Agriculture Analytics to Decarbonize our Food and Energy Needs

Intelligent Data for Energy & Agriculture Logistics and Supply Chains (IDEALS) Lab

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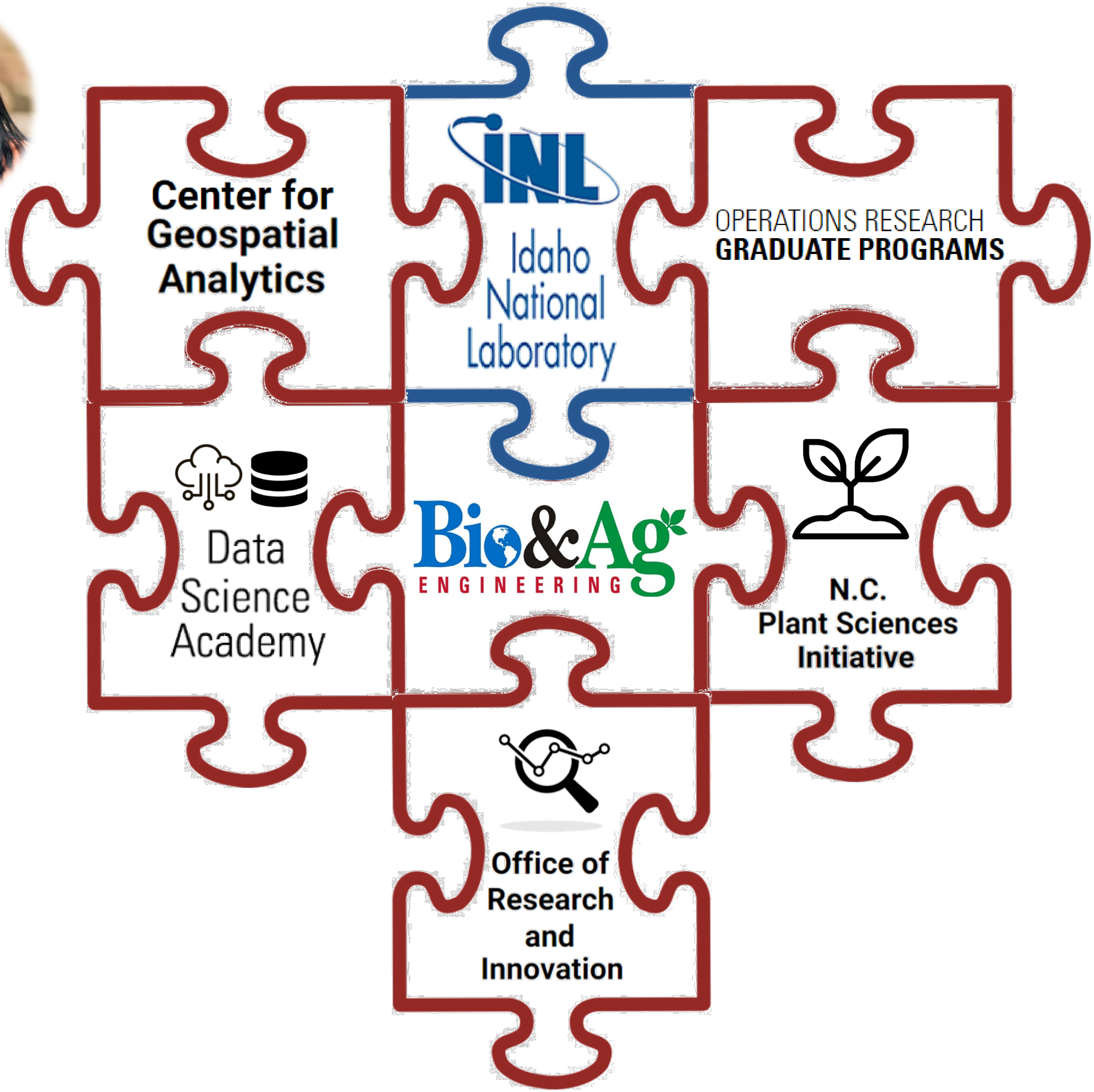
September 2023


Center for Geospatial Analytics
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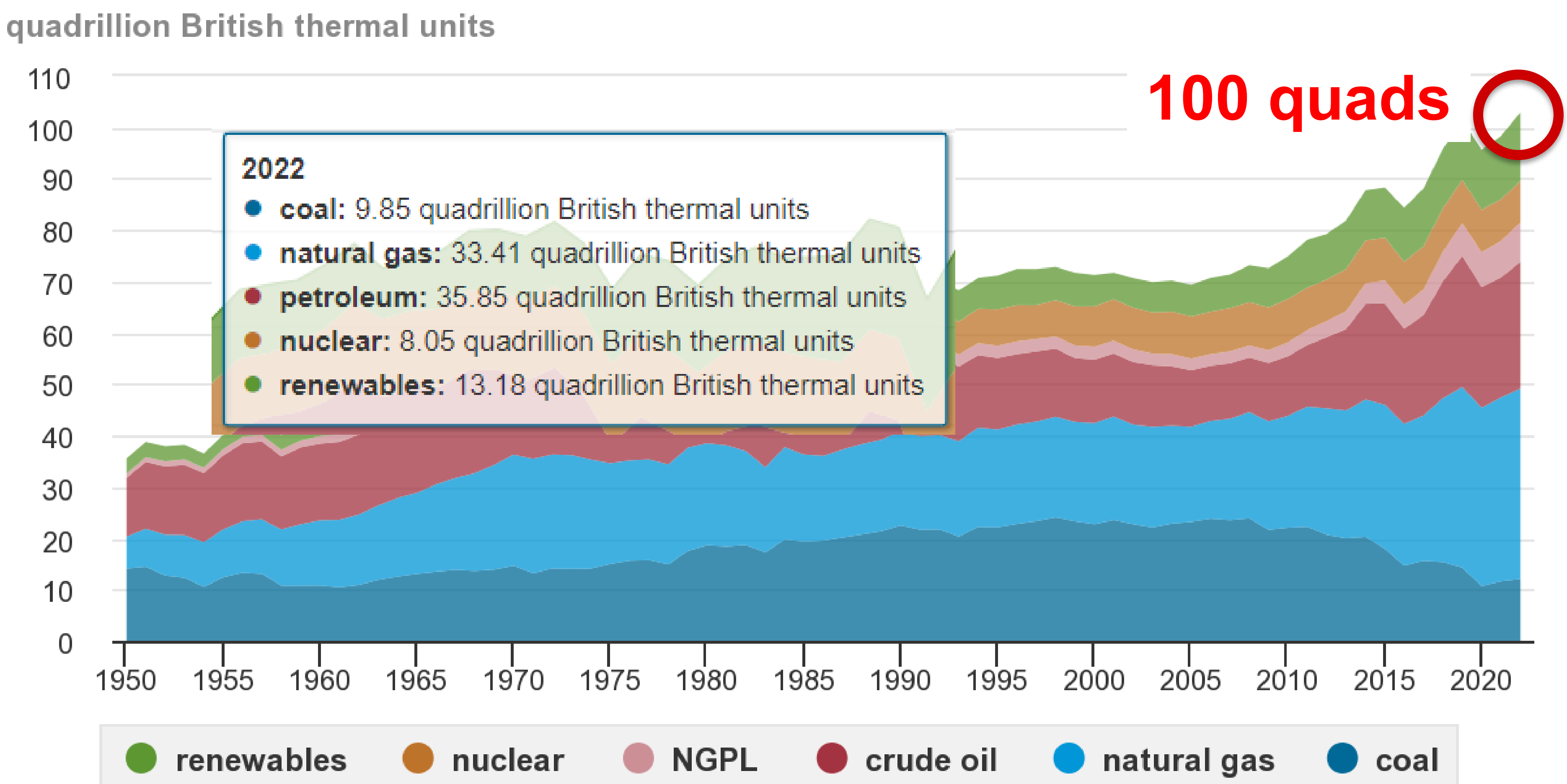
Office of Research and Innovation

U.S. Energy Consumption in 2022

U.S. primary energy production by major sources, 1950-2022

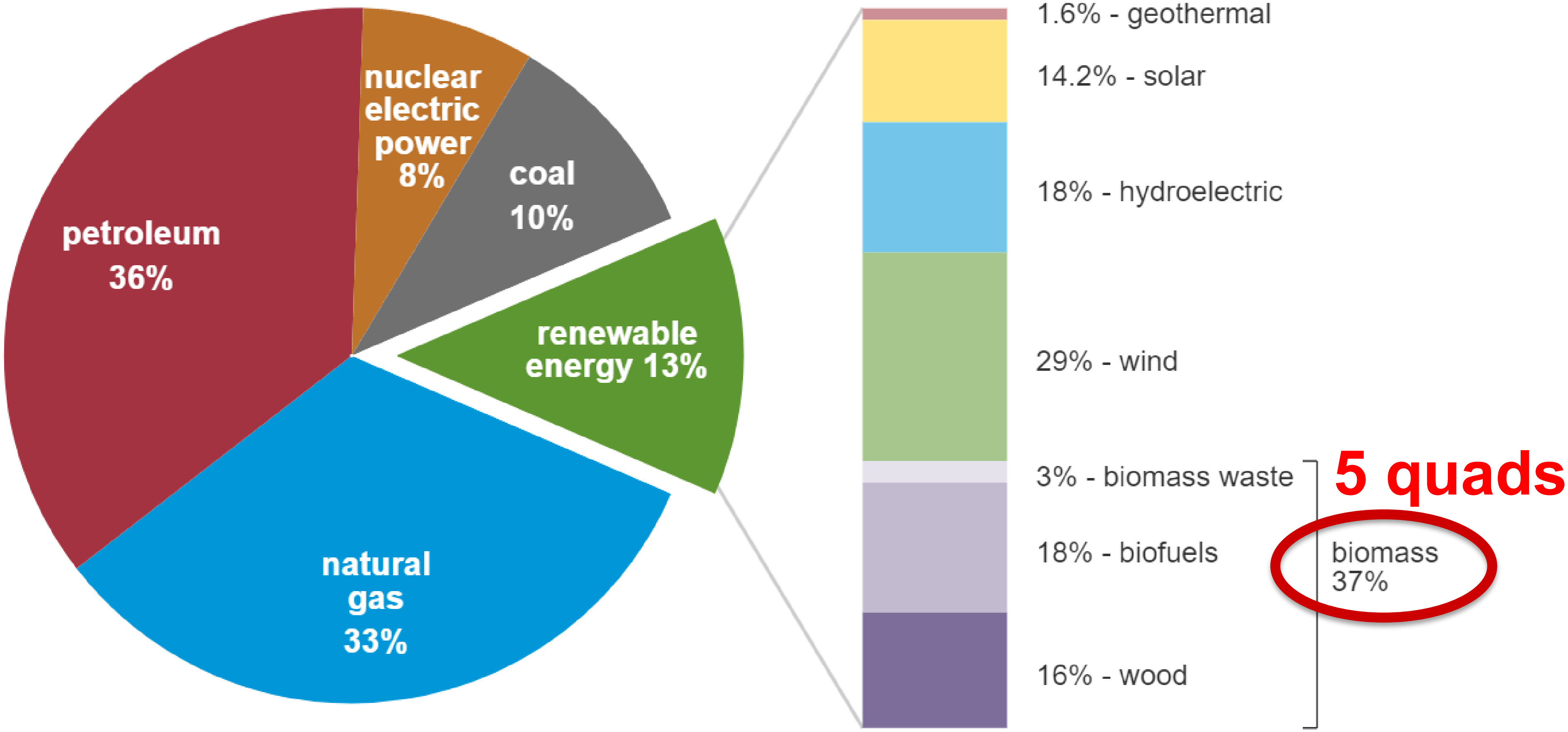


Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.2, April 2023, preliminary data for 2022
Note: NGPL is natural gas plant liquids.

