Optimal Biomass Transportation and Biorefinery Locations in Illinois

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Project "Economic and Environmental Impacts of Biofuels: Implications for Land Use and Policy"

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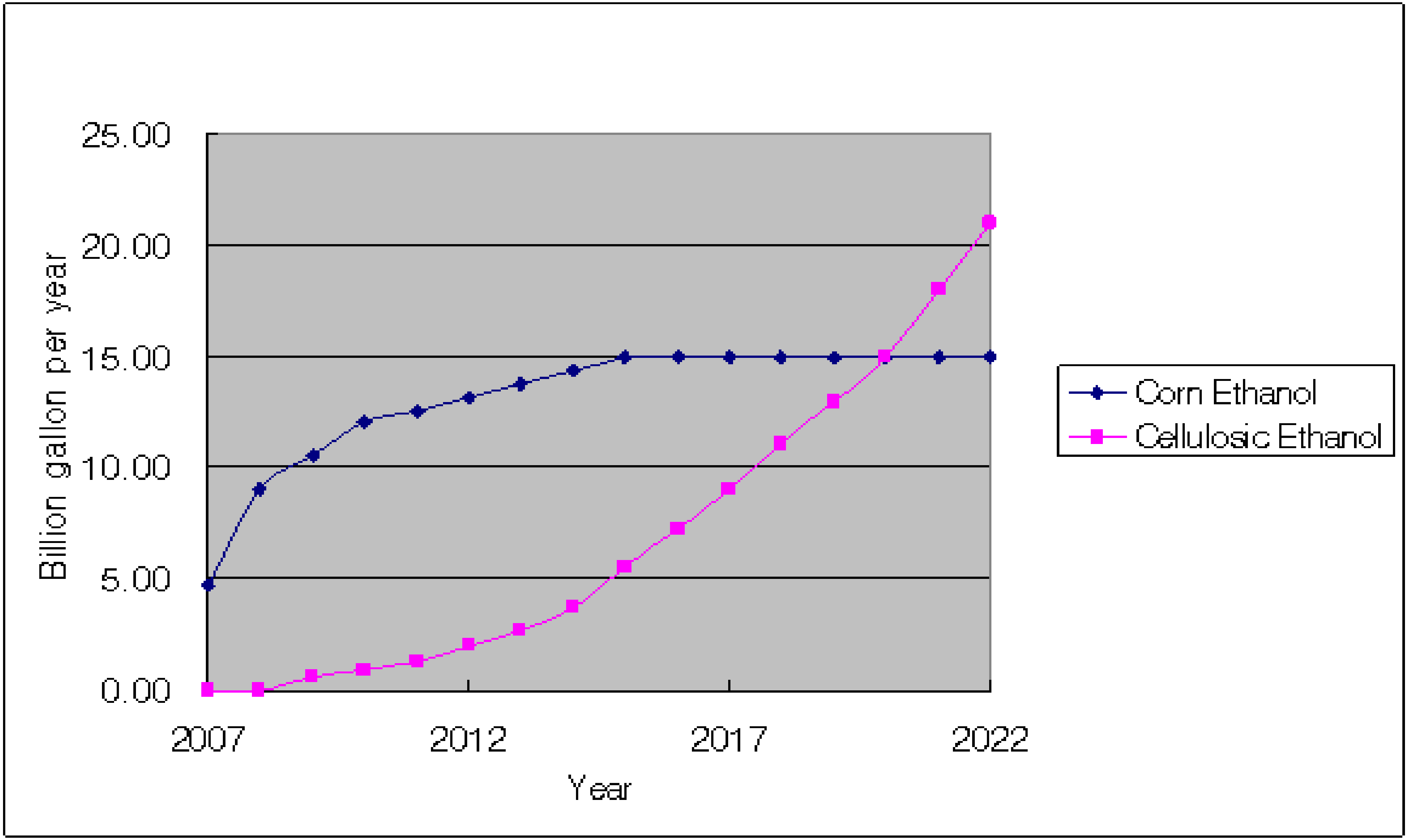
Renewable Fuel Standard: Logistics requirements

Renewable Fuel Standard (RFS): mandates production targets for both corn-based and cellulosic ethanol.

