# *Assessing Impact of Biofuel Production on Regional Water Resource Use and Availability*

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Department of Energy Webinar
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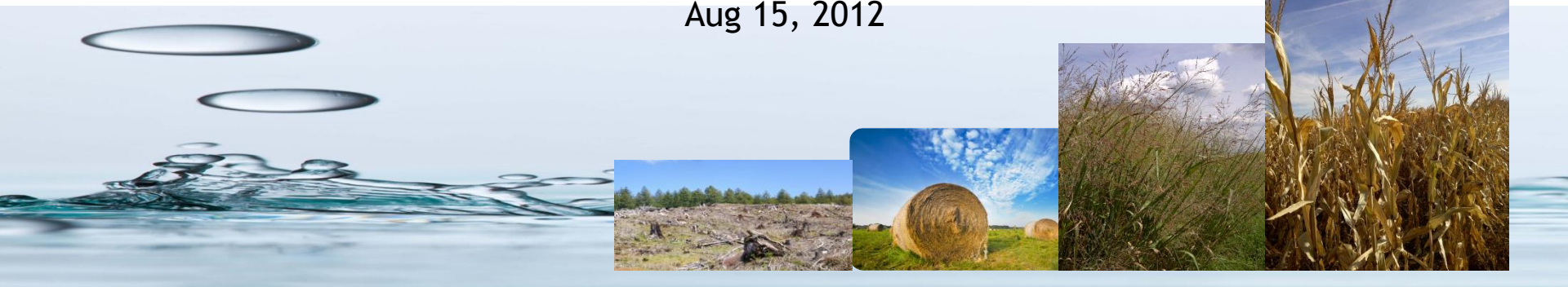


# Biofuel Is a Key Component in Water-Energy Nexus

Large-scale biofuel feedstock production

- Increase chemical and nutrient loading in surface and ground water

Competing water use from multiple sectors and projects

- Power
- Biofuel
- Agricultural
- Urban development

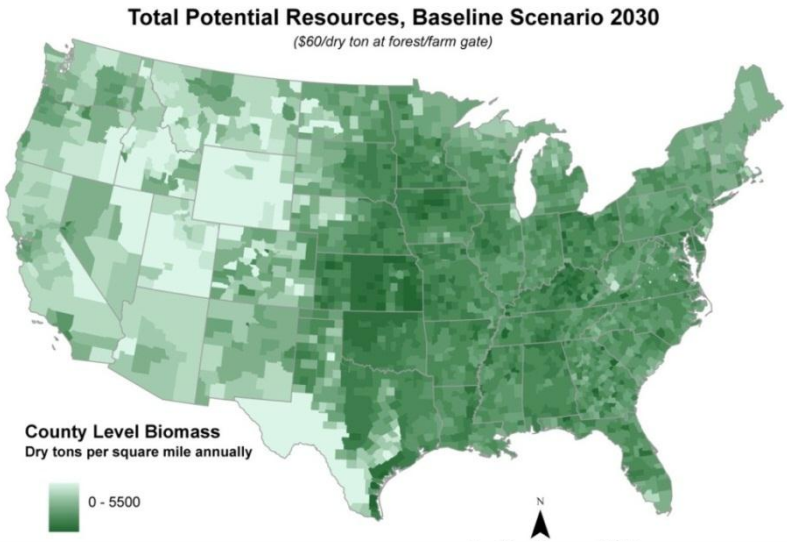
Compounding effect on water body

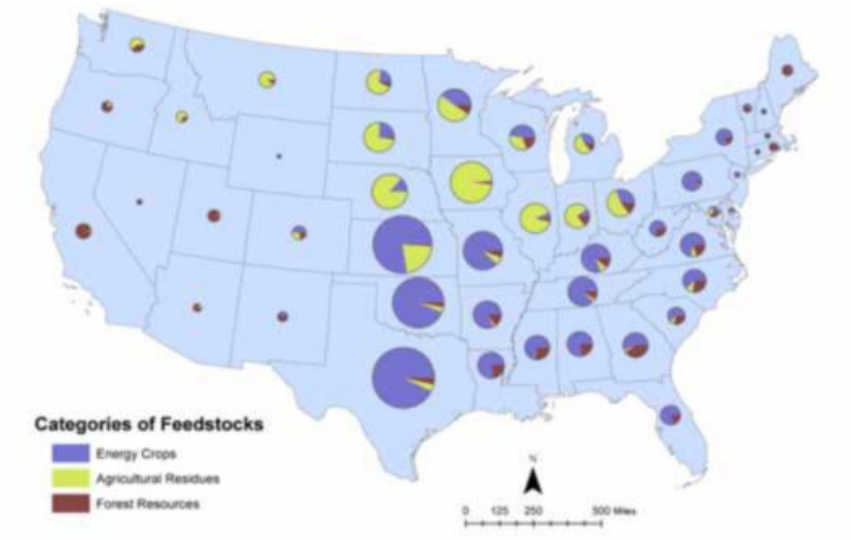
- Aquatic ecosystem degradation
- Ground water depletion