U.S. primary energy consumption by energy source, 2022

total = 100.41 quadrillion British thermal units (Btu)

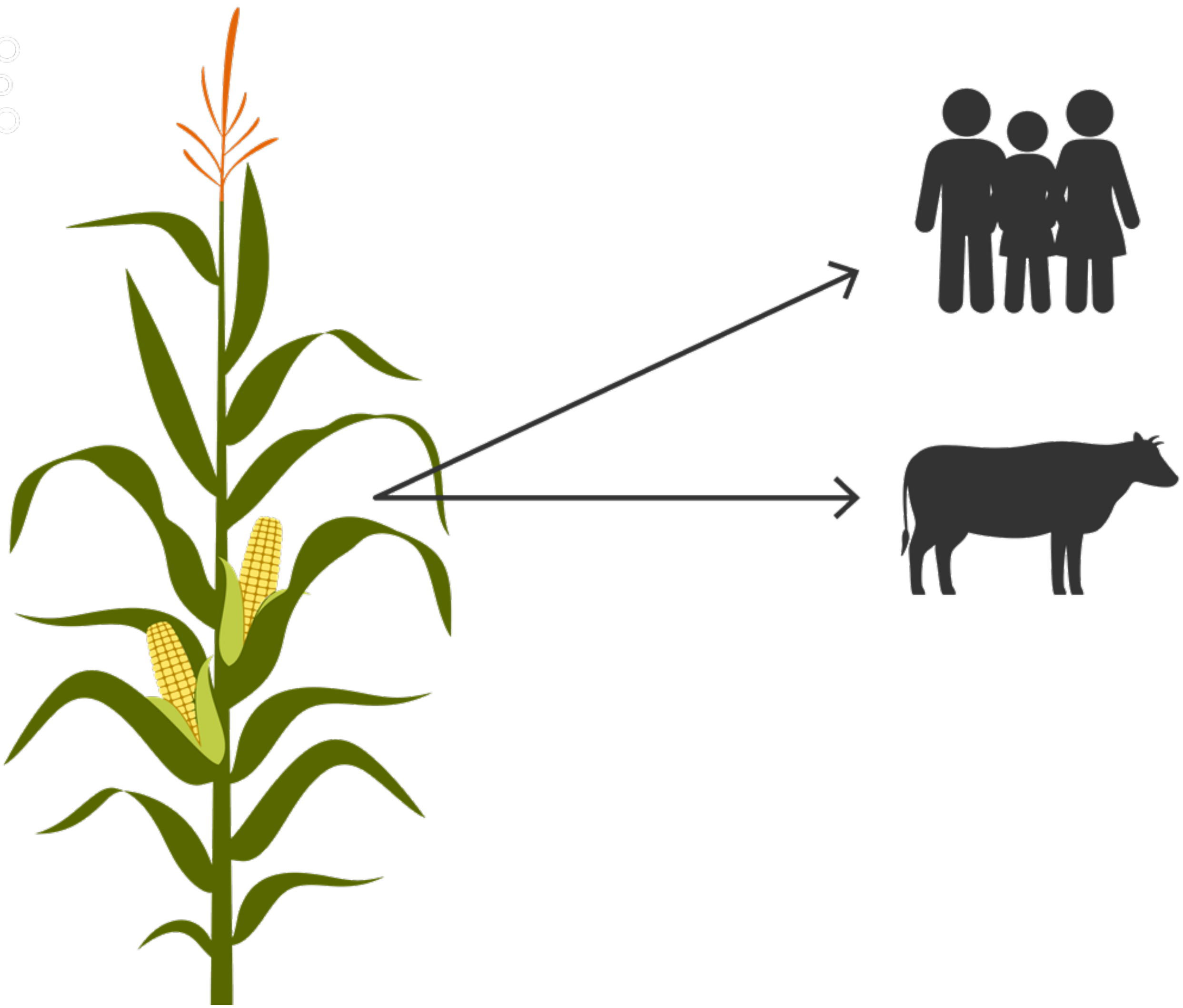
total = 13.18 quadrillion Btu

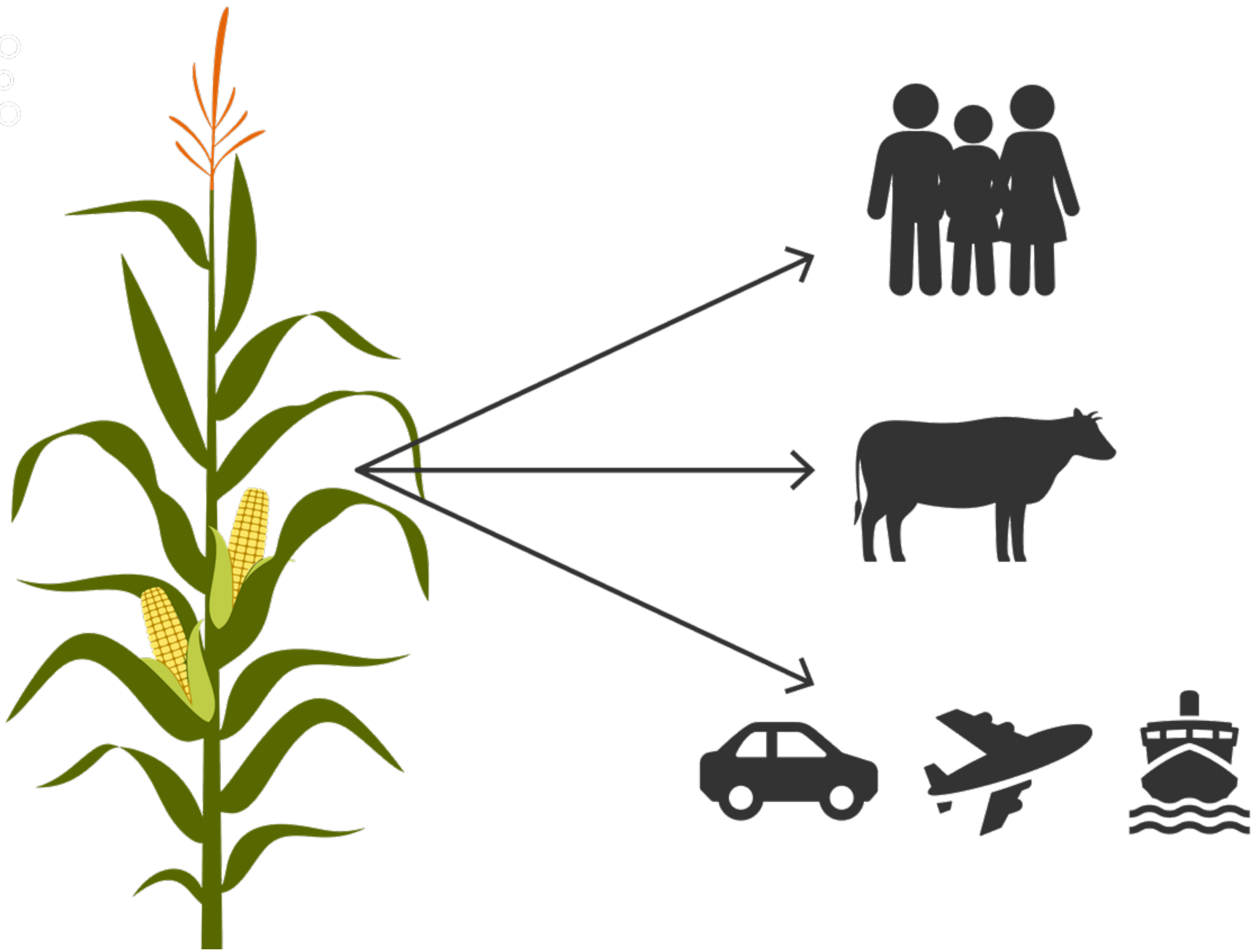


Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2023, preliminary data

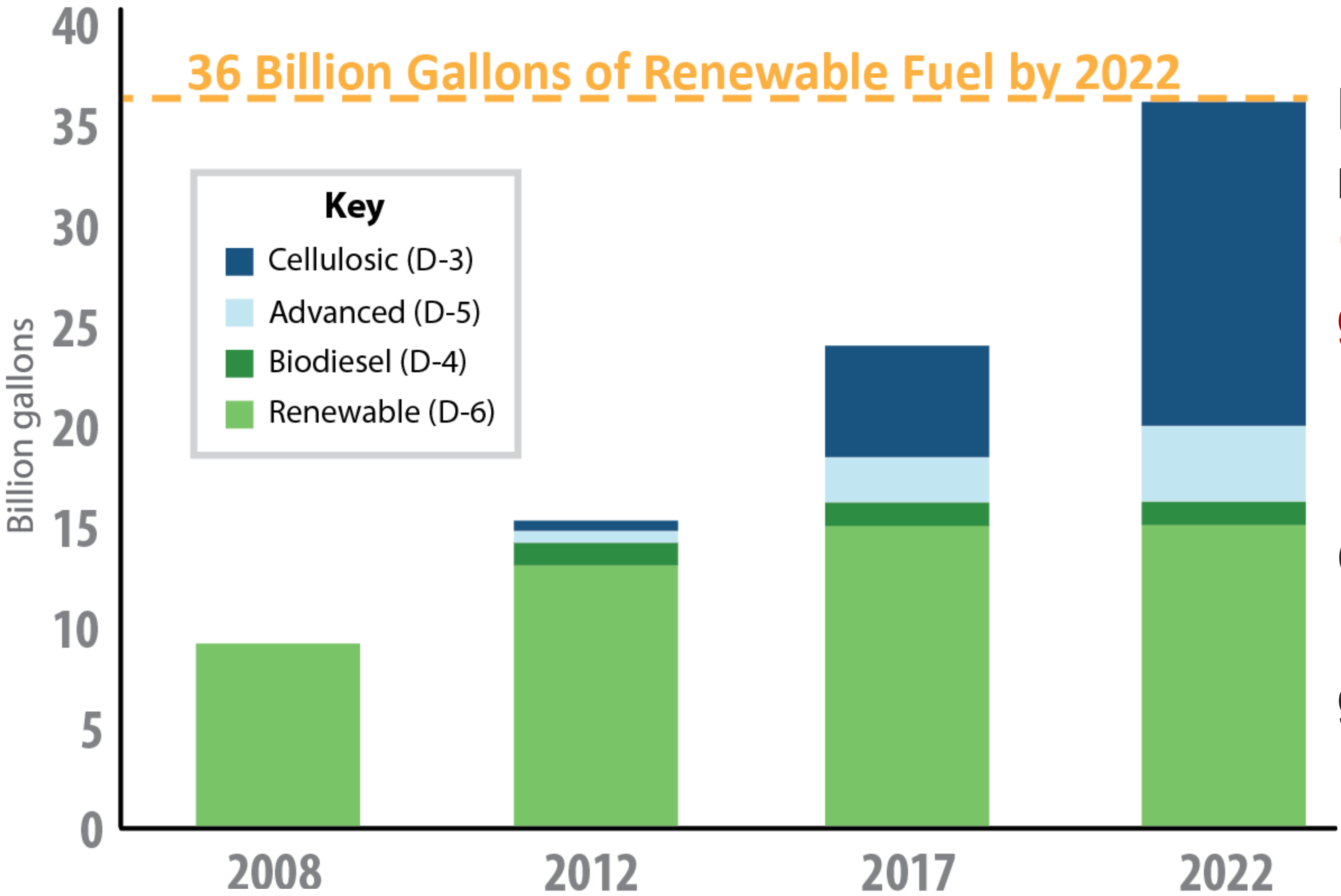
Note: Sum of components may not equal 100% because of independent rounding.


Unleaded 91
Unleaded E10
formulated with 10% ethanol
MAY CONTAIN UP
TO 10% ETHANOL
WARNING





Congressional Volume Target for Renewable Fuel



Must be more than 16 billion gallons

Capped at 15 billion gallons

United States Environmental Protection Agency

Sustainable Aviation Fuel Grand Challenge

2030 3 BGY

2040 17 BGY

2050 35 BGY

Biomaterial

Herbaceous biomass

Crop residues

Energy crops

Oilseeds

Woody biomass

Woody residues