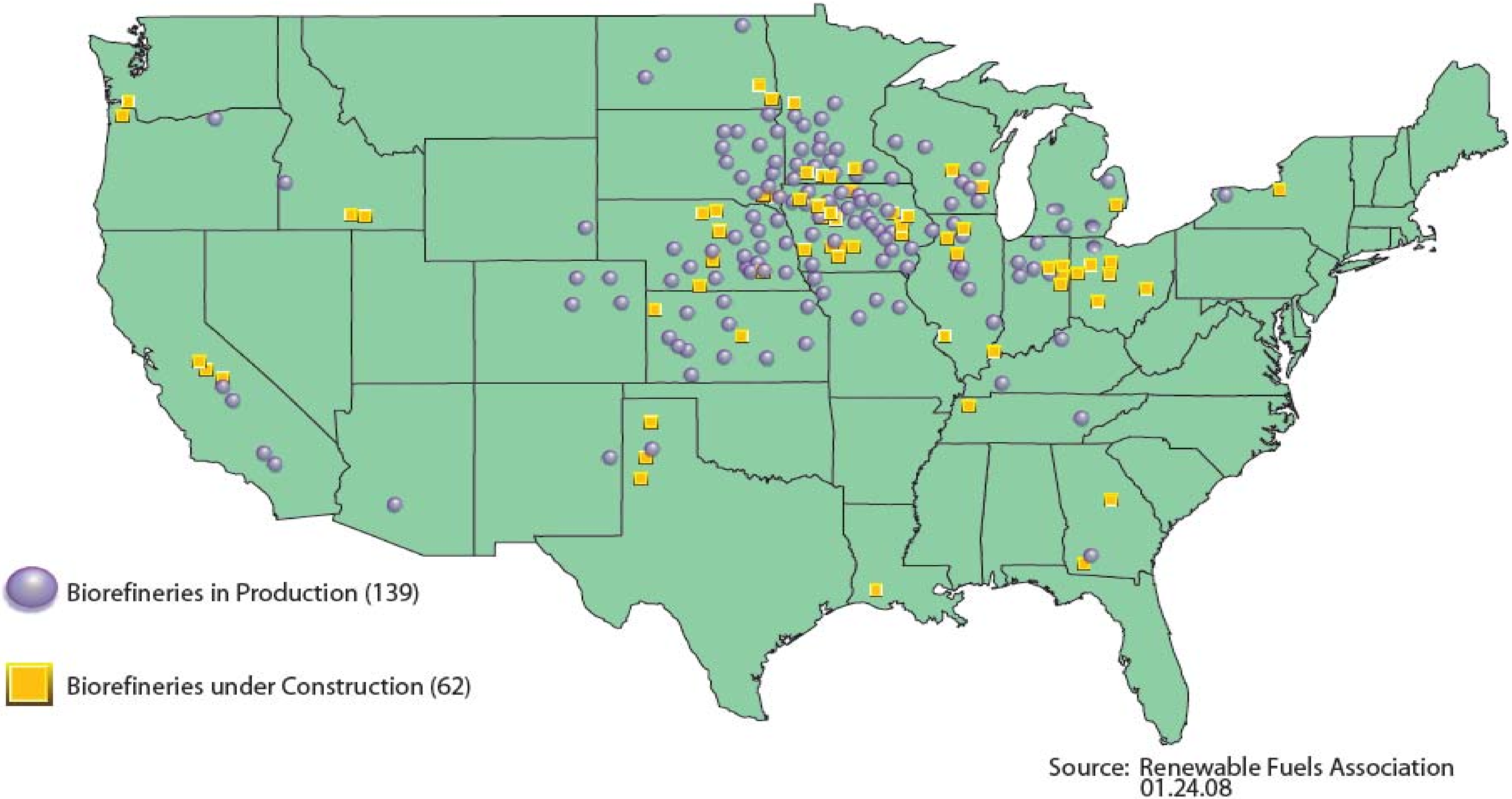
- ➢7.5 billion gallons (bgy) by 2012, 15 bgy upper limit
- ➢36 bgy by 2022, 21 bgy cellulosic inputs

→ Competitiveness of biofuel industry depends on economic and strategic plans for facility location, transportation infrastructure, and logistics

Production mandate of the Renewable Fuel Standard



Biorefineries in production or under expansion/construction



Objectives

Minimize total cost of all operations:

- Optimal transportation & processing of raw materials and products (ethanol)
- Biorefinery type, capacity and location decisions to meet mandated ethanol targets in 2007-2022 period
- Costs of processing, and fixed investment costs of building refineries
- Use byproduct credits (DDGS and electricity generated by burning wastes of cellulosic biomass).

Optimal size and location of biorefineries

Optimal land use allocation for feedstock production

→ Develop **transportation and site selection model** to identify optimal locations for ethanol plants and bio-refineries