# *Potential Cellulosic Biomass Resources for Biofuel Production*




- **Biofuel feedstock types**
  - Starch

    Corn, wheat, sorghum, cassava
  - Oil crops

    Soybean, rapeseed, palm oil, algae, *Jatropha*, waste oil
  - Sugar

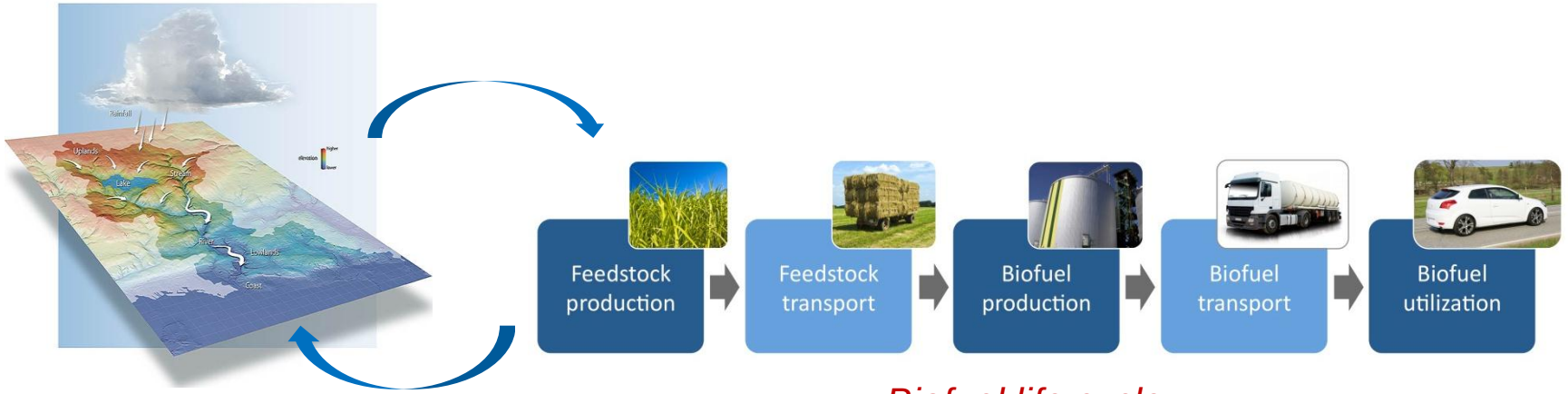
    Sugar cane, sugar beet, sweet sorghum
  - Cellulosic

    Crop residue, perennial grass, short-rotation woody crop, forest wood residue, municipal solid waste
- **Billion-Ton Resource Update (DOE)**
  - Cellulosic biomass feedstock of nearly **1.1 billion dry tons** potentially available for biofuel production by 2030
  - Replace approximately 30% of the nation's current petroleum consumption