Woody Energy Crops

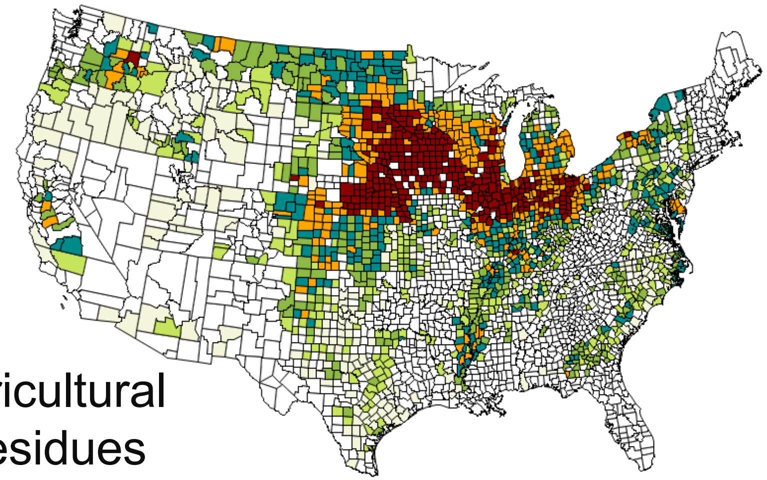
Biofuels
Bioproducts
Biopower

National challenges
- Mitigate carbon emissions
- Improve land use
- Strategize for food/energy for a growing population

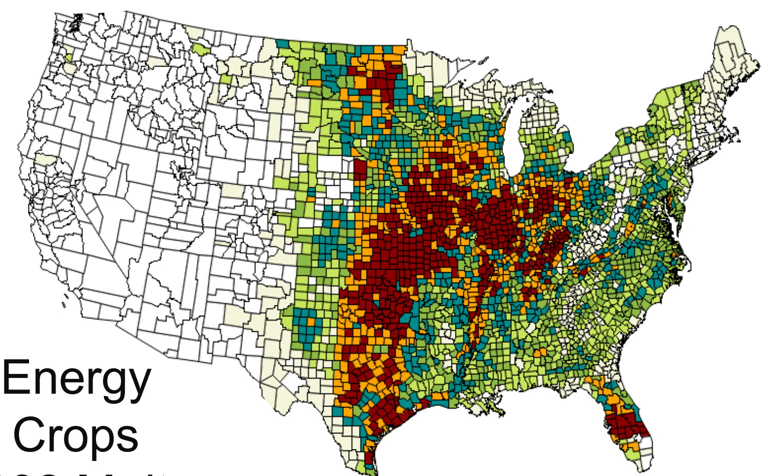
Biomass Potential

Oak Ridge National Laboratory

Billion-Ton Study, 2016



Agricultural Residues 393 M dt



Energy Crops 382 M dt

30 billion gallons by 2040

Production (dry ton/sq. mile)

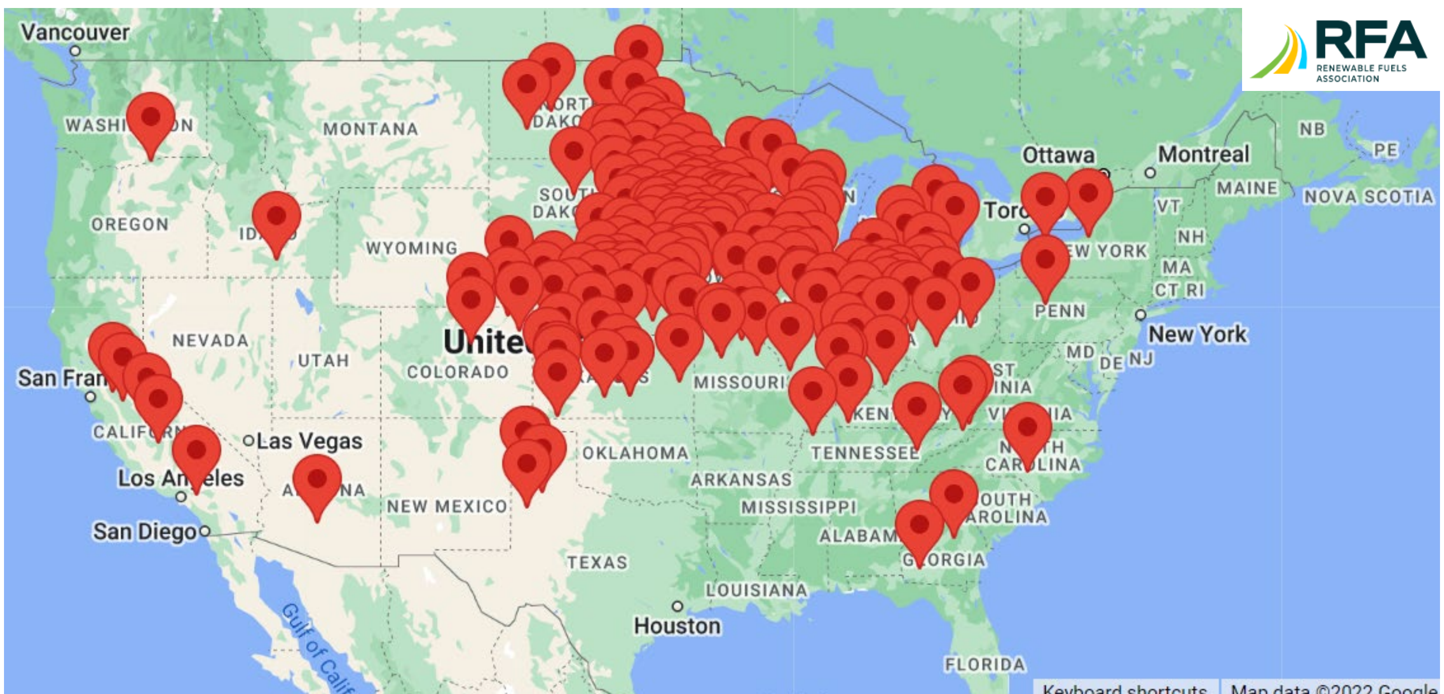
0-50 | 100-150 | 150-250 | 250-350 | 350-500 | 500-1300

Cellulosic Biofuel: Current status

197 Biorefinery Plants

192 plants with conventional ethanol production only

5 plants with **cellulosic ethanol** capabilities alongside conventional ethanol



Cellulosic Biofuel: Current status

POET-DSM Plant, Emmetsburg, IA

- Annual Capacity: 20M gallons
- 2014 – 2019 (Production Paused)