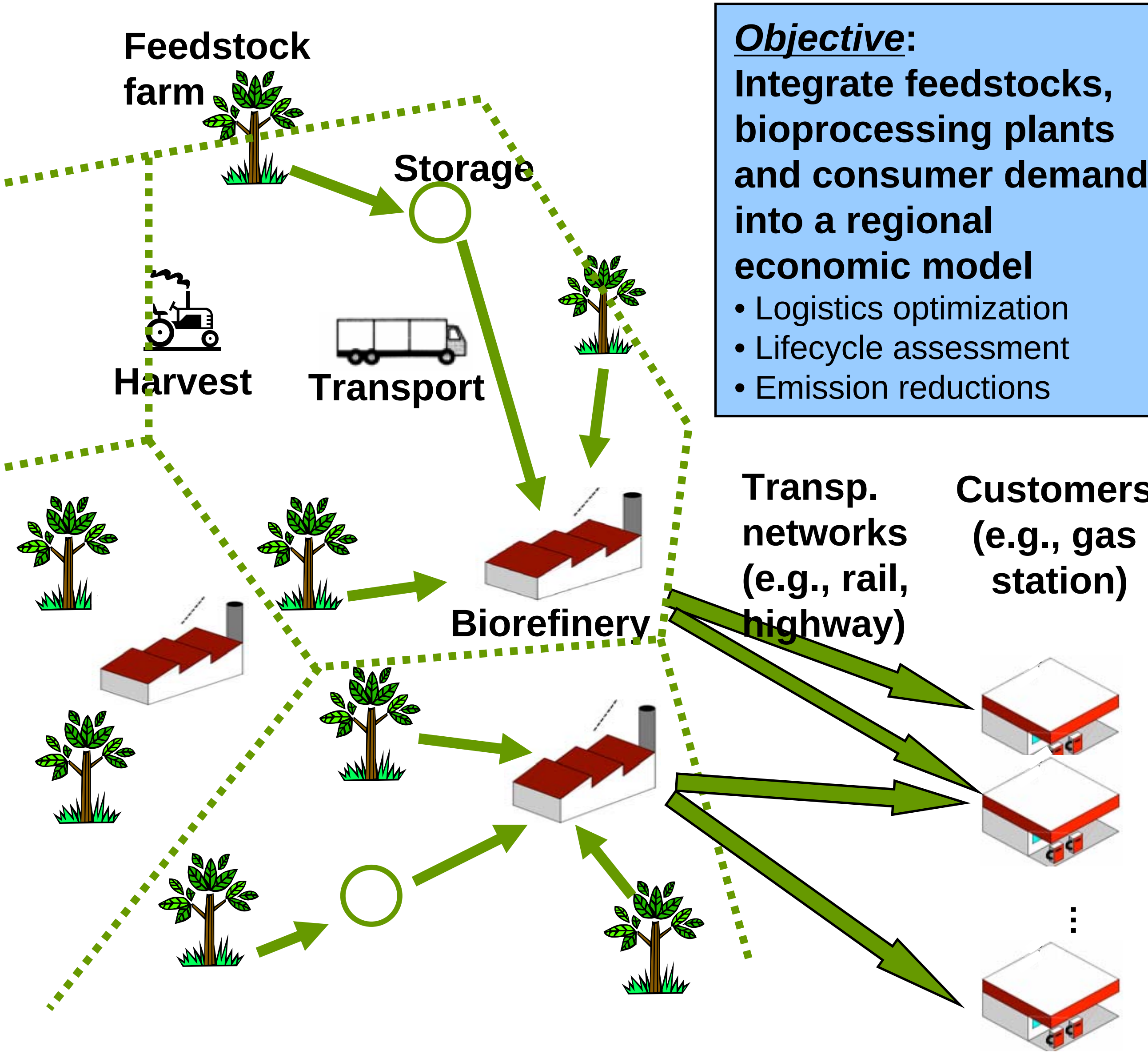
Distances (transportation costs) between feedstock sources and road/railroad network

→ Certain locations may be more suitable for corn and corn-stover based ethanol plants, others may be more suitable for producing ethanol using perennial grasses.

Develop model to determine **optimal location** of plants and optimal transportation patterns.

Biomass transportation, biorefinery locations and biofuel distribution

Objective:
Integrate feedstocks, bioprocessing plants and consumer demands into a regional economic model
- Logistics optimization
- Lifecycle assessment
- Emission reductions



Cost Analysis
- Transp.
- Facility
- Inventory
- Environmental externalities

Refinery Planning
Site Selection based on:
- Resources (e.g., water)
- Farms
- Transp. networks
- Storage (optional)

Feedstock Shipping
- Transp. mode
- Fleet design (e.g., vehicle capacity)
- Dispatch route & schedule
- Handling at farm/storage

Fuel Distribution
- Transp. mode & fleet
- Dispatch route & schedule
- Price and demand uncertainty

