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ISTC Sustainability Seminar
Feb. 23rd, 2012

Implications of Biofuel Water Footprint in Water Sustainability

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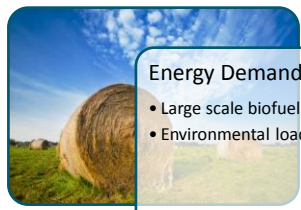
May Wu

Argonne National Laboratory
Energy System Division

Water-Energy Nexus Must Be Addressed at Regional Level



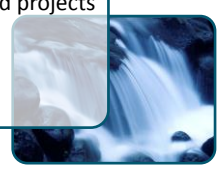
Energy Demand

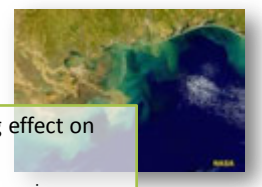
- Large scale biofuel feedstock production
- Environmental loading to waterways

- Objectives
- Model framework
- Results
- Remarks and suggestions

Competing water use from multiple sectors and projects

- Power
- Biofuel
- Agricultural
- Urban development





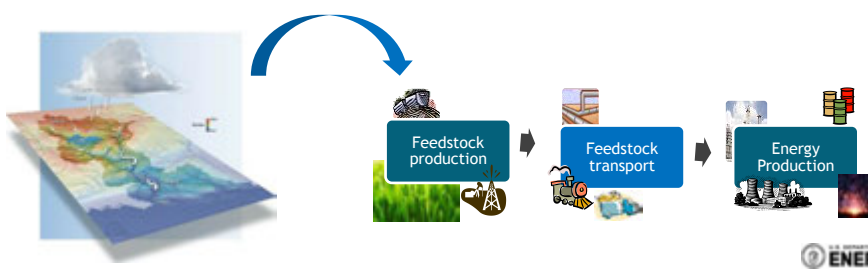
Compounding effect on water body

- Hypoxia zone expansion
- Aquatic ecosystem degradation

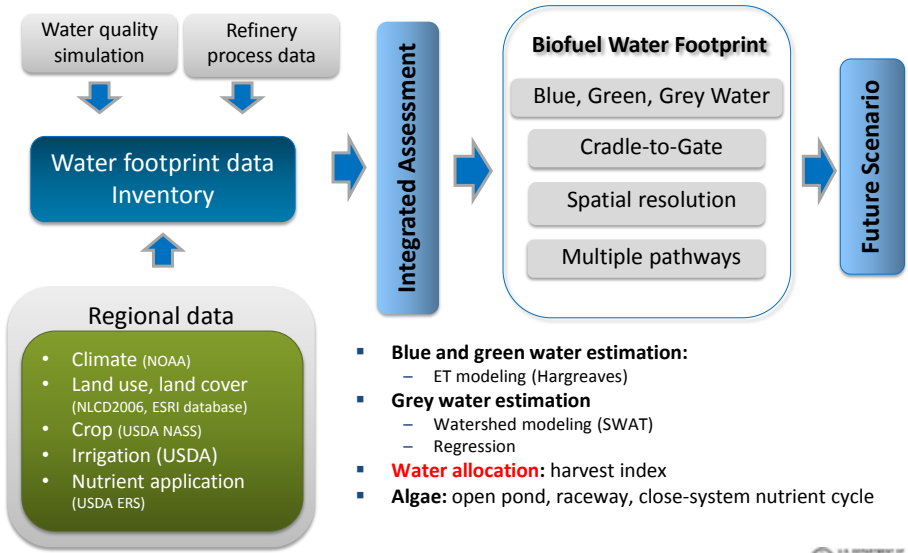
3

Objectives

- Establish a standardized calculation framework to reach consistent analysis and comparison
- Quantify freshwater footprint of cellulosic and advanced biofuel and its regional water demand with county-level resolution
  - ***Blue** water:* *Consumptive irrigation lost through application and ET + refinery process water*
  - ***Green** water:* *Precipitation consumed and returned to atmosphere through ET*
  - ***Grey** water:* *Water required to assimilate pollutant loading (volume-equivalent, not actual consumption)*
- Compare multiple pathways: corn stover, soybean, wheat stalk, and algae