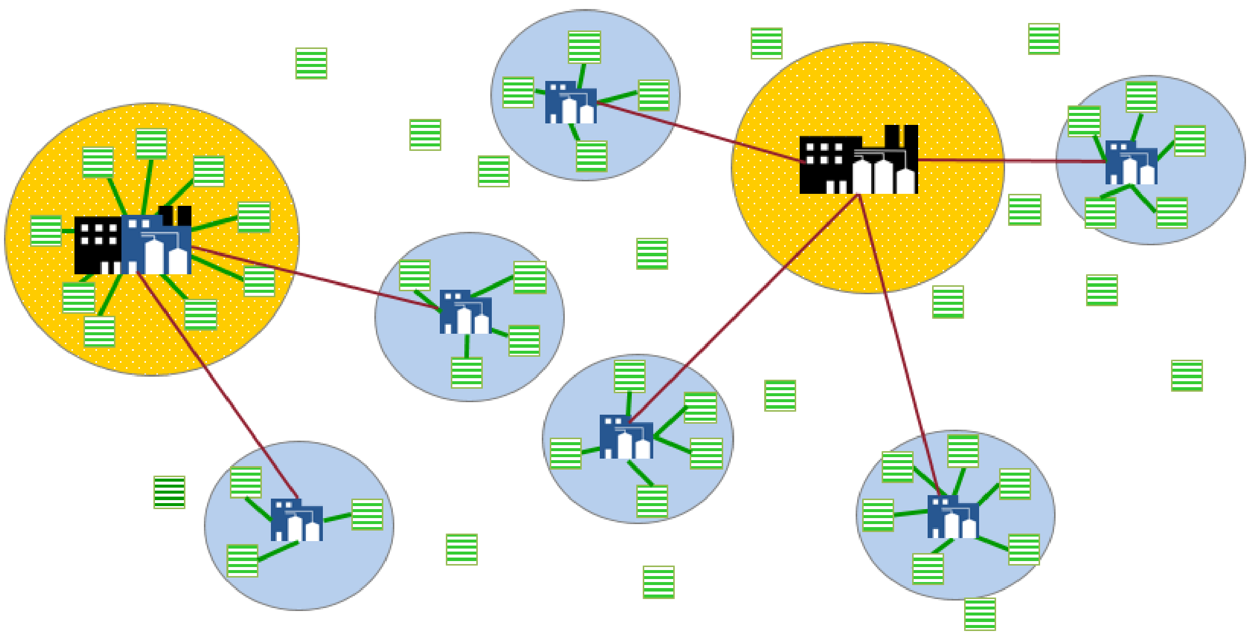
DuPont Plant, Nevada, IA

- Annual Capacity: 30M gallons
- 2015 – 2018 (decommissioned)

Abengoa Plant, Hugoton, KS

- Annual Capacity: 25M gallons
- 2014 – 2015 (decommissioned)

Logistic Challenge



Bales

Fields

Chopped biomass

Oilseed

Logs

Pellets

Depots

Biorefineries

Methodologies

Supply Chain Challenge

1. Optimization
2. Geospatial Analytics
3. Simulation
4. Hands-on pelletizing

Land Conservation Challenge

1. Remote Sensing and AI

Optimization

Objective: Maximize biomass accessible to a facility at a target price and target biomass characteristics

$$\max \sum_{j\in J}\sum_{k\in K}\sum_{f\in F} X_{jkf}$$

Constraints:

No.	Constraint Name	Mathematical Formulation
1	Feedstock purchase	$\sum_{p\in P} Z_{ifp} \le t_{if};\ \forall\, i \in I, f \in F$
2	Maximum supply	$X_{ifp} \le a_{ifp} * Z_{ifp};\ \forall\, i \in I, f \in F, p \in P$
3	Depot Capacity	$\sum_{i\in I}\sum_{f\in F} X_{ijf} \le D * C_j;\ \forall\ j \text{ in } J$
4	Biorefinery Capacity	$\sum_{j\in J}\sum_{f\in F} X_{jkf} \le B * C_k;\ \forall\ j \text{ in } J$
5	Flow balance for field-depot	$\sum_{p\in P} X_{ifp} = \sum_{j\in J_i} X_{ijf};\ \forall\, i \in I, f \in F$
6	Depot Utilization	$\sum_{i\in I}\sum_{f\in F} X_{ijf} \ge U * E * C_j;\ j \in J$
7	Flow balance for depot-biorefinery	$\sum_{i\in I} X_{ijf} = \sum_{k\in K_j} X_{jkf};\ \forall\, j \in J, f \in F$
8	Maximum Biorefinery Capacity	$C_k \le 4 * L_k;\ k \in K$
9	Maximum Ash Content	$\sum_{j\in J}\sum_{f\in F} X_{jkf} * \alpha_f \le S * \sum_{j\in J}\sum_{f\in F} X_{jkf};\ \forall\, k \in K$
10	Blending Ratio	$\sum_{j\in J}\sum_{f\in SRWC} X_{jkf} \le P * B * C_k;\ \forall\, k \in K$
11	Cost target	$FC_j + VC_{ijkfp} \le G * X_{jkf}$
12	Variable constraints	$X_{ifp} \ge 0;\ \forall\, i \in I,\ f \in F, p \in P$ $X_{ijf} \ge 0;\ \forall\, i \in I,\ j \in J,\ f \in F$ $X_{jkf} \ge 0;\ \forall\, j \in J,\ k \in K,\ f \in F$ $C_j \ge 0;\ \forall\, j \in J$ $C_k \ge 0;\ \forall\, k \in K$
13	Binary constraints	$Z_{ifp} \in \{0,1\};\ \forall\, i \in I,\ f \in F,\ p \in P$ $L_j \in \{0,1\};\ \forall\ j \in J$ $L_k \in \{0,1\};\ \forall\, k \in K$

- Facility capacities
- Facility utilization: 90%
- Cost target: \$2.5 GGE
- Quality target:
  - Ash
  - Carbohydrates
  - Moisture

Herbaceous Biomass

Biochemical Conversion

Target Qualities

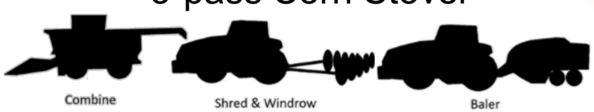
Carbohydrate ≥ 59%
Ash ≤5%
Moisture ~20%