Source: US DOE 2011

# Questions

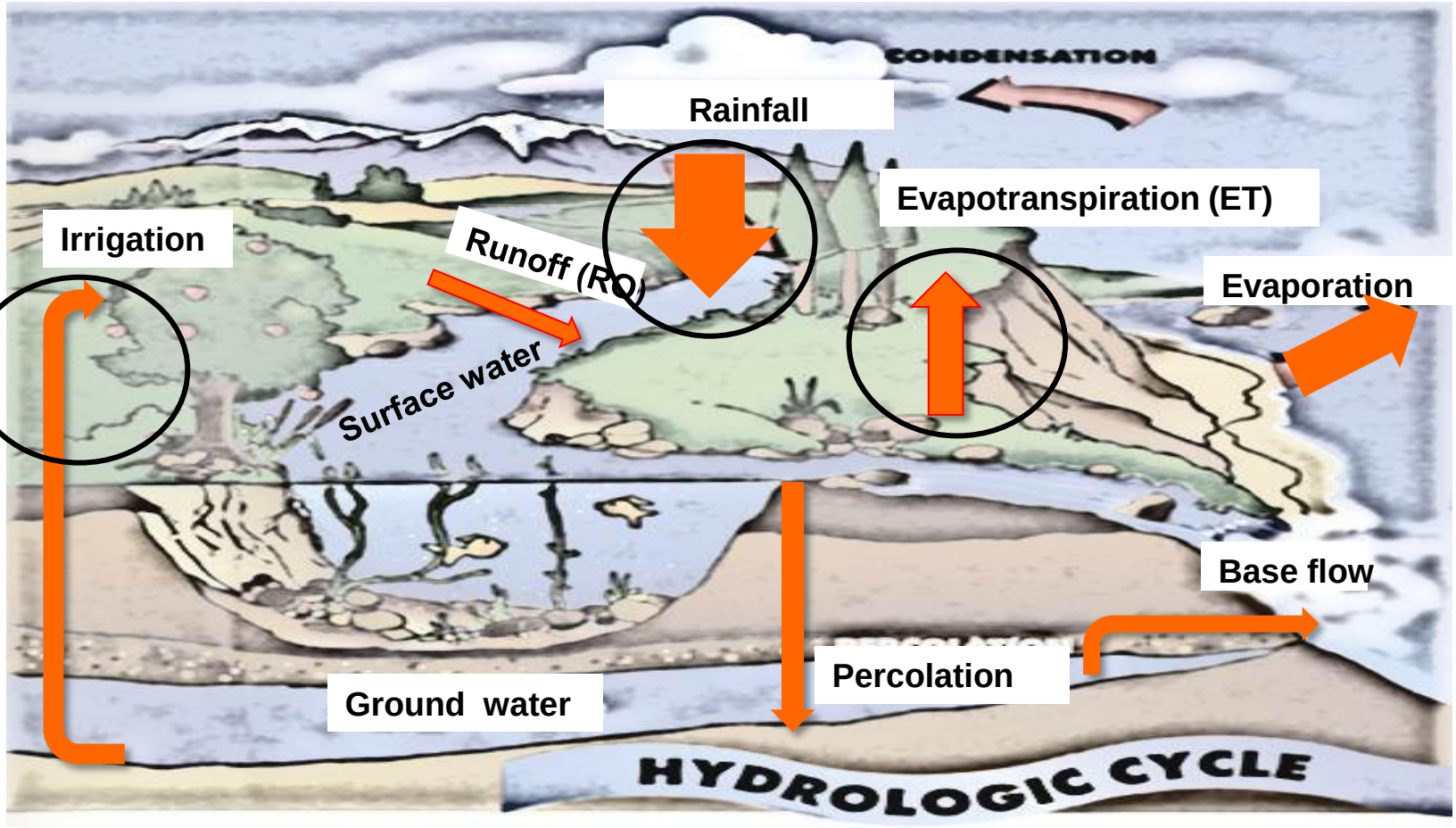
- How does the choice of feedstock affect water usage in producing one gallon of biofuel?
- How does the choice of different regions for growing feedstock affect the types of water needed as well as the water availability?
- How does the choice of refinery siting affect water sustainability?
- How does the choice of feedstock and location impact down stream water quality?