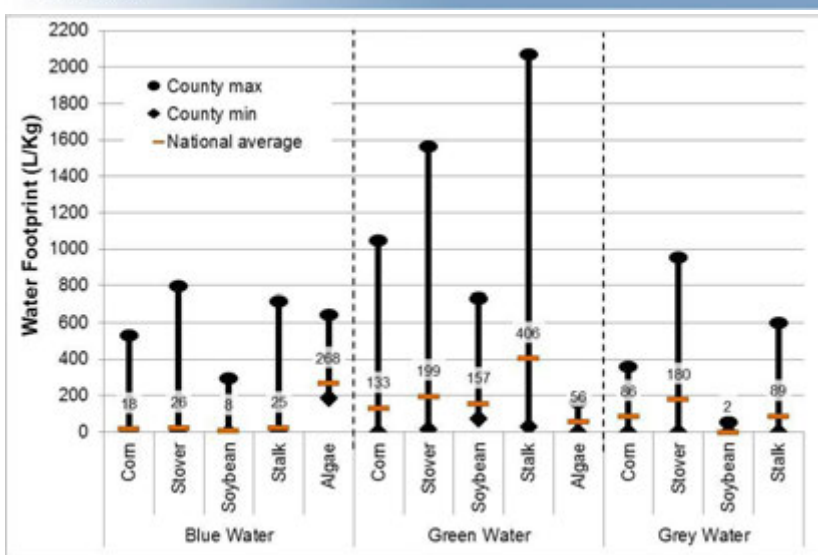
Water Footprint Analysis Framework



- **Blue and green water estimation:**
  - ET modeling (Hargreaves)
- **Grey water estimation**
  - Watershed modeling (SWAT)
  - Regression
- **Water allocation:** harvest index
- **Algae:** open pond, raceway, close-system nutrient cycle

Results: Feedstock water comparison

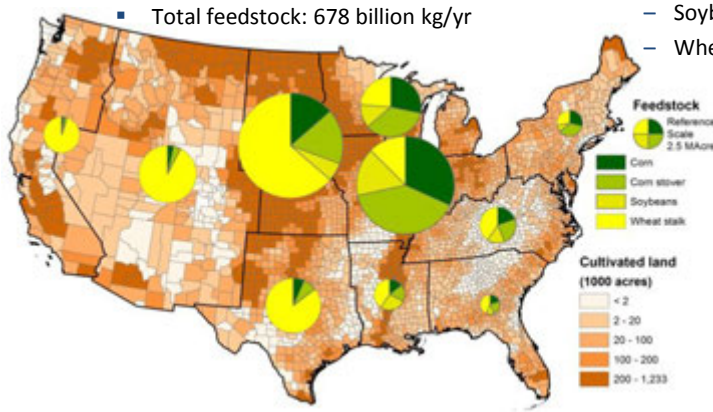
County variances vs. national average



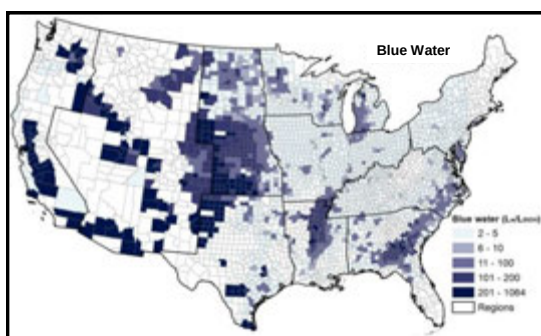
Results: Production Potential

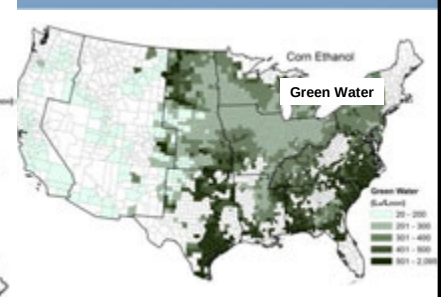
- Feedstock
  - Corn acquisition: 30% production
  - Corn stover: 24% stover removal rate
  - Soybean acquisition: 12% production
  - Wheat stalk: 30% removal rate
- Total feedstock: 678 billion kg/yr