Transportation

Feedstock

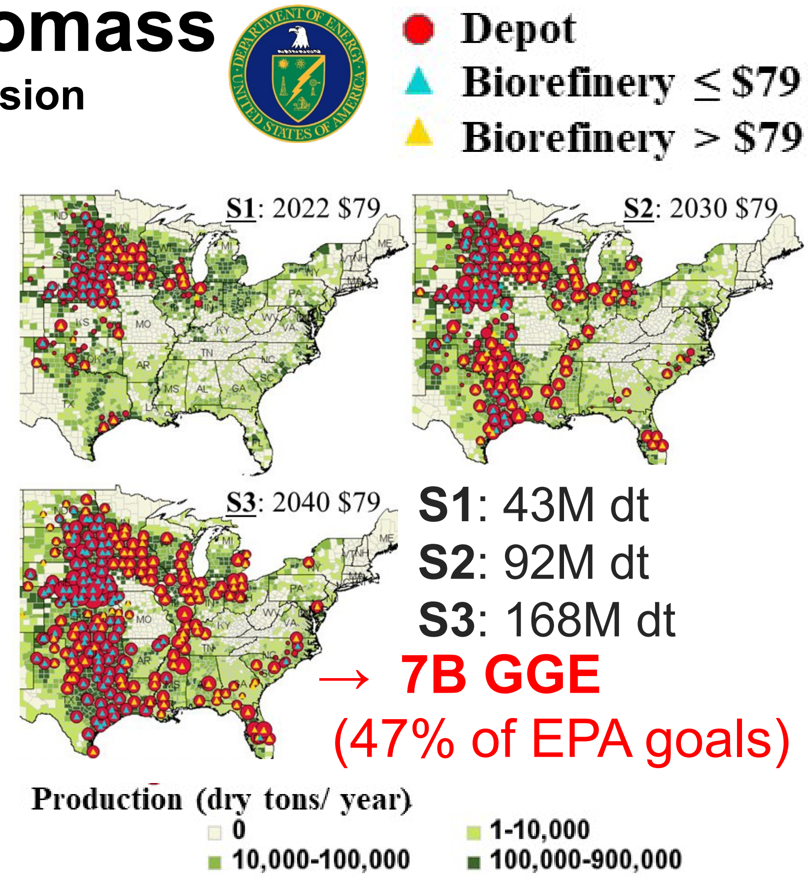
2-pass Corn Stover

3-pass Corn Stover



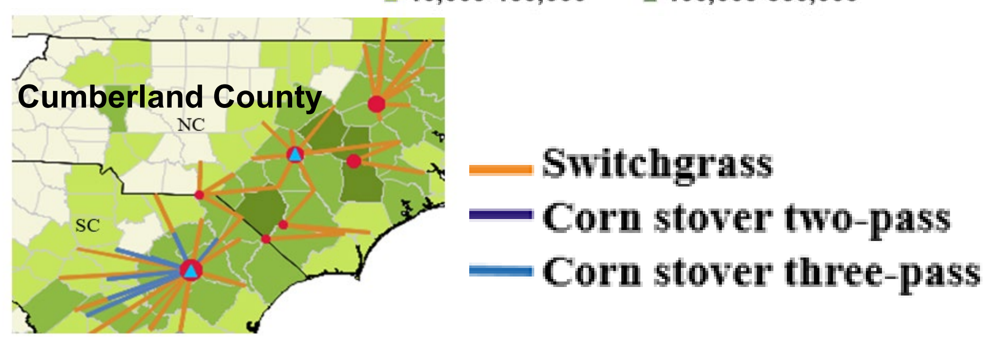
Switchgrass

Miscanthus



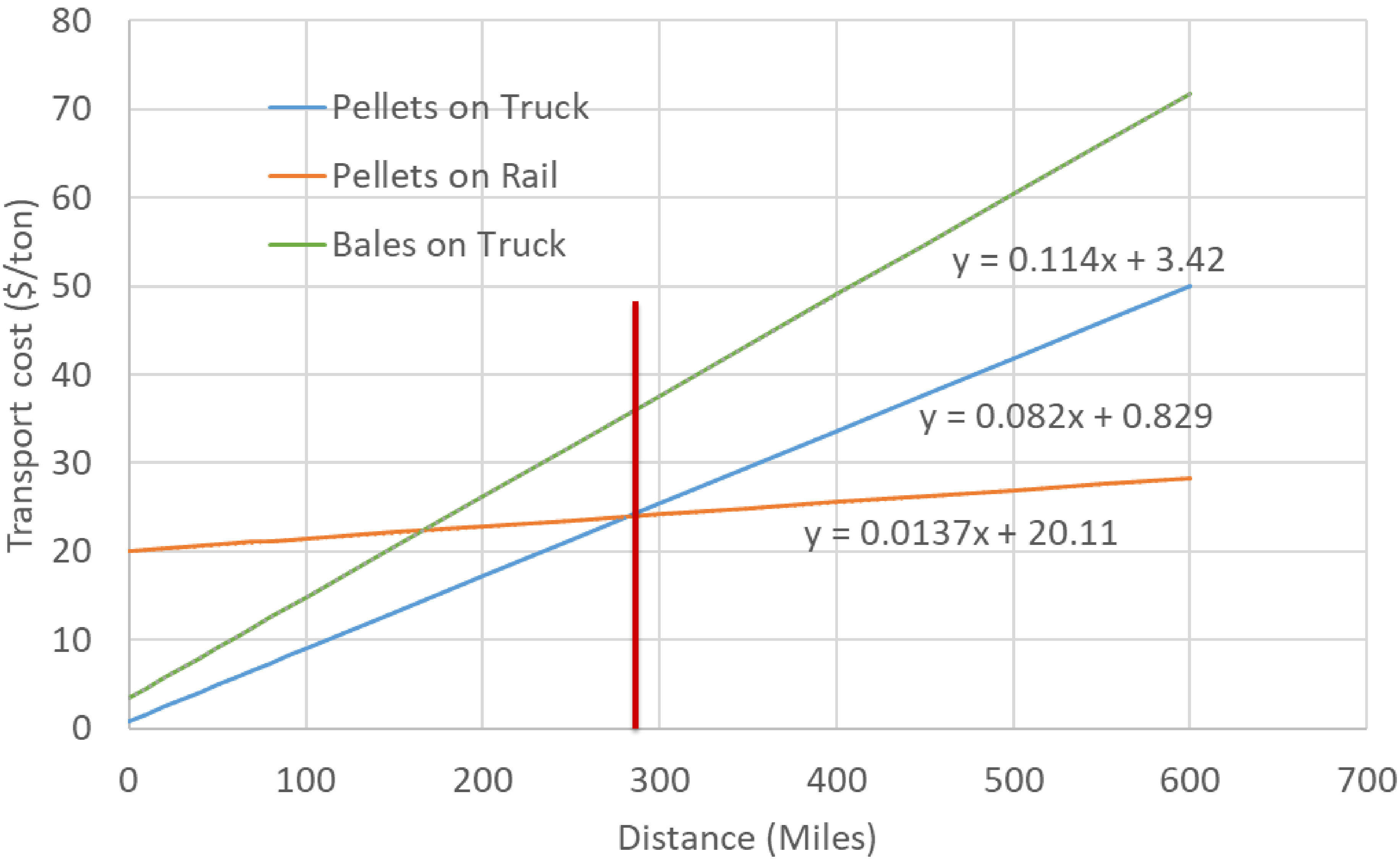
S1: 43M dt
S2: 92M dt
S3: 168M dt
→ **7B GGE**
(47% of EPA goals)

~1M decision variables
20,000 constraints



T. Hossain, **D. S. Jones**, et al. (2021). The nth-plant scenario for blended feedstock conversion and preprocessing nationwide: Biorefineries and depots. *Applied Energy*, 294, 116946.

Transportation Cost



Gonzales, D., Searcy, E. M., & Ekşioğlu, S. D. (2013). Cost analysis for high-volume and long-haul transportation of densified biomass feedstock. *Transportation Research Part A: Policy and Practice*, *49*, 48-61.

Herbaceous Biomass

Biochemical Conversion

Depot
Biorefinery ≤ \$79
Biorefinery > \$79

Target Qualities

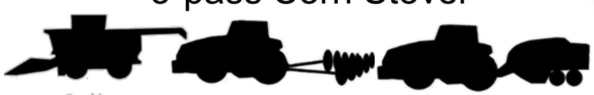
Carbohydrate ≥ 59%
Ash ≤5%
Moisture ~20%

Transportation

Feedstock

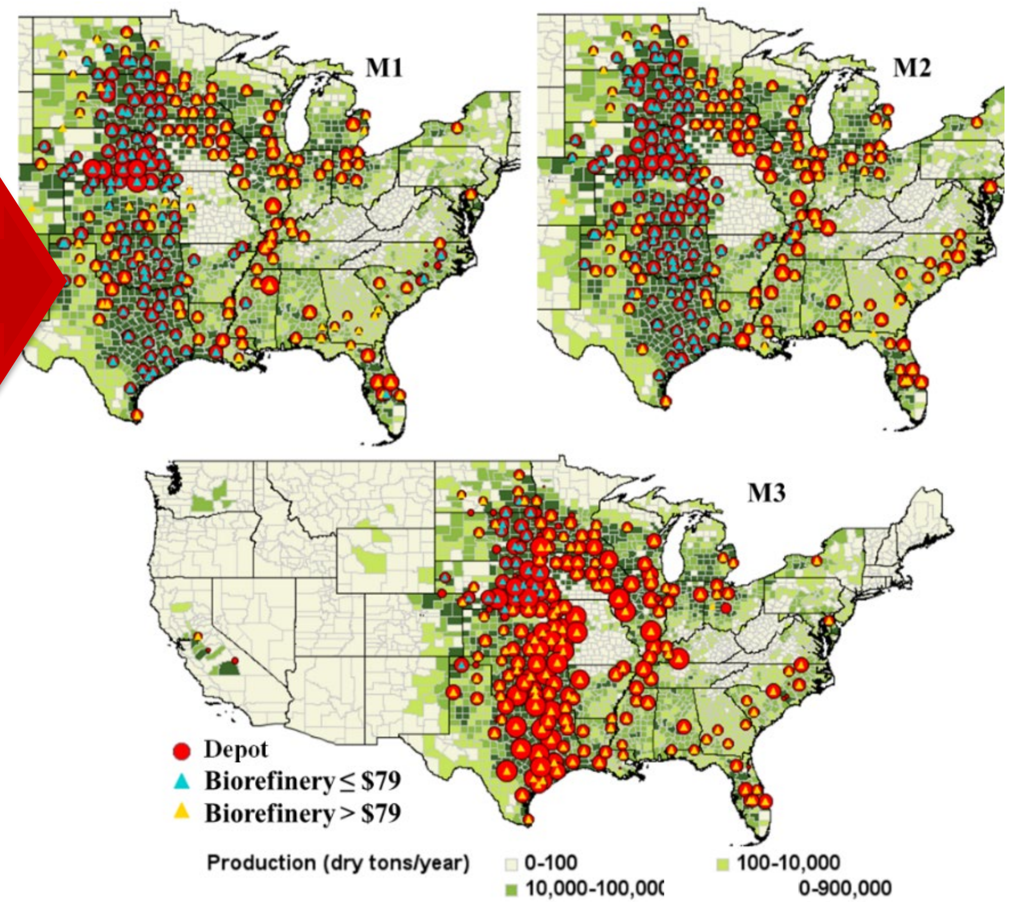
2-pass Corn Stover

3-pass Corn Stover



Switchgrass

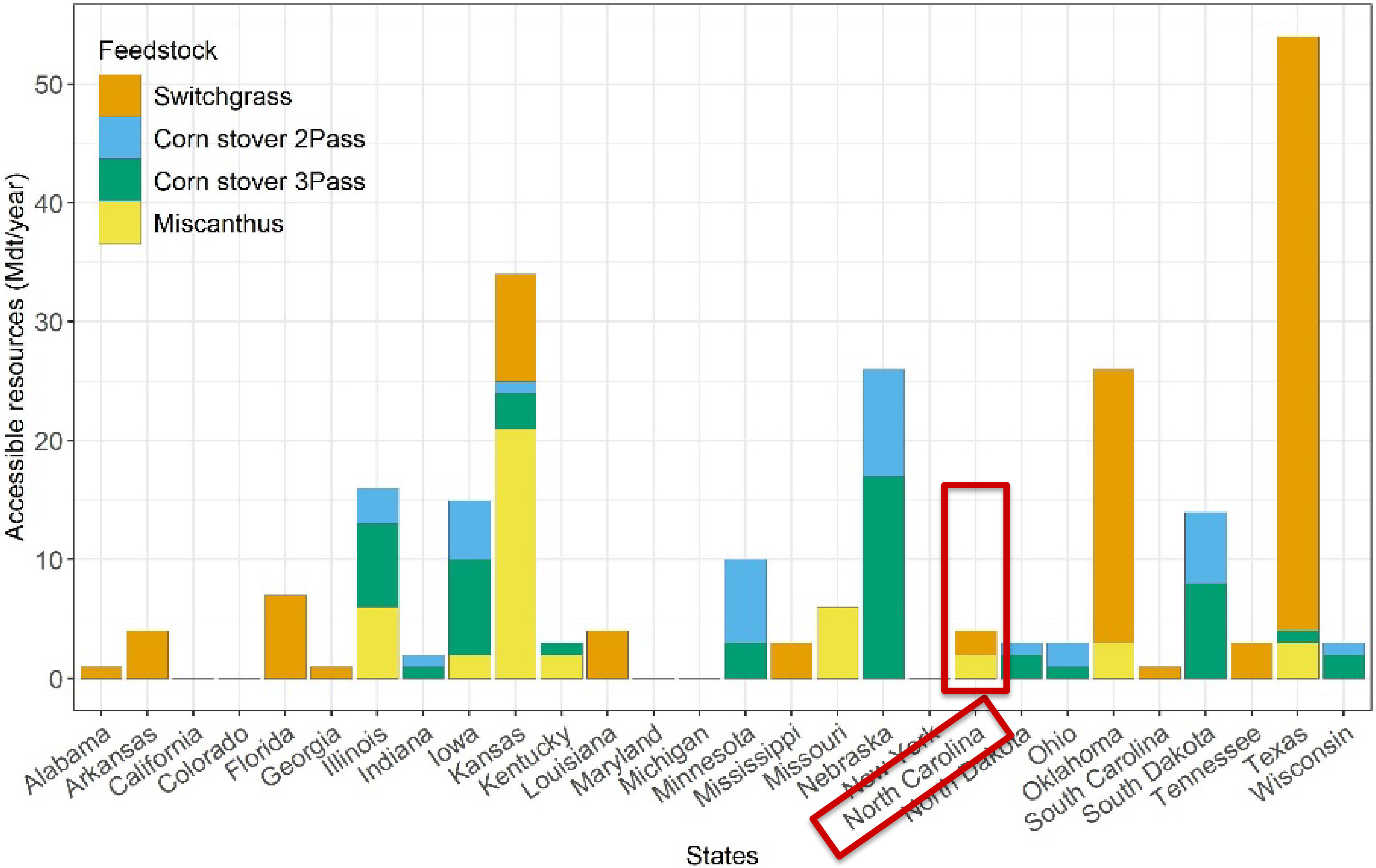
Miscanthus



M1: 168M dt
M2: 173M dt
M3: 280M dt
→ **13B GGE**
(78% of EPA goals)

