

Biofuel industry resulting from BTS2 scenarios

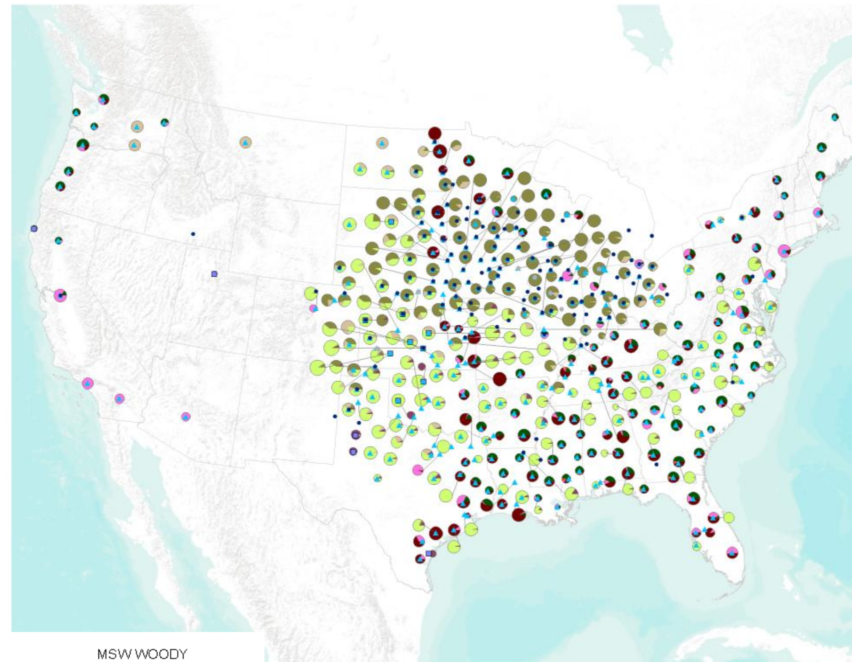
Map of the cellulosic biorefineries to meet the 2022 RFS2 mandate using the $50/ton BTS resource data



$3.60/gge fuel price

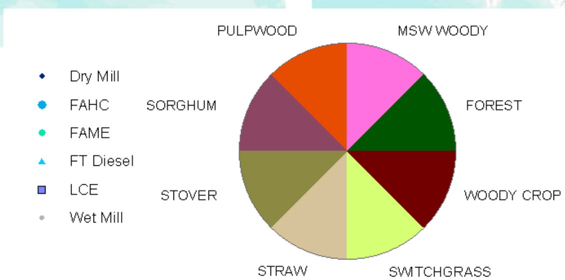
15.6 BGGEY cellulosic biofuels

Map of the cellulosic biorefineries using the $60/ton BTS resource data.