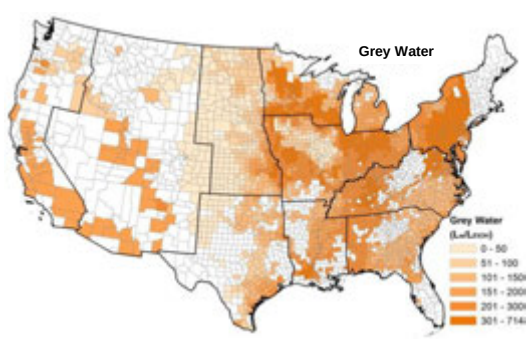
- Annual biofuel production potential: 64 billion liters (17 billion gallons)
  - Corn EtOH: 54%
  - Corn stover EtOH: 29%
  - Soybean biodiesel: 2%
  - Wheat stalk EtOH: 15%



Water Footprint of Corn Bioethanol

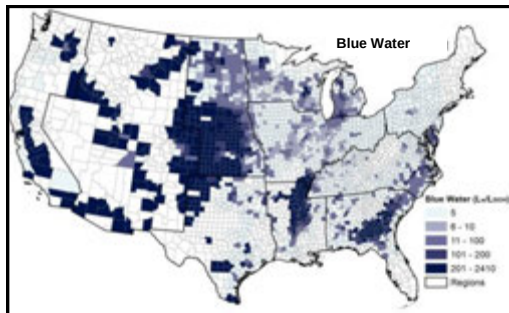


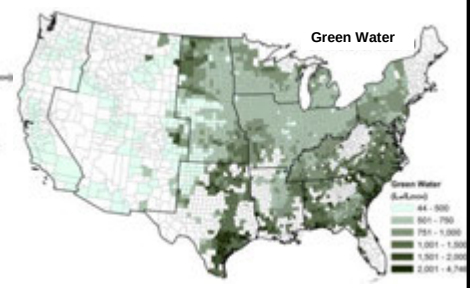


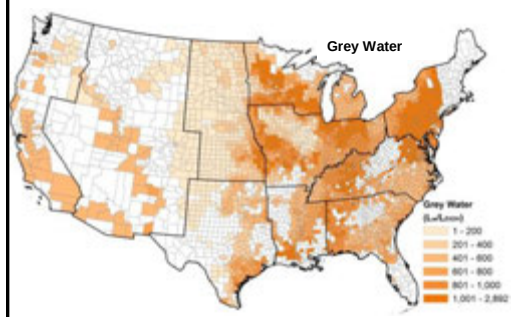


- **Total blue water requirement** 1,306 B liters/yr (345 BGY)
- **Groundwater**
  - Regional: 4 – 211 L_w/L_{EtOH}
  - Avg 32 L_w/L_{EtOH}
- **Surface Water**
  - Regional: 1 – 219 L_w/L_{EtOH}
  - Avg 6 L_w/L_{EtOH}

Water Footprint of Corn Stover Bioethanol







- **Total blue water requirement**
  1,518 B liters/yr (401 BGY)
- **Groundwater**
  - Regional: 5 – 457 L_w/L_{EtOH}
  - Avg 70 L_w/L_{EtOH}
- **Surface Water**
  - Regional: 2 – 507 L_w/L_{EtOH}
  - Avg 12 L_w/L_{EtOH}