T. Hossain, **D. S. Jones**, et al. (2023). Nth-plant scenario for blended pellets of Miscanthus, Switchgrass, and Corn Stover using Multi-Modal Transportation: Biorefineries and depots in the contiguous U.S. *Submitted to Applied Energy.*

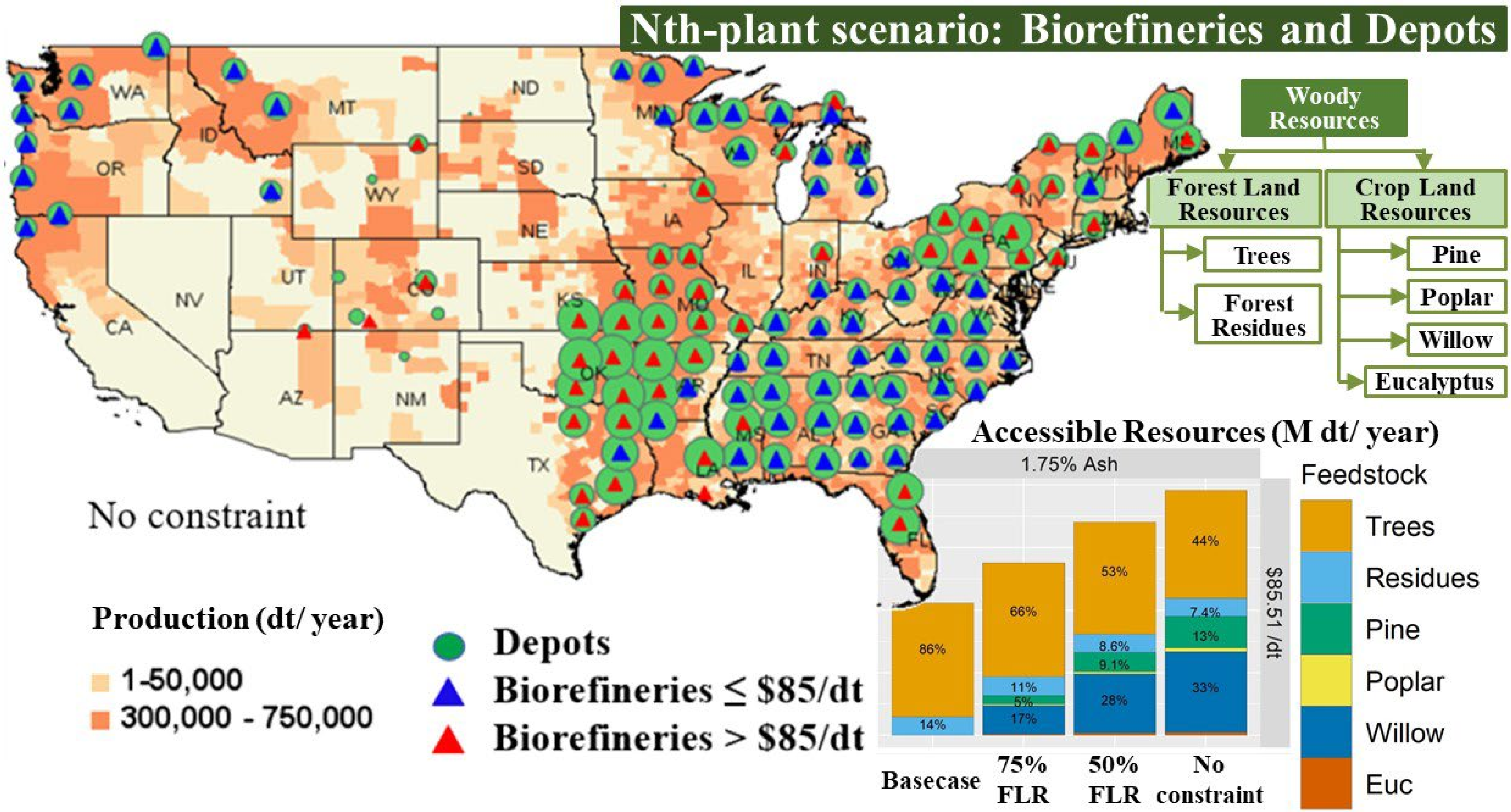
US biomass sources by state in 2040



T. Hossain, **D. S. Jones**, et al. (2023). Nth-plant scenario for blended pellets of Miscanthus, Switchgrass, and Corn Stover using Multi-Modal Transportation: Biorefineries and depots in the contiguous U.S. *Submitted to Applied Energy.*

Woody Biomass

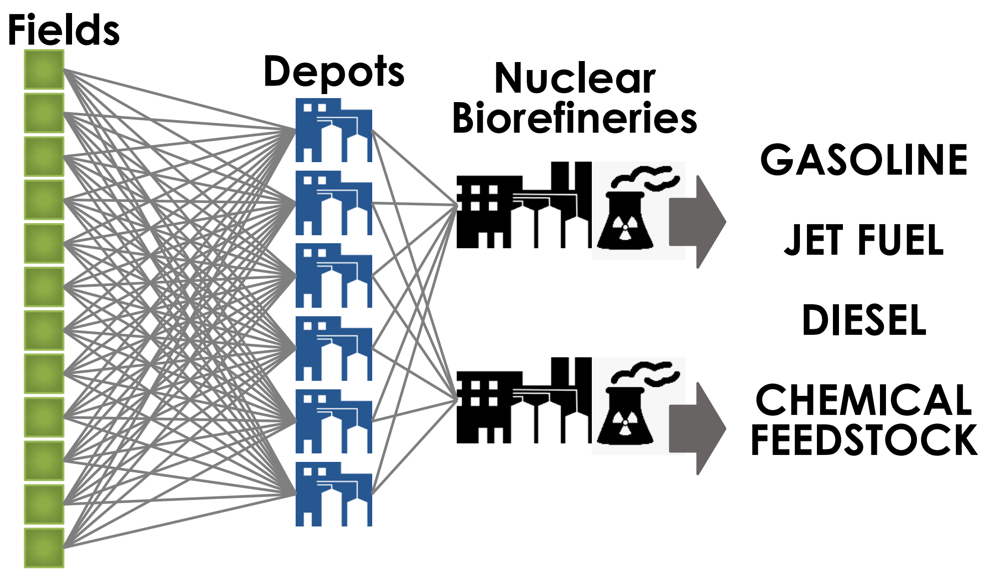
Thermochemical Conversion

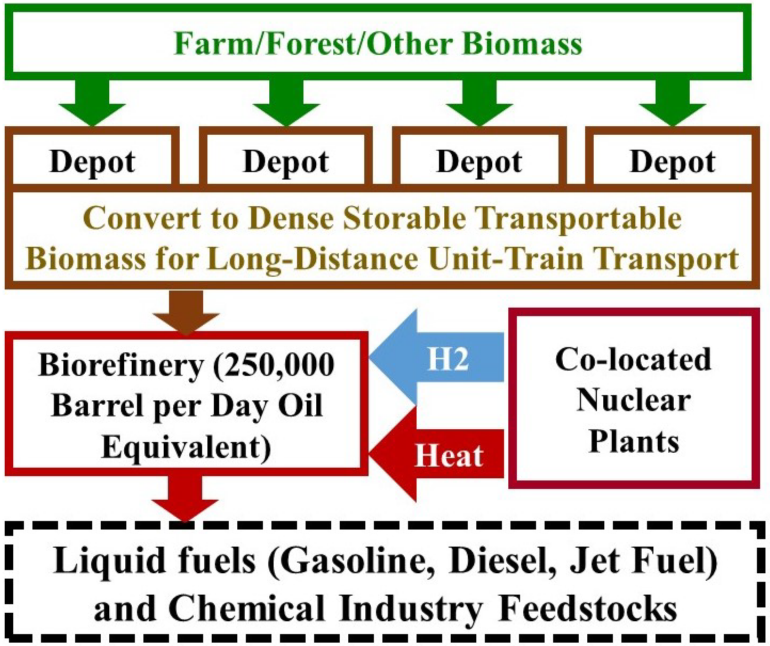


→ **9 B GGE** (55% of EPA goals)

Hossain, T., **Jones, D. S.**, et al. (2022). Nth-plant scenario for forest resources and short rotation woody crops: biorefineries and depots in the contiguous US. Applied Energy. Volume 325, 2022, 119881, ISSN 0306-2619

Nuclear Biofuels





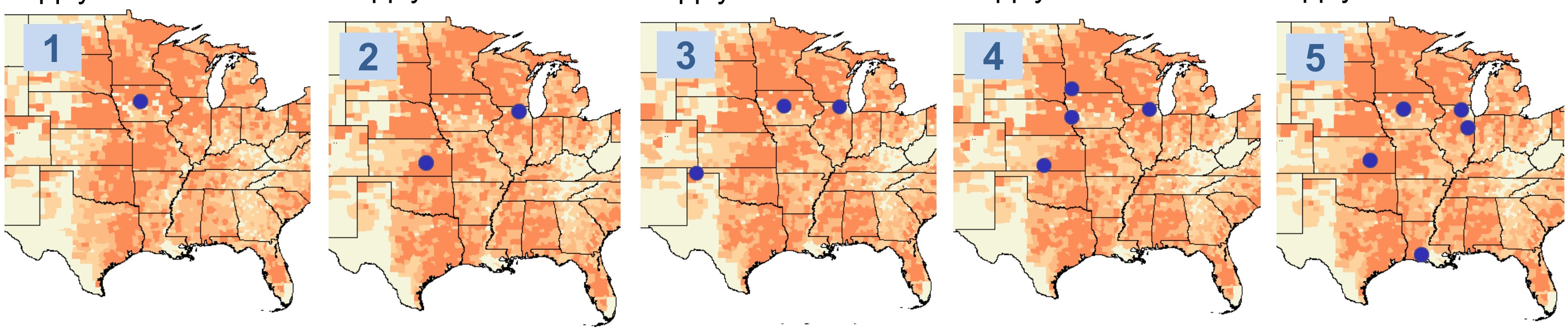
Forsberg, C. W., Dale, B. E., **Jones, D. S.**, et al. (2021). Replacing liquid fossil fuels and hydrocarbon chemical feedstocks with liquid biofuels from large-scale nuclear biorefineries. Applied Energy, 298, 117225.

Nuclear Biofuels

MICHIGAN STATE UNIVERSITY

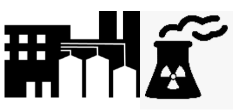
Objective: Minimize the price of delivering biomass to ***n* nuclear biorefineries** with capacities of **250k barrels per day** while meeting feedstock quality specs.