$3.70/gge fuel price

23.5 BGGEY cellulosic biofuels



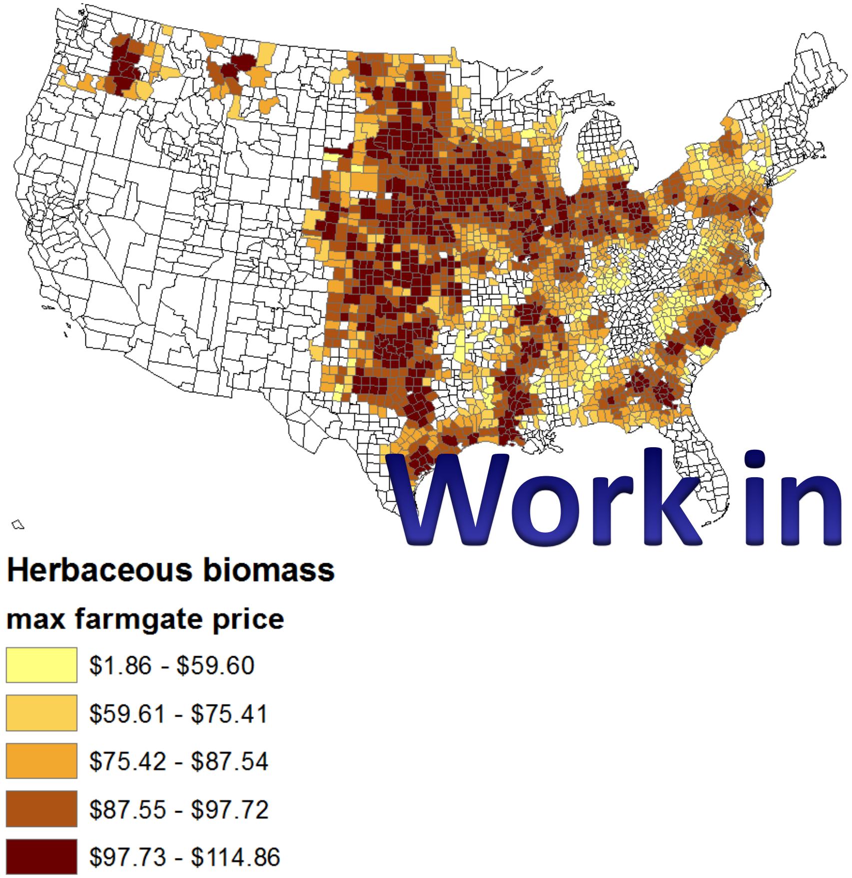
Impacts of feedstock supply method

- RFS2 2022 (36 billion gal) achieved at \$3.40/gge and \$50/ton

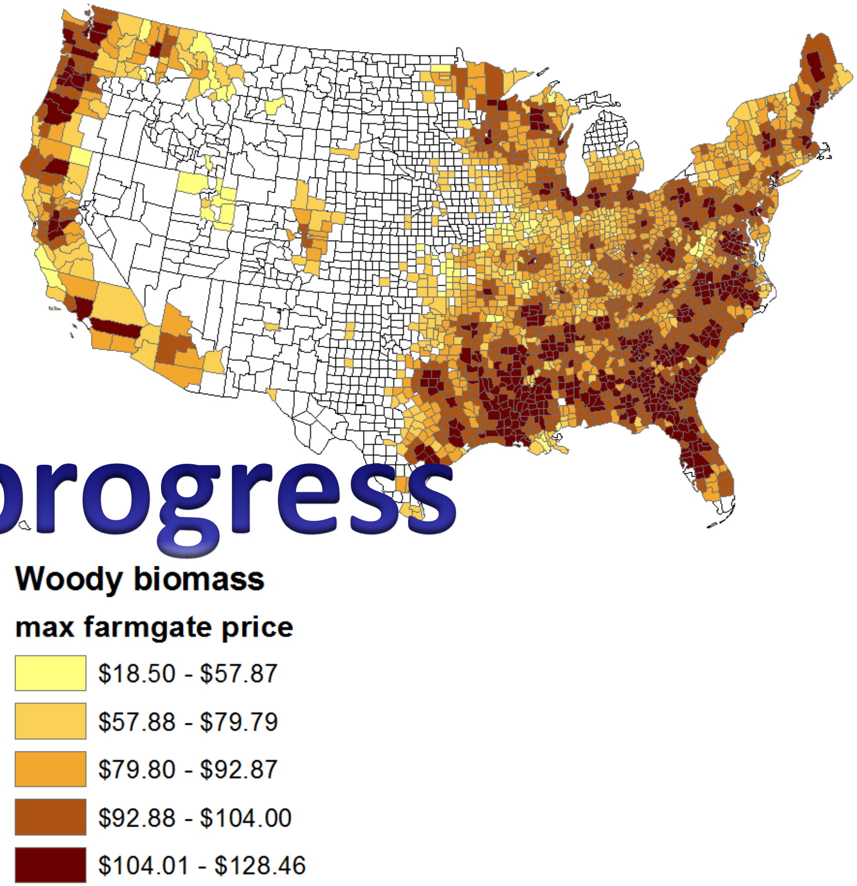
- Relative importance of feedstock differs:
  - 3x energy crop utilization in BTS
  - Greater use of MSW, pulpwood in UCD scenario

- Spatial layout of system differs:
  - BTS biorefineries in Midwest and Plains states
  - UCD biorefienries in Southeast and population centers

Spatial variability in willingness to pay for feedstock



Work in progress



Based on BTS2 2022 $50/ton baseline scenario.

Summary and Lessons Learned

- **Geospatial and optimization modeling adds extensive assessment capabilities in attempting to predict industry transition, infrastructure needs, sectoral competition, environmental and economic performance, and policy influence**

- **Supply outcomes dependent on coupling of feedstock value to values of end-products: farm gate prices will vary spatially due to the existence of biorefineries and high transport costs.**

- **Extensions of the model will enable improved temporal analysis and more comprehensive environmental and resource impact assessment.**