*Biofuel life cycle*

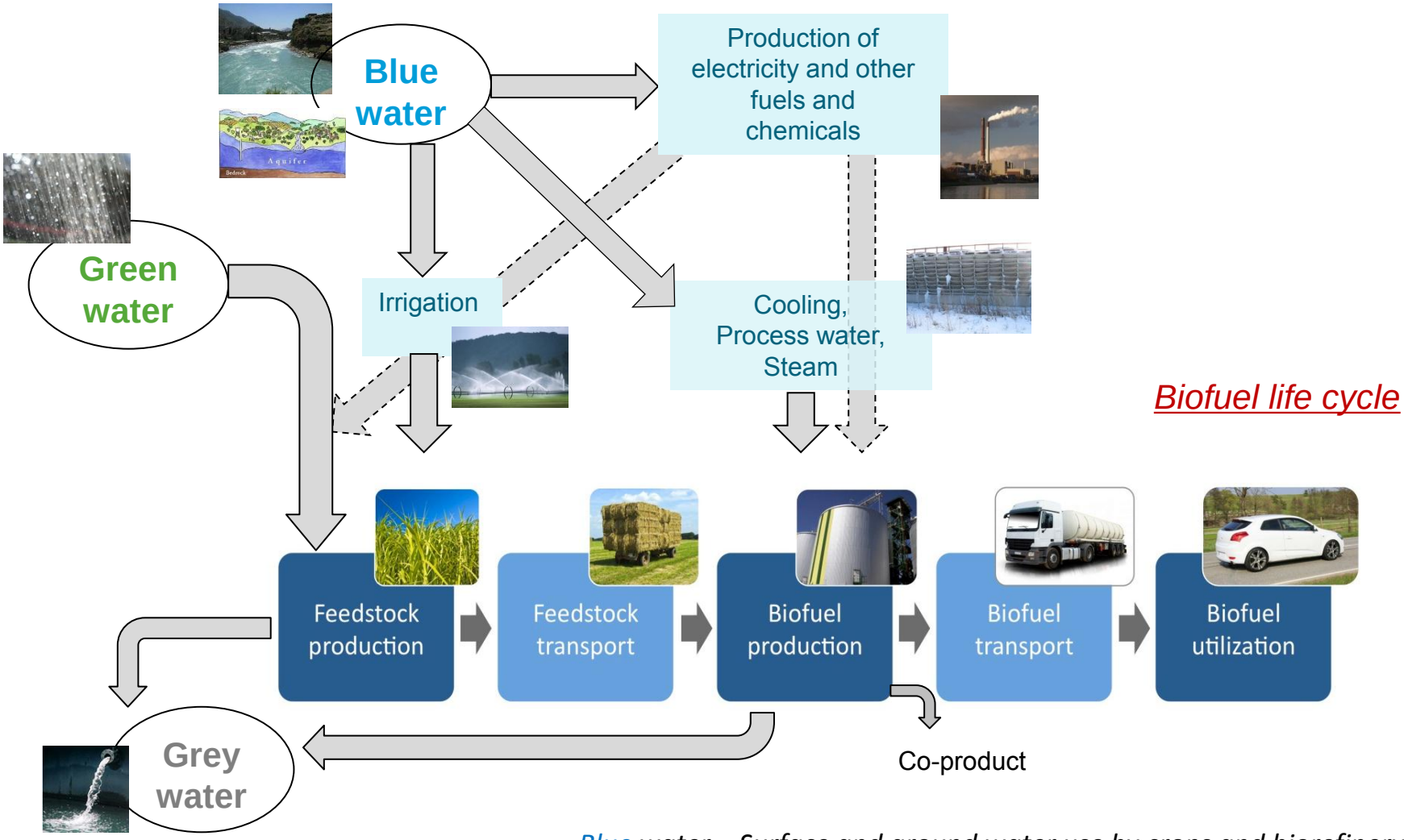
# Major Considerations of Water Use in Biofuel Production

- Spatial variability
  - Climate, water resource, soil, feedstock
- Feedstock type
  - Annual crop, perennial grass, forest wood residue
  - Yield, water requirement
- Management and practices
  - Chemical input, irrigation, harvest
- Biofuel production pathway
  - Type of conversion process, process water use efficiency, co-product
- Indirect inputs
  - Energy, chemicals




| | |
|---|---|
| **Water resource input:** | Primarily rainfall |
| **Consumptive water use**: | Water loss by evaporation from soil and water surfaces, and by transpiration from plants |

# Biofuel Water Footprint Accounting



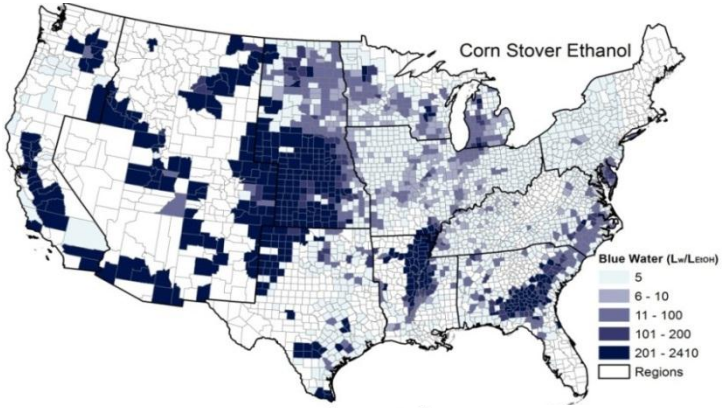

*Blue water – Surface and ground water use by crops and biorefinery*

*Green water – Rainfall use by crops*

*Grey water – Volume-equivalent water required to dilute chemicals to acceptable level*

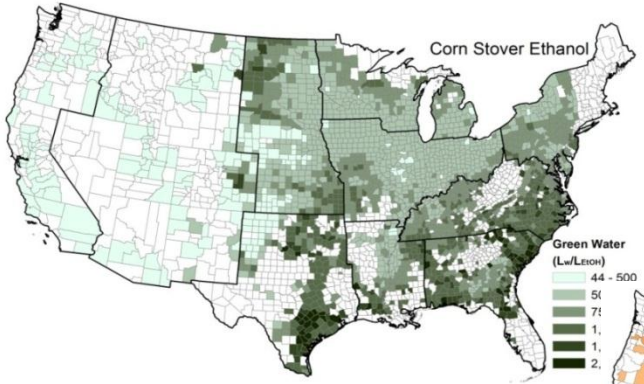
# Spatial Distribution of Water Footprint:
## Corn Stover Ethanol