# of Depots: 157	# of Depots: 315	# of Depots: 462	# of Depots: 604	# of Depots: 755
Cost per ton: $89.83	Cost per ton: $93.98	Cost per ton: $98.99	Cost per ton: $95.88	Cost per ton: $99.39
Supply: 82 M tons	Supply: 164 M tons	Supply: 246 M tons	Supply: 328 M tons	Supply: 410 M tons



● Biorefineries   Production (dt /year)   0   1-5,000   5,000-30,000   30,000-150,000

Nuclear Biofuels Biorefinery Size
= 82 M dt /day
= 250k barrels/ day



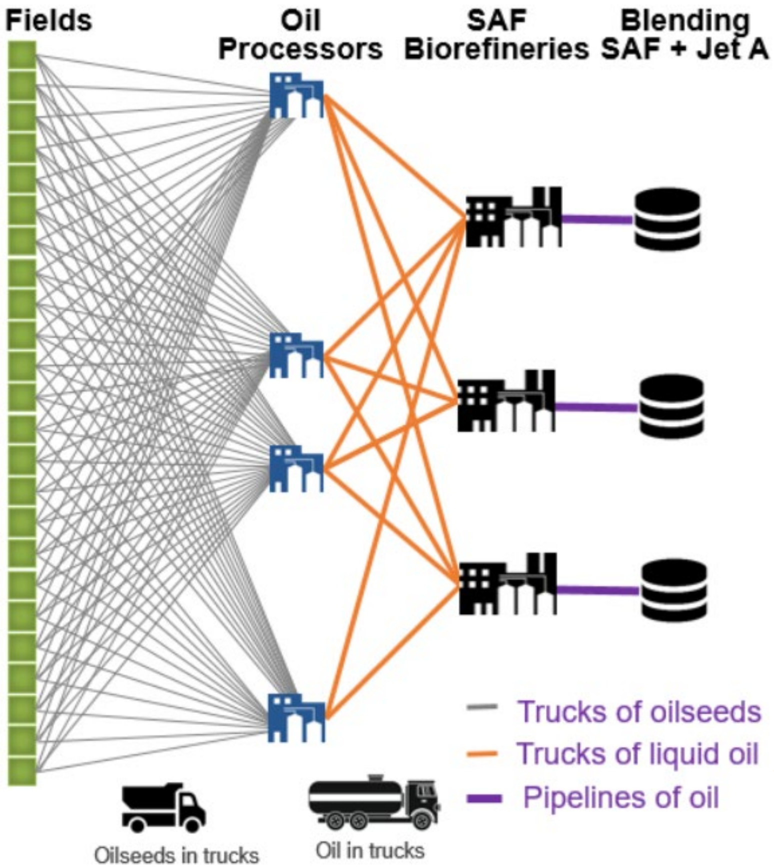
Jones, D. S., Hossain, et al. (2022). Techno-economic feasibility of nuclear biofuels. Manuscript in preparation.

Oilseeds

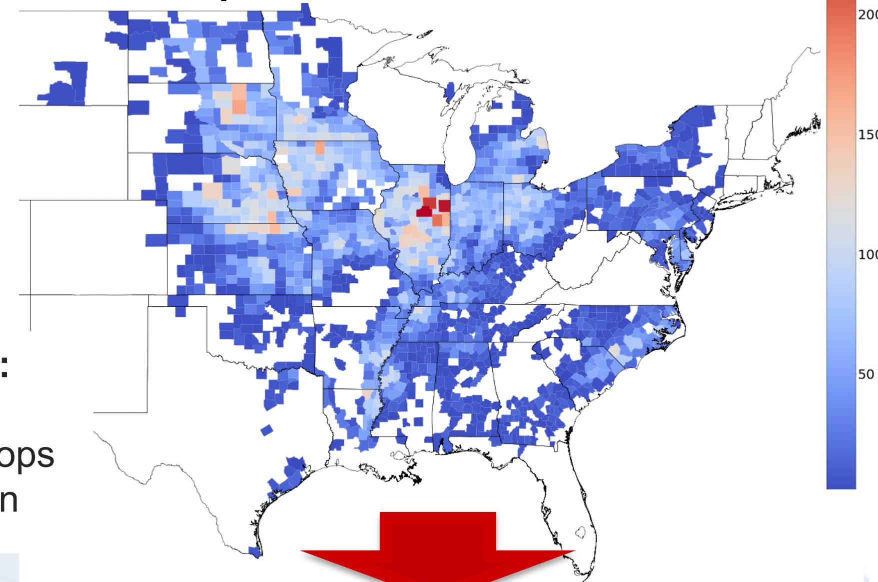
SAF GOALS

2030 3 BGY
2040 17 BGY
2050 35 BGY

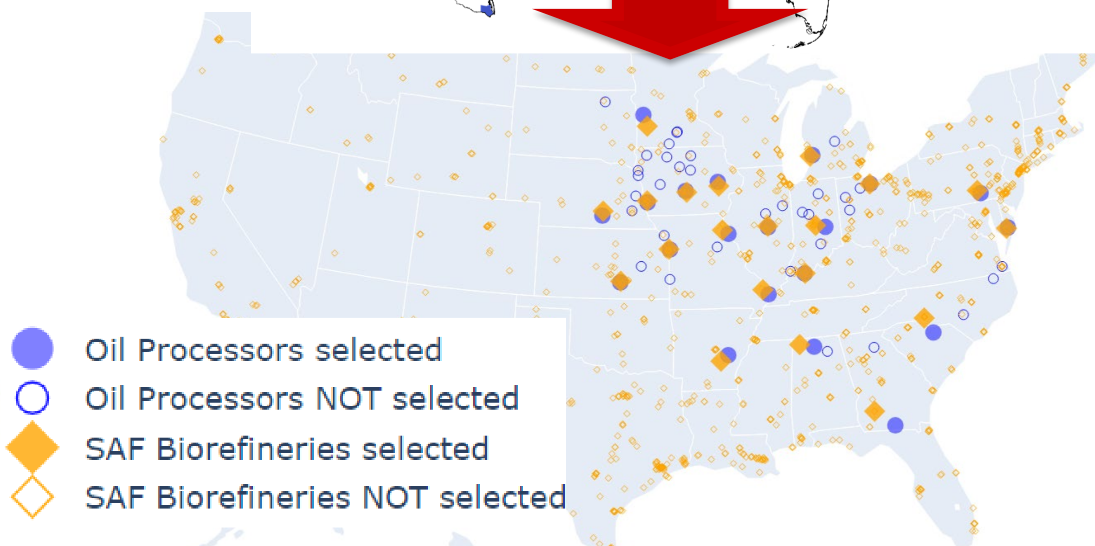
Oil Seeds
- Soybeans
- Cover Crops
  - Carinata
  - Camelina
  - Pennycress



Oilseed production at $0.25/lb for 2048



Rotation:
Corn
-> Cover Crops
->Soybean



Pin, J., **Jones, D. S.**, et al. (2024). Supply chain analysis of pennycress, carinata, and camelina for sustainable aviation fuel. Manuscript in preparation.