Model description

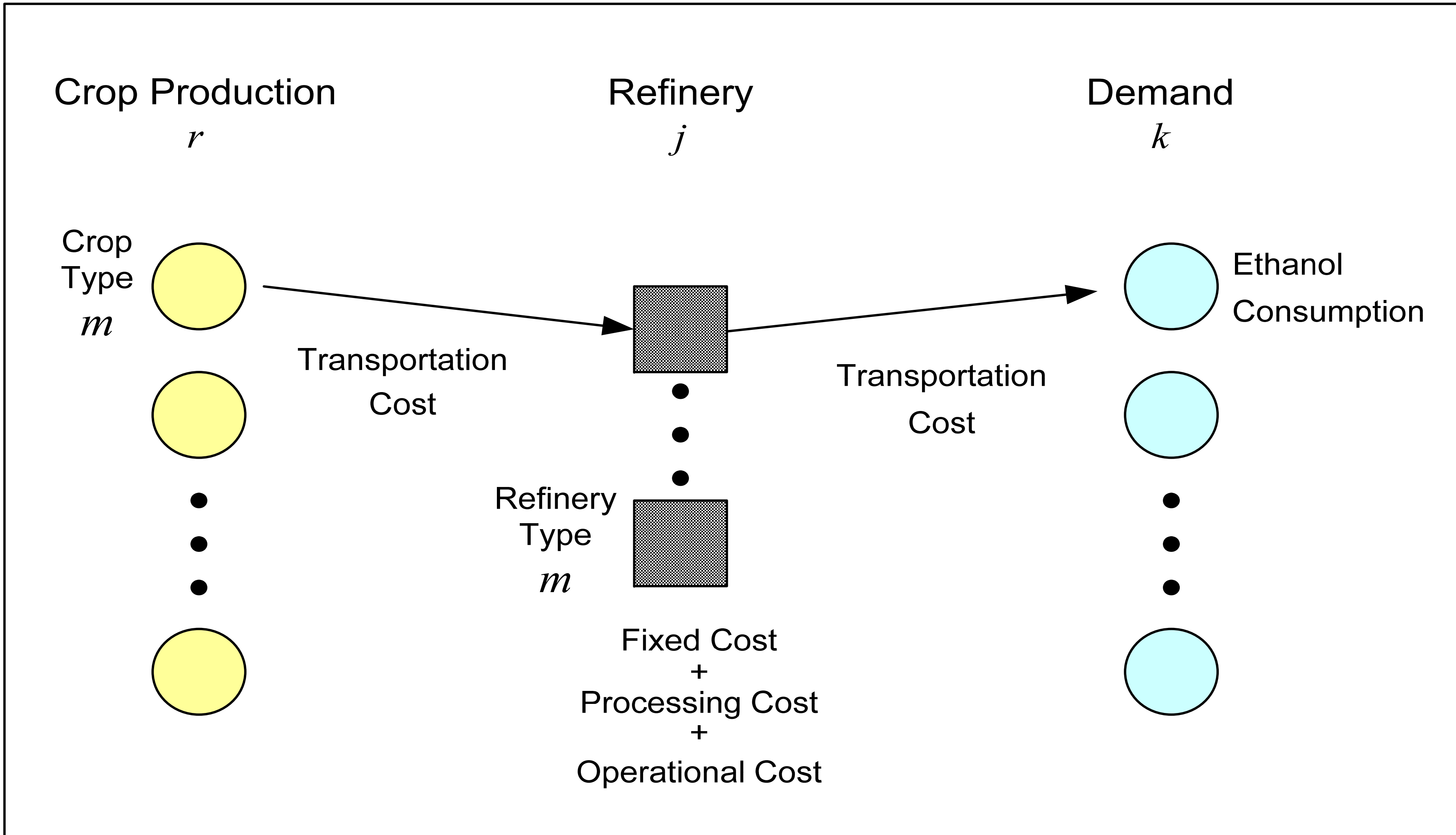
Decision layers:

- Type of processing facilities, capacities, locations, year built
- Amount of raw materials (corn, stover, perennial grasses)
- Transport from production regions to biorefineries
- Amount of ethanol deliveries to the demand destinations (blending facilities).

Transshipment problem with network flows:

- Linear mixed-integer programming model
- Transportation decisions
- Decision to build biorefinery at predetermined locations
- Biorefinery capacity

Model framework



Model assumptions and constraints

Supply constraint for each production region and year: corn and biomass shipped from any given region to all biorefineries in the system cannot exceed the available supply in that region.

In/out constraint: restricts ethanol produced by biorefinery to the corresponding amount of raw inputs coming into that facility.

- Total ethanol produced < processing capacity (decision variable).
- Expanding capacity of a previously built biorefinery over time.
- Build biorefinery at given location and year remains operational
- Plant capacity between upper and lower limit
- Capacity utilization restricted to minimum percentage of construction capacity.

Illinois model

Study on transportation logistics & refinery location in Illinois:

- Major corn producer state, with nearly 20% of corn grain for ethanol
- Major ethanol consumption region, including Chicago
- Major transportation hub

Illinois model for period 2007-2022 (RFS): 19% of national ethanol targets in Illinois (current share)

Biomass supply allocation

Spatial distribution of bioenergy input supply: supply response component of *Agricultural Policy Analysis Model (APAM*)

- County-level crop yields, production costs, and land availability
- Regional supplies of energy crops (corn, corn stover, and perennial grasses) that meet ethanol target levels 2007-2022.
- Energy crops compete for land
- Resource allocation and price effects
- Maximizing sum of consumer and producer surplus subject to resource constraints and production possibilities.
- Farmer resource allocation flexibility (e.g. rotation practices)
- Utilization of each crop's output to aggregate production
- Supply of cellulosic biomass related to land allocated to corn (stover), switchgrass and miscanthus