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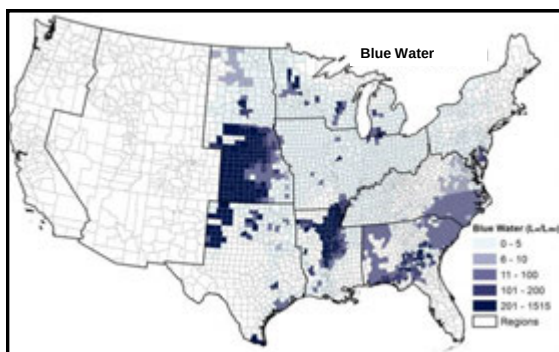
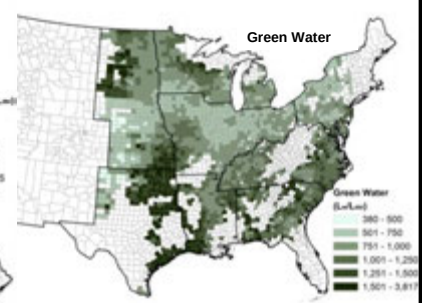
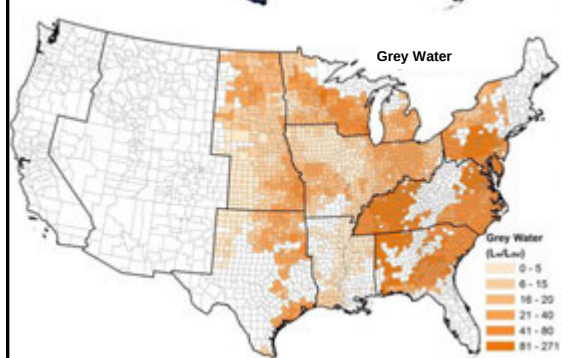
Water Footprint of Soybean Biodiesel







- **Total blue water requirement**
  63 B liters/yr (17 BGY)
- **Groundwater**
  - Regional: 2 – 225 L_w/L_{EtOH}
  - Avg 36 L_w/L_{EtOH}
- **Surface Water**
  - Regional: 0.2 – 37 L_w/L_{EtOH}
  - Avg 5 L_w/L_{EtOH}

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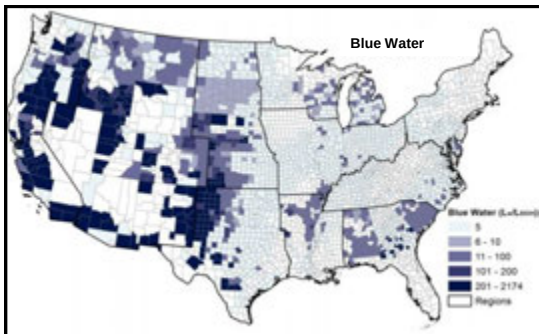
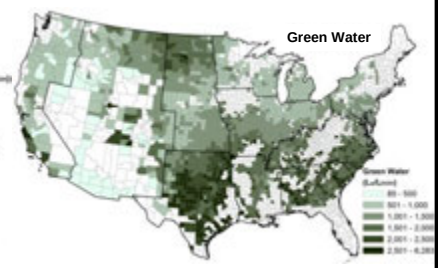
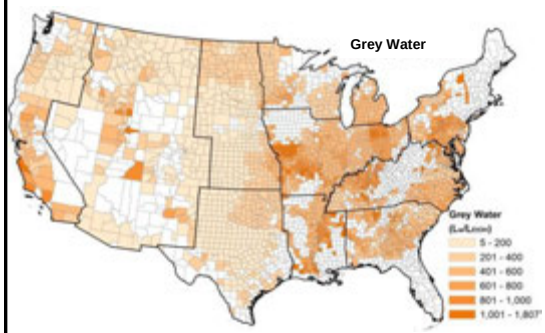
Water Footprint of Wheat Stalk Bioethanol







- **Total blue water requirement**
  757 B liters/yr (200 BGY)
- **Groundwater**
  - Regional: 4 – 127 L_w/L_{EtOH}
  - Avg 47 L_w/L_{EtOH}
- **Surface Water**
  - Regional: 2 – 201 L_w/L_{EtOH}
  - Avg 33 L_w/L_{EtOH}