Methodologies

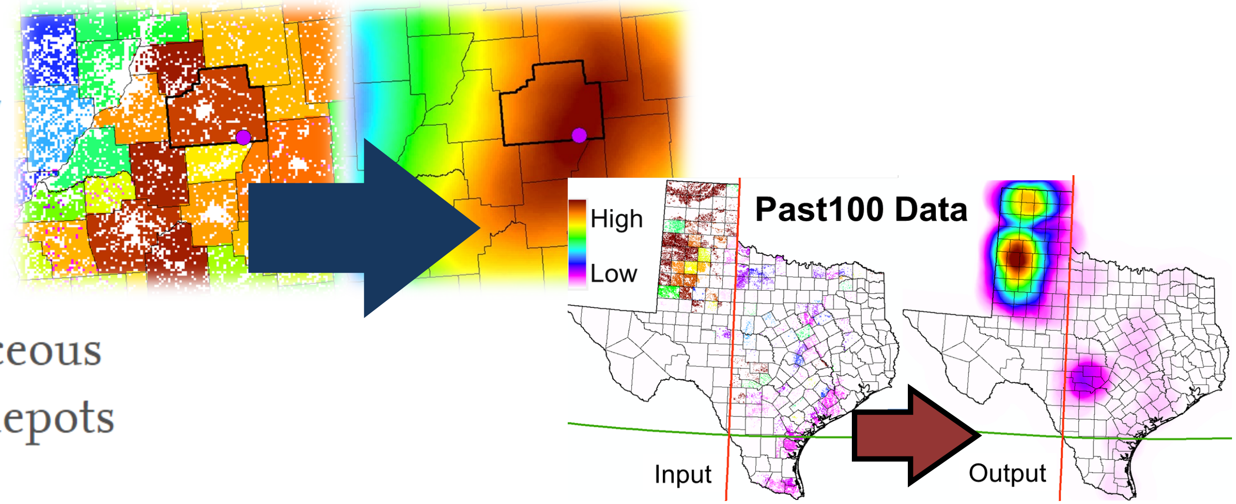
Supply Chain Challenge

1. Optimization
2. Geospatial Analytics
3. Simulation
4. Hands-on pelletizing

Land Conservation Challenge

1. Remote Sensing and AI

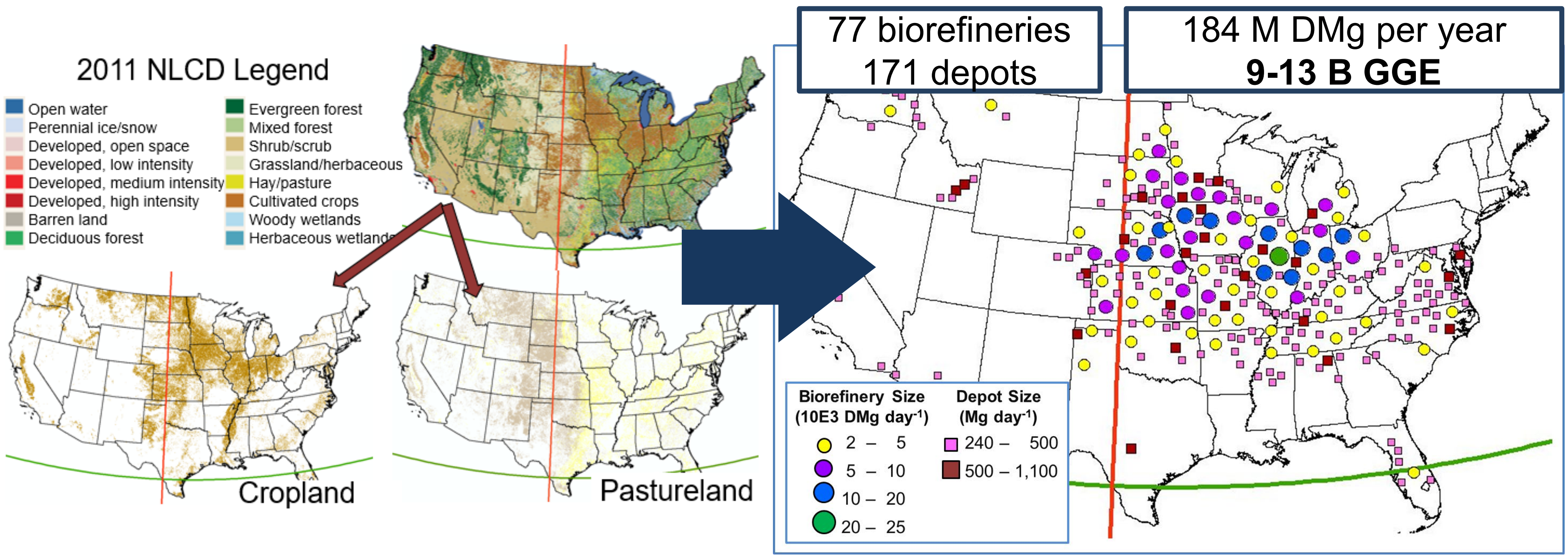
Biomass and Bioenergy
Volume 97, February 2017, Pages 1-10



Research paper

GIS-based allocation of herbaceous biomass in biorefineries and depots

Daniela S. Gonzales, Stephen W. Searcy



Gonzales, D. S., Searcy, S. W. (2017). GIS-based allocation of herbaceous biomass in biorefineries and depots. Biomass and Bioenergy Journal, 97, 1-10.

Methodologies

Supply Chain Challenge

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2. Geospatial Analytics
3. Simulation
4. Hands-on pelletizing

Land Conservation Challenge

1. Remote Sensing and AI

Bioeconomy Simulation

D. S. Jones, S. W. Searcy. (2021). Techno-economic analysis of BioMODS - a hybrid system for biomass storage and transport. Manuscript in preparation.

Methodologies

Supply Chain Challenge

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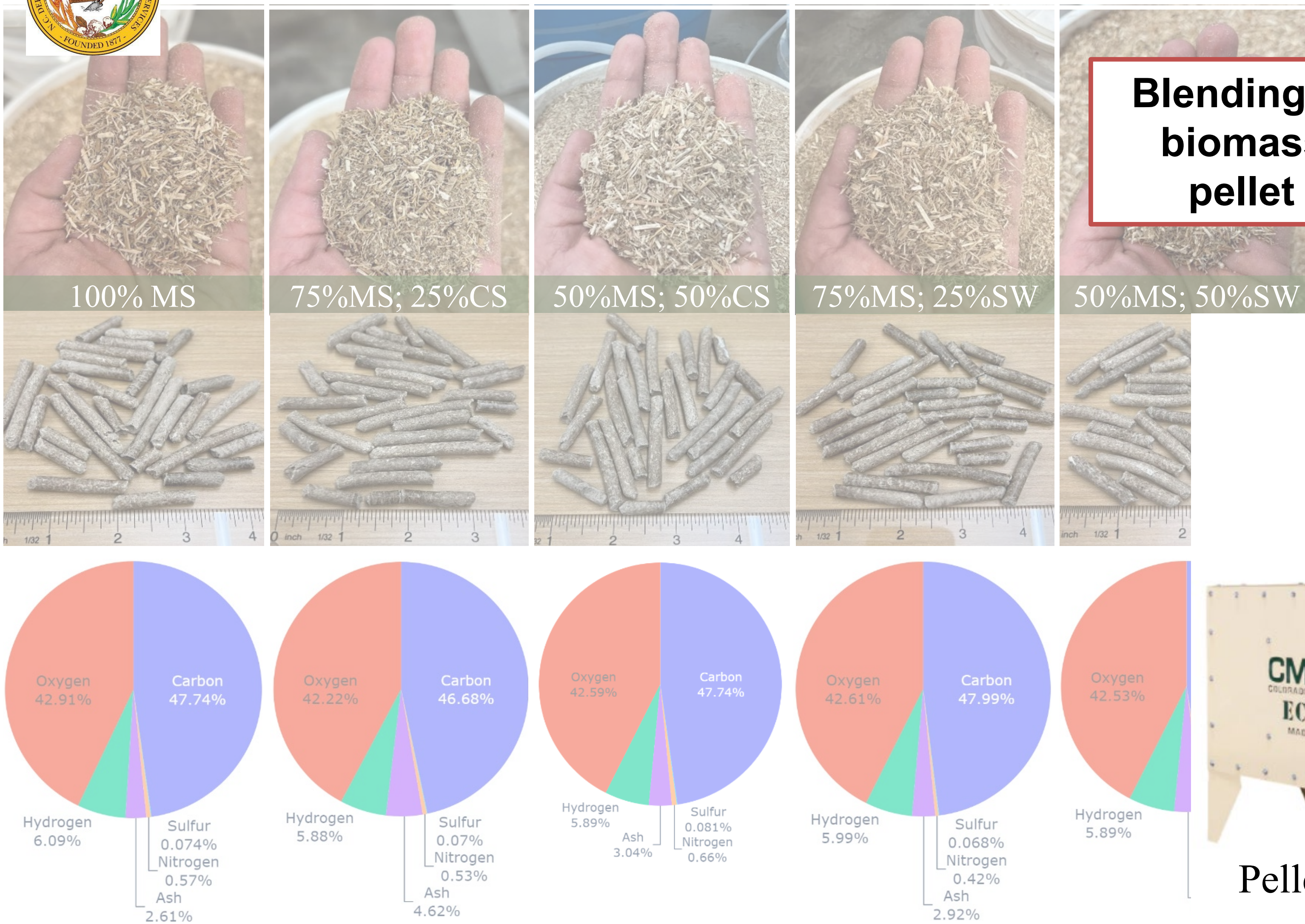
2. Geospatial Analytics
3. Simulation
4. Hands-on pelletizing

Land Conservation Challenge

1. Remote Sensing and AI

Densifying Biomass

Blending herbaceous biomass improves pellet durability



Pellet Mill

Hossain, T., **Jones, D. S.**, Godfrey, E., Chinn, M., D, Saloni, D. (2022). Value-added Miscanthus blended pellets with Corn Stover and Switchgrass. Submitted to *Applied Energy*.

Methodologies

Supply Chain Challenge

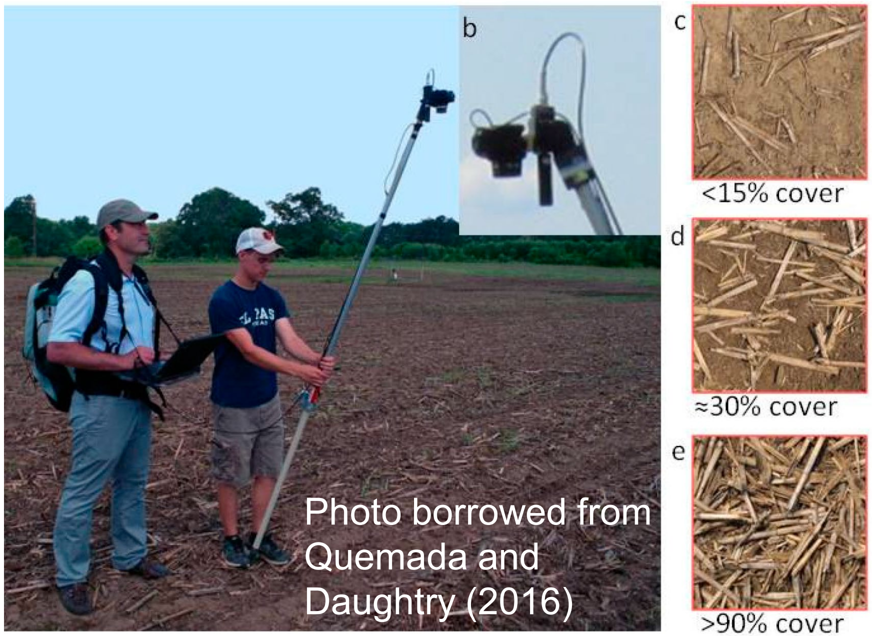
1. Optimization
2. Geospatial Analytics
3. Simulation
4. Hands-on pelletizing

Land Conservation Challenge

1. Remote Sensing and ML

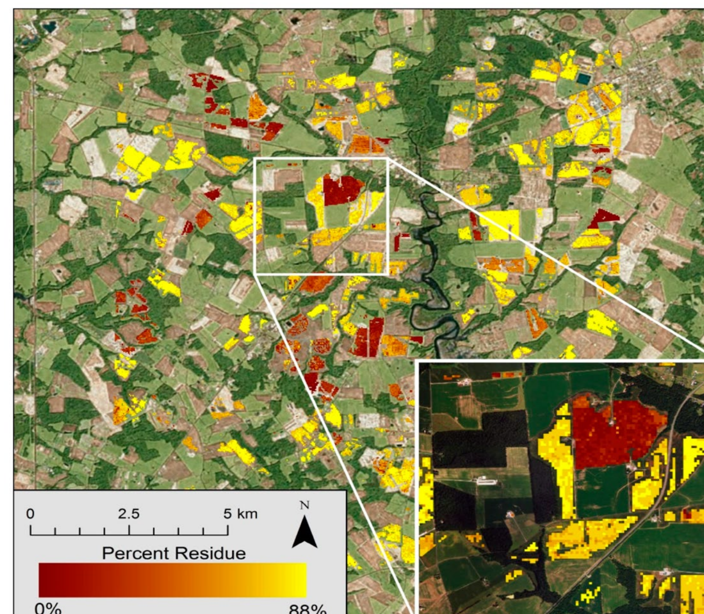
Cover Crop for Carbon Sequestration

Objective: Quantify carbon in soil correlating reflectance in satellite images



Training set: World View 3 3x3 m ($$)
Testing set: Landsat 30x30 m (free)

OUTPUT – Map cover crop percentage residue



Santos, L, **Jones, D. S.**, et al. (2024). Cover crop mapping and biomass estimation using satellite imagery and machine learning. Manuscript in preparation.

Thank you for your attention!

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