Multi-modal transportation

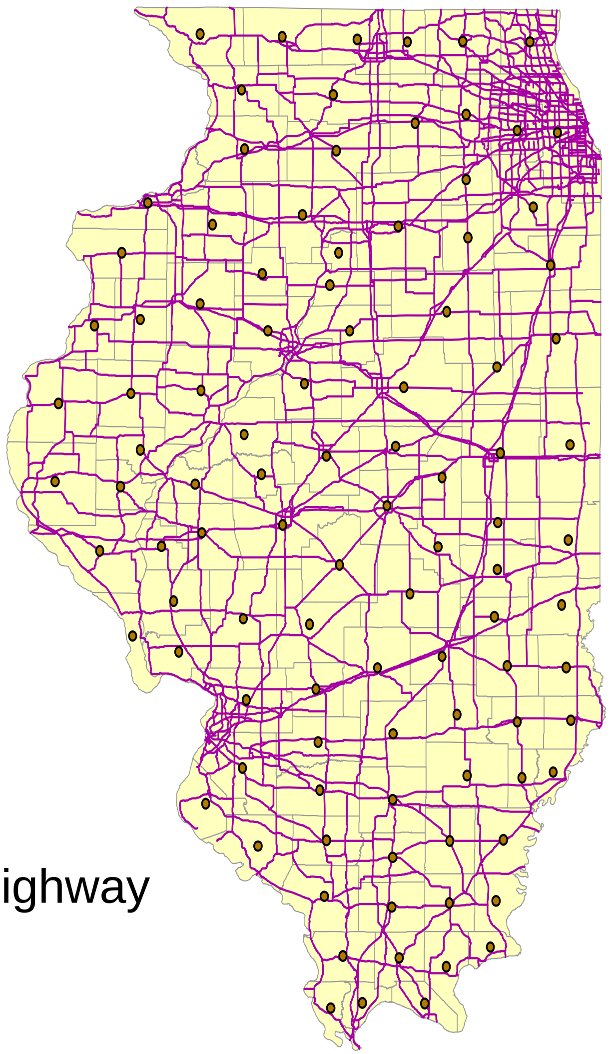
Minimum unit transportation costs between production regions and potential refinery locations and between refineries and blenders:

- Delivery through multimodal transportation network (highway or railway)
- Shortest-path algorithms and cost functions
- 102 county centroids as candidate plant locations for corn-based or cellulosic plants
- Four existing gasoline blending facilities as demand locations

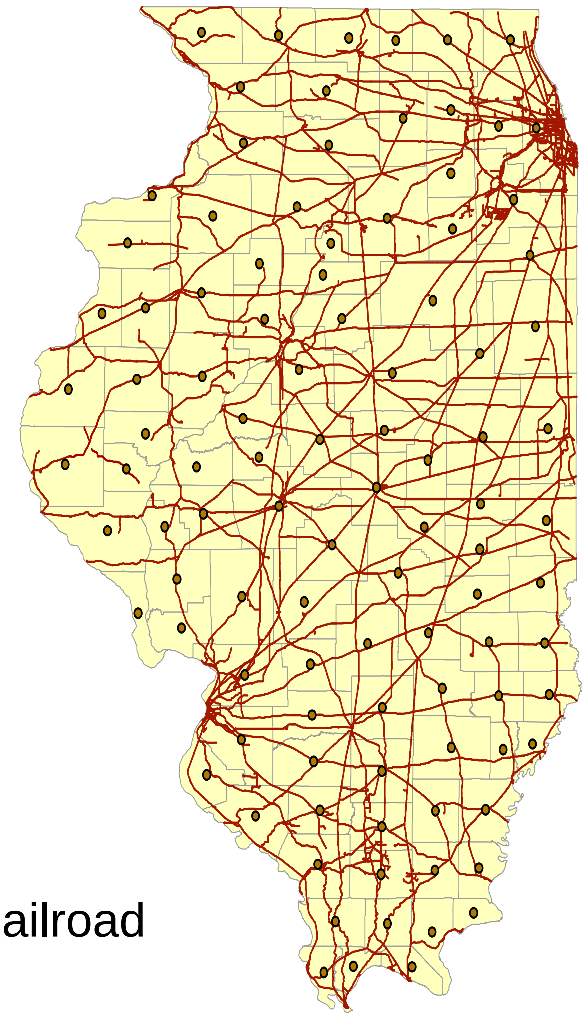
Transportation unit costs for biomass and ethanol

Mode	Corn	Cellulosic Biomass	Ethanol
Truck	\$0.0034/bushel/km	\$0.137/ton/km	\$0.00012/gallon/km
Rail			
Fixed Cost	\$0.545/bushel	\$21.8/ton	\$0.016/gallon
Variable Cost	\$0.0007/bushel/km	\$0.028/ton/km	\$0.00004/gallon/km