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Water Appropriation
Blue Water / Available Water

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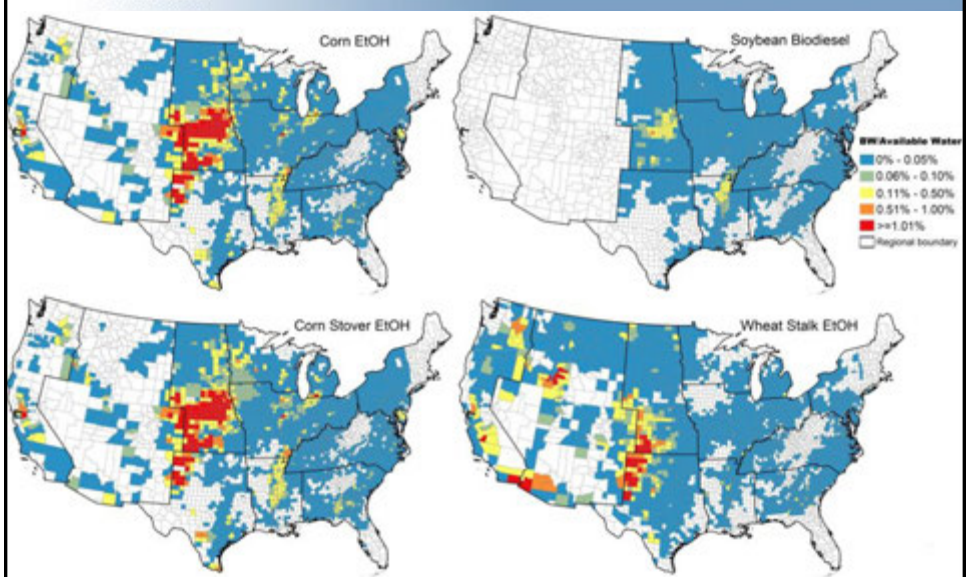

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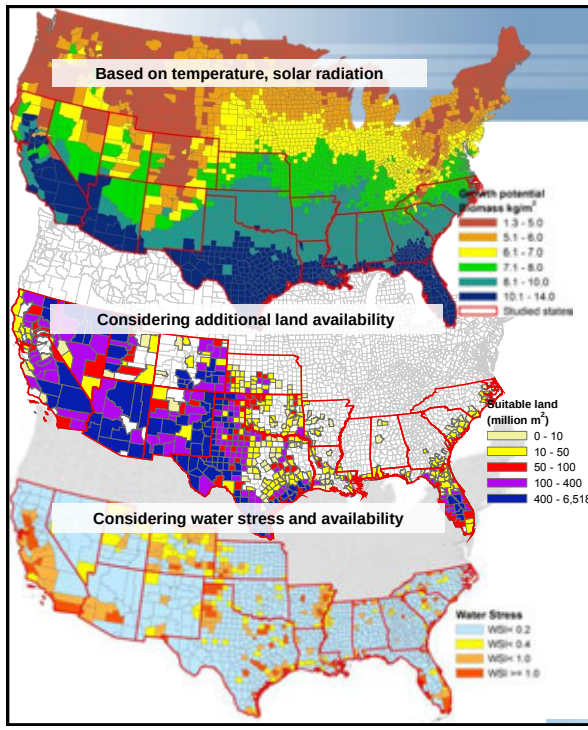
Algae Biodiesel Production Potential



- Raceway open pond
- Site selection criteria
  - Excluding forest, federal land, parks and conservation areas
  - Low-intensity development
  - Shrub, grasslands, pasture /hay
  - Slope <=1%
  - Minimal 1 site = 490HA (400HA of ponds and 90HA of operation facility)
  - Southern 17 states only (higher algae growth potential)
- Water criteria
  - Water stress index (WSI)
    - WSI> 0.4 severe
    - WSI> 0.2 mid-high
  - Municipal wastewater (MWW) availability