**Blue Water**

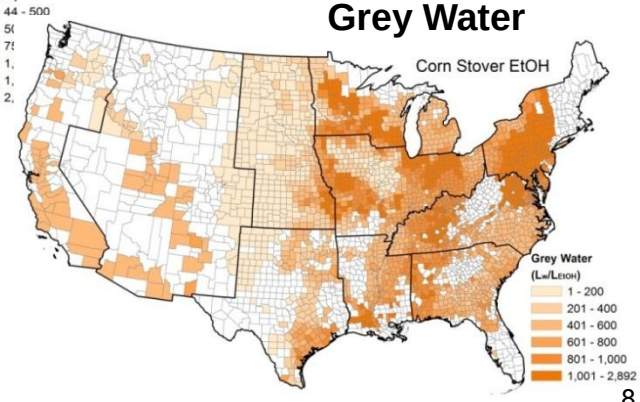


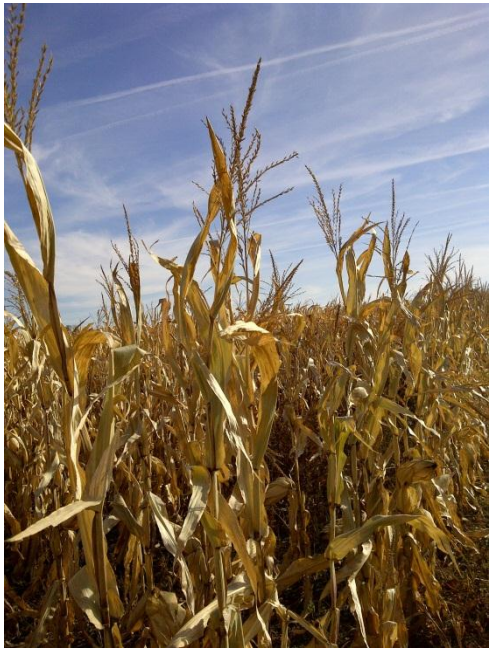

- Requirement: 401 billion gallons of blue water to produce 4.9 billion gallons of biofuel annually
  - 24% stover removal