Illinois highway and rail network

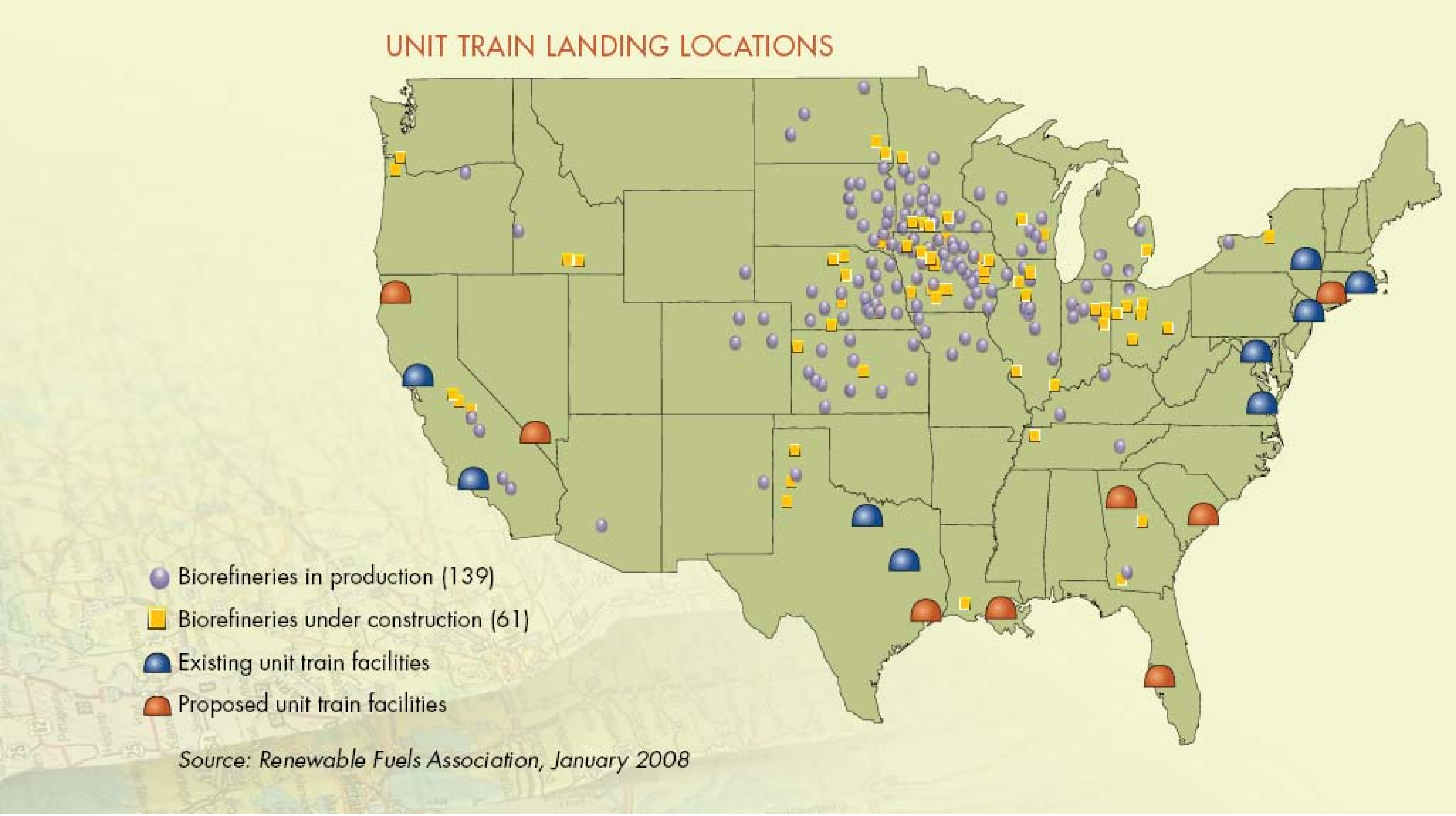


Highway



Railroad

Unit train landing locations



Water resources in Illinois

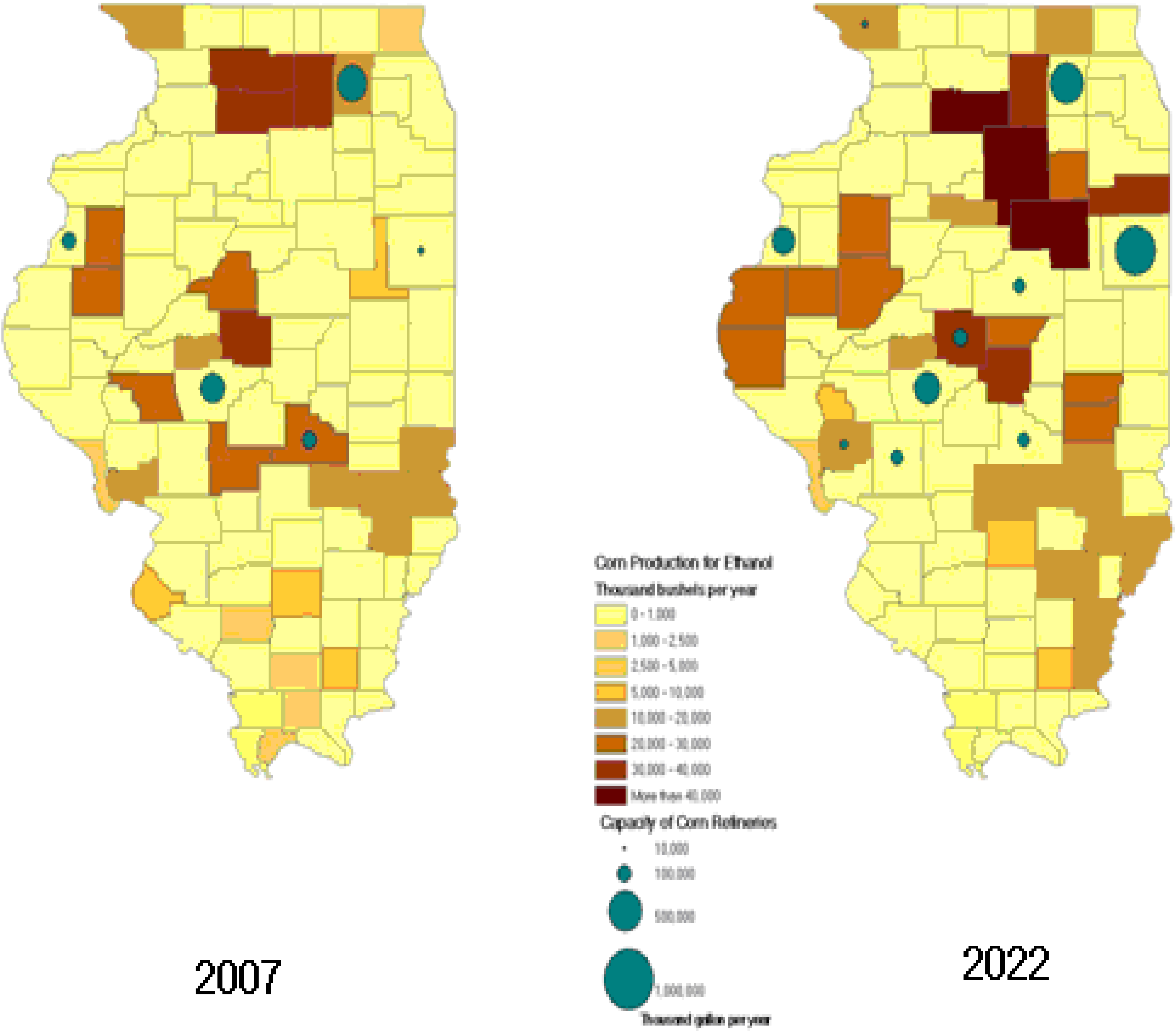
Major Surface Water

Deep Bedrock Aquifers

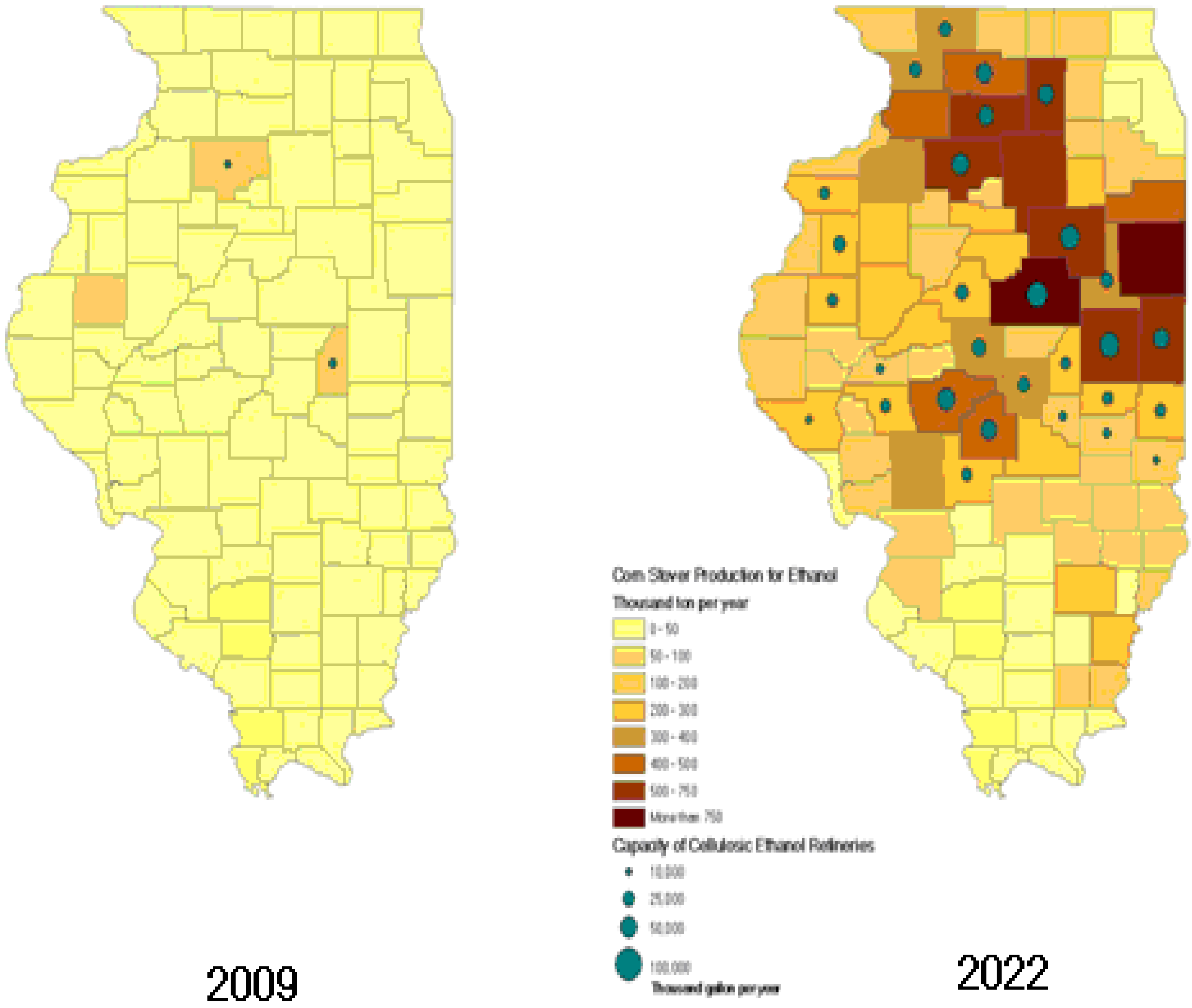
Sand and Gravel Aquifer

Shallow Bedrock Aquifers

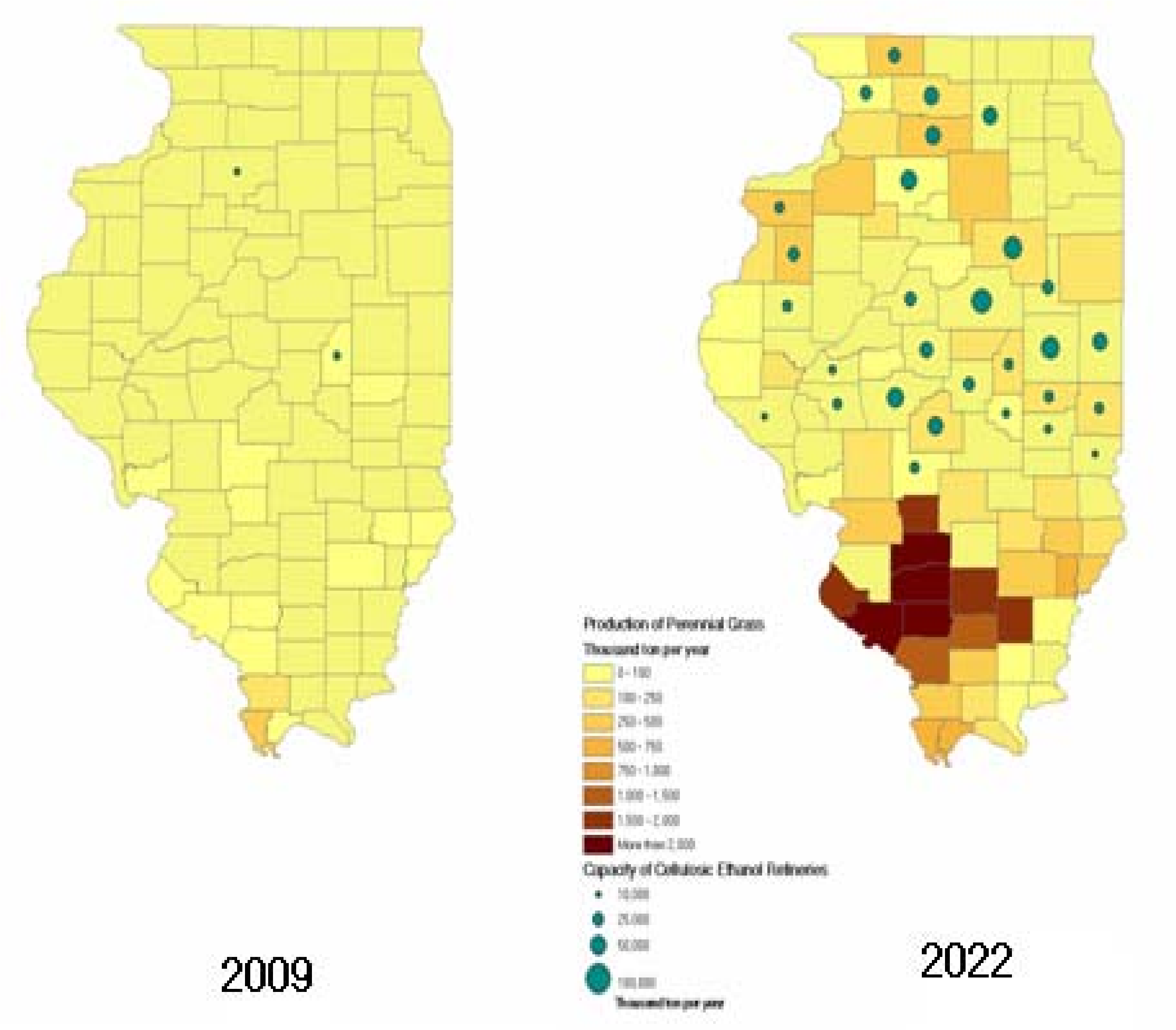
Corn production and corn ethanol refinery locations



Corn stover production and cellulosic ethanol refinery locations



Perennial grass production and cellulosic ethanol refinery locations



Possible extensions

1. Expansion to Midwest/USA
2. Advanced optimization methods (Lagrangian relaxation)
3. Model refinery capacity and distribution as a function of corn/biomass allocation which affects refinery location within county.
4. More realistic pre-selection of adequate biorefinery locations (highway/rail intersection, water access, distance from demand centers)
5. More realistic model of refinery cost structure for appropriate refinery design using data from pilot plants for cellulosic biomass:
   - big vs. small cost plants
   - fixed cost as a function of capacity
   - building and equipment costvariable cost
   - insurance, taxes
   - economies of scale
6. Include DDGS demand centers and livestock locations
7. More transshipment layers: blending/consumer locations, storage facilities
8. Highway congestion, water constraints, bottlenecks, experience with existing refineries