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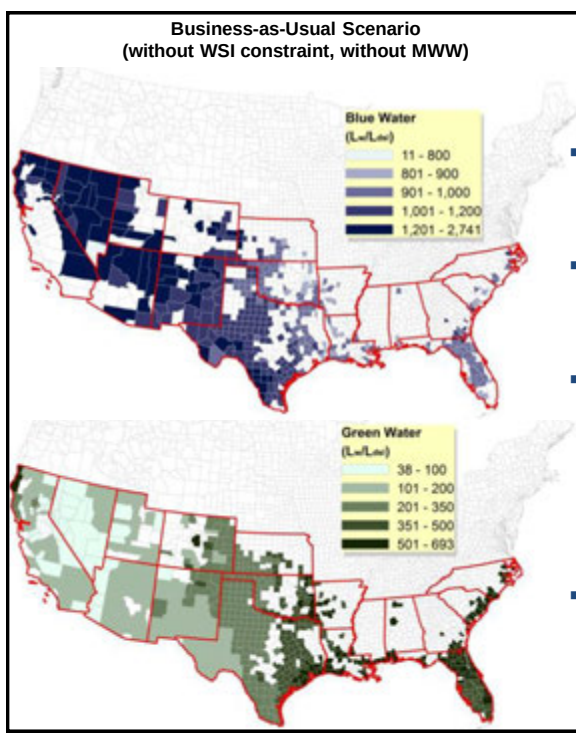
Water Footprint of Algal Biodiesel



- Suitable land
  - 38.6 million acres
  - 4% of the selected 17 states
- "Sustainable land"
  - 9.0 million acres (WSI<0.4)
  - 4.7 million acres (WSI<0.2)
- Technical assumptions
  - Lipid content: 25%
  - Harvest efficiency: 81%
  - Processing efficiency: 81%
  - Operational water loss (blowdown): 0.15 m^3/m^2/month
- County-level biodiesel
  - Lowest: 0.30 $L/m^2/yr$
  - Highest: 2.57 $L/m^2/yr$

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Water Stress Effects

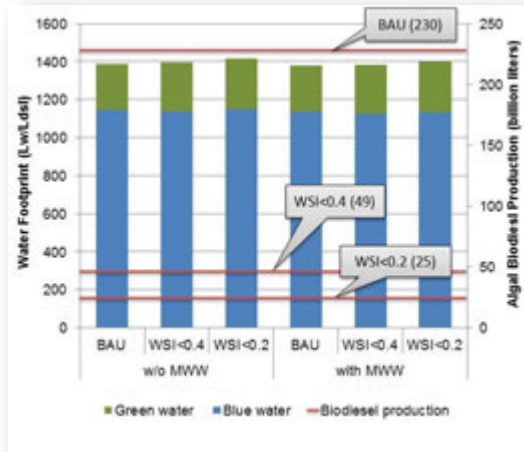
Counties change from BAU to WSI<0.4

- Required refinery reduction: 154
- Eliminated: 132 (550 → 418)