**Green Water**



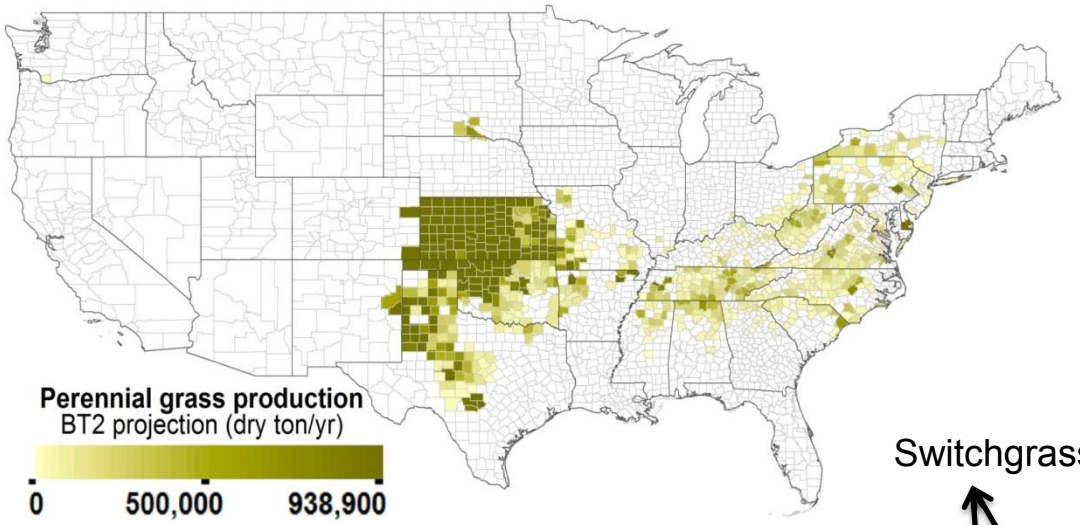

**Grey Water**



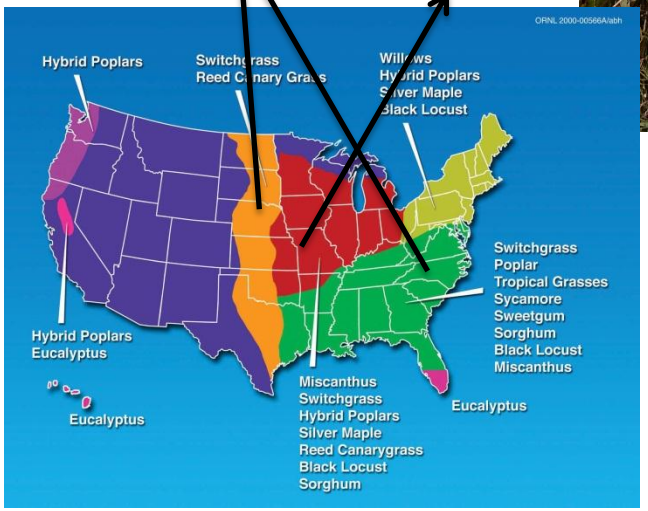
Sources: Chiu and Wu 2012

# Projected Perennial Feedstock Production




Switchgrass

Miscanthus



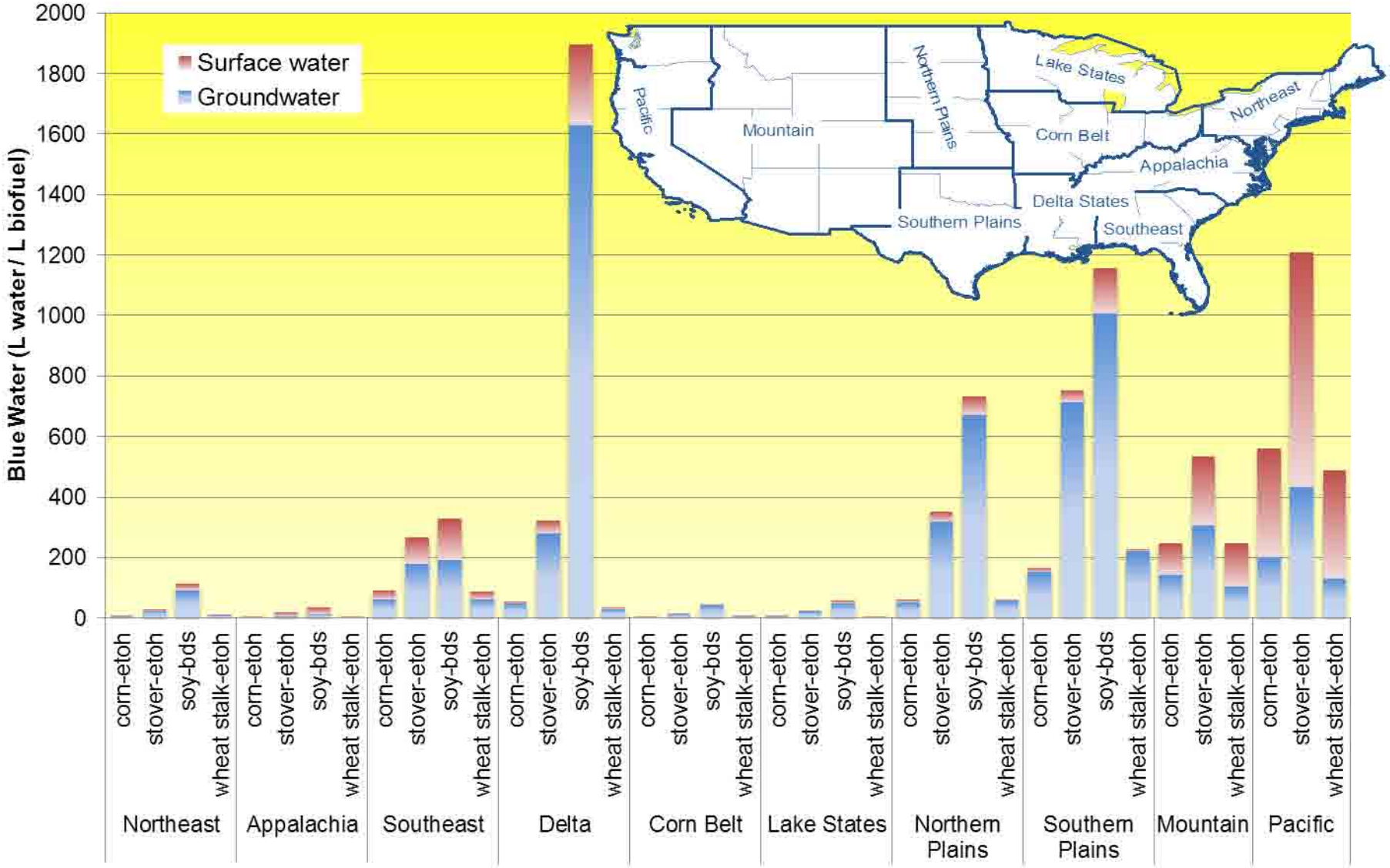

Scenario: 2022
Feedstock: perennial

Source: USDOE (2011)

Areas suitable to grow perennials

Source: USDOE 2006 (https://public.ornl.gov/site/gallery/detail.cfm?id=138&topic=&citation=8&general=&restsection=)

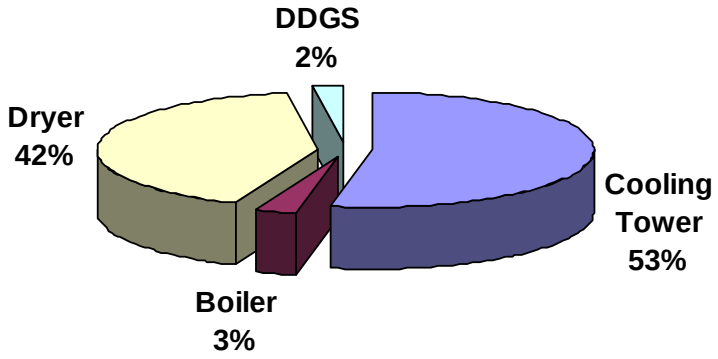
# Spatial Heterogeneity in Types of Water Used

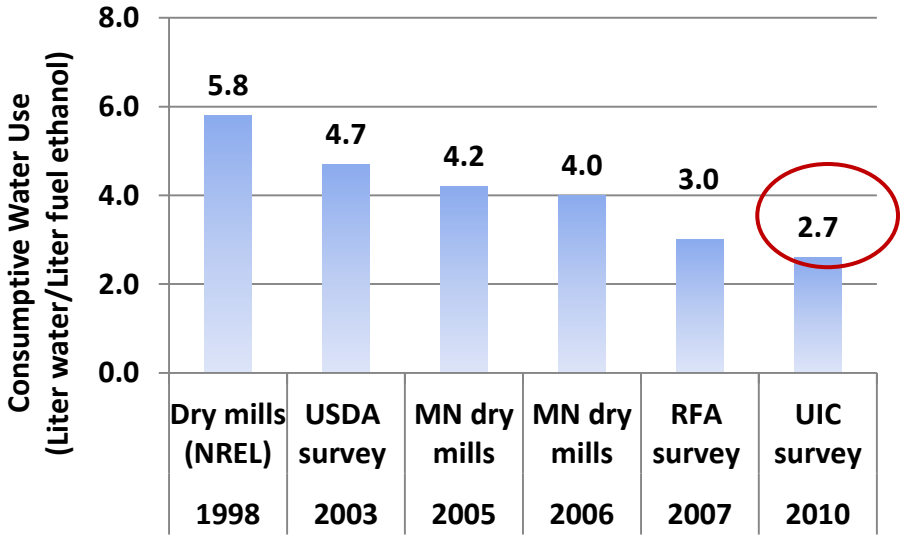



Sources: Chiu and Wu 2012

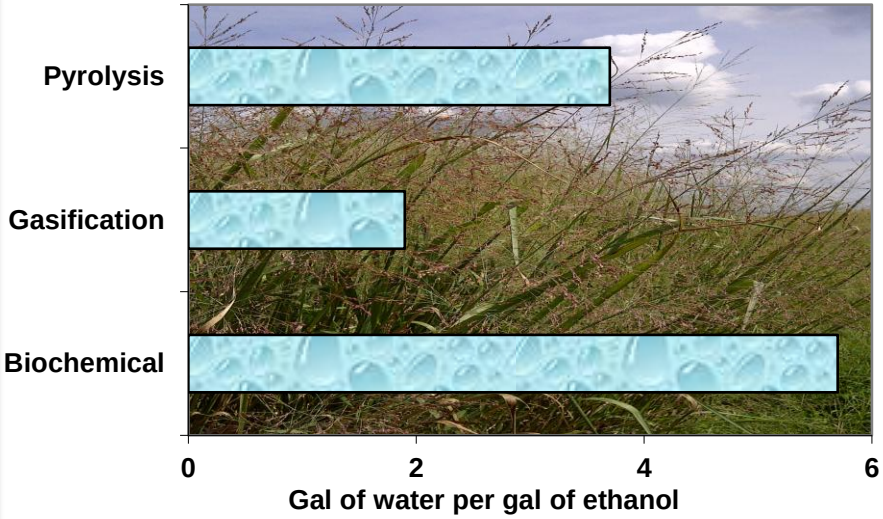
# Water Use in Biorefinery Varies with Feedstock and Conversion Process

## Conventional biofuel - Corn dry mill




## Cellulosic biofuel - Biorefinery




Source: Wu et al. 2009; Humbird et al. 2011; Jones et al. 2009

# Multiple Products Produced from Biorefinery

Agricultural residue, grain starch, oil seeds, forest wood residue, perennial grass, Municipal waste, algae, other biomass…