Refinery reduction: 31,526 →7,408

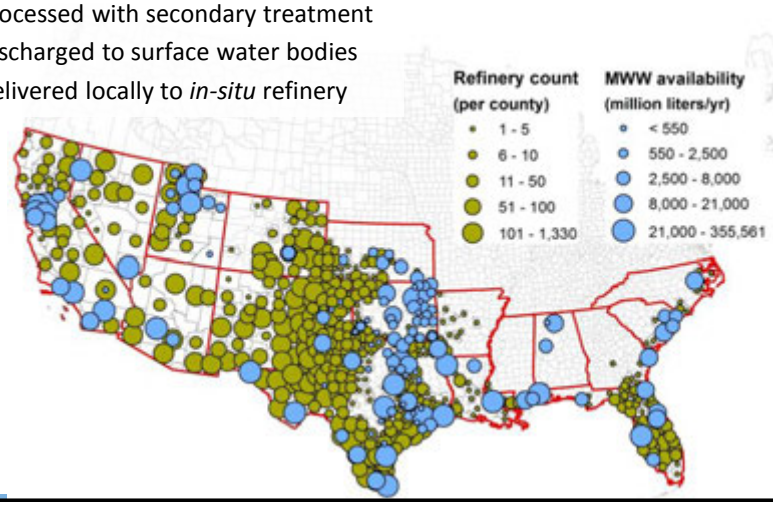
WSI<0.4 with MWW

- Blue water (81% WFP)
  - Evaporation: 413 L/L
  - Operational loss: 724 L/L
  - MWW: 13 L/L
  - Net blue water: 1,124 L/L
- Green water (19% WFP)
  - Rain-fed evap.: 258 L/L
- Biodiesel production
  - Primarily governed by WSI



Wastewater as water source

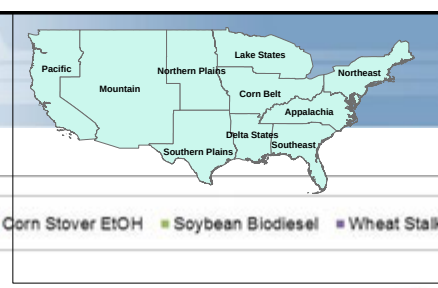
- Effluent selection criteria
  - Treated in public-owned facilities
  - Processed with secondary treatment
  - Discharged to surface water bodies
  - Delivered locally to *in-situ* refinery

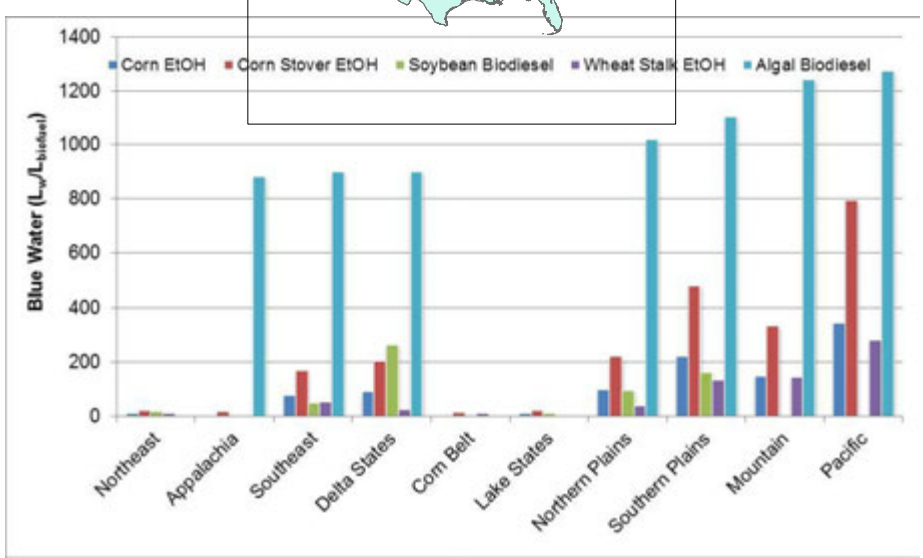


Wastewater as water source

- Temporal constraint
  - 5,770 billion liters suitable MWW are temporally available
  - 79% of suitable MWW in 2008 in the 17 studied states under BAU
- Geographical constraint
  - 42% of the temporally-available MWW can be delivered to refinery
- Minimal effect on reducing blue water
  - 33% of the total suitable MWW is actually usable (2,427 billion liters)
  - 1% of algal refinery blue water displacement under BAU

Site Selection





Remarks and Suggestions

- Take local criteria into account
- Estimate resources requirement under different scenarios
- Determine sustainable pathways to optimize biofuel supply
- Prioritize regional target feedstock based on water demand and supply

Thank You

For Questions, please contact

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Grey Water

$$Grey\ Water(m^3) = \frac{kgNO_3 \text{ applied}}{EPA \text{ standard } kgNO_3 / m^3 - \text{back gorund } kgNO_3 / m^3}$$