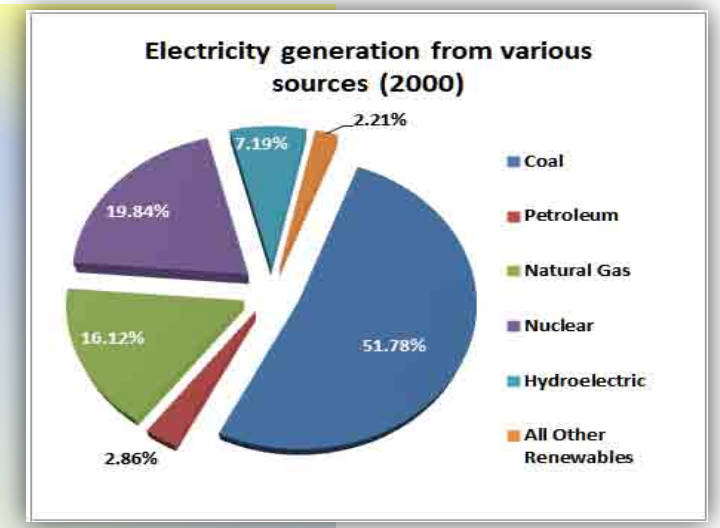
Conversion process

Biochemical
thermochemical
physical/chemical

- Biofuel
- Bio-electricity
- Biogas
- Animal feed
- Fertilizer
- Chemicals

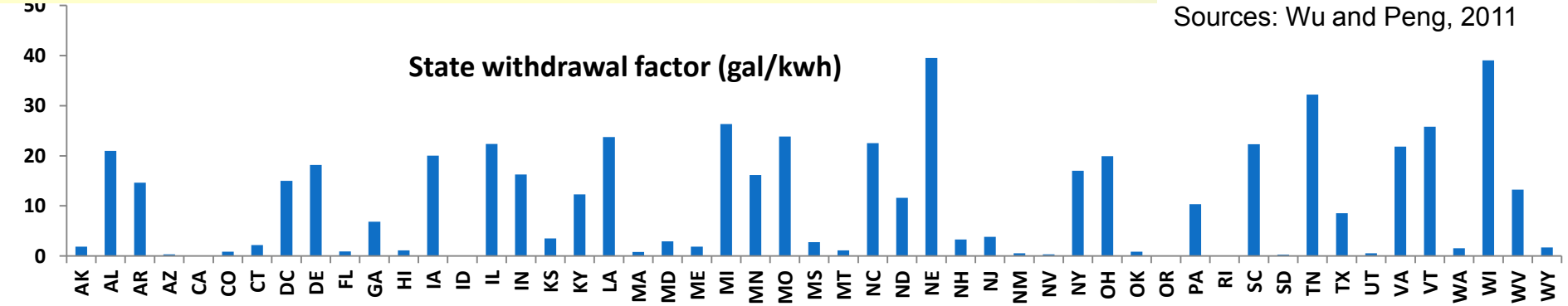
*Water use in producing displaced products contributes to water credit.*

# Water Intensity in Electricity Generation

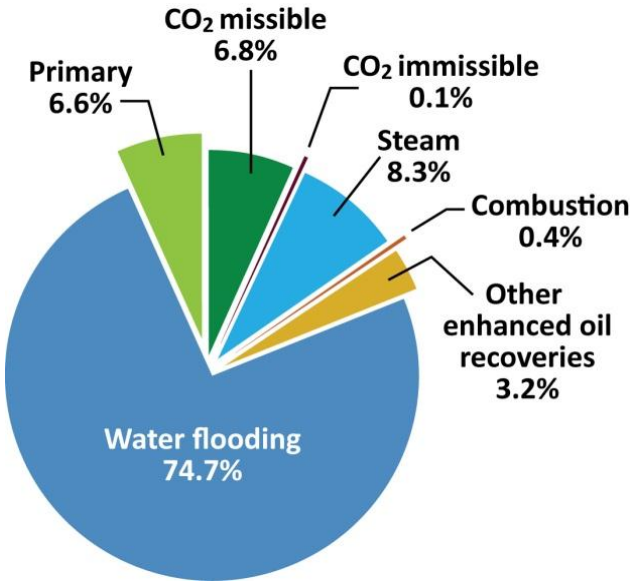



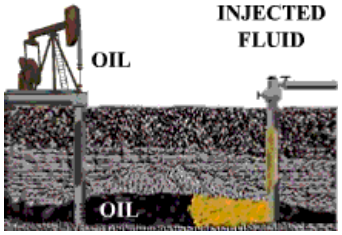

About 3% of the water withdrawn is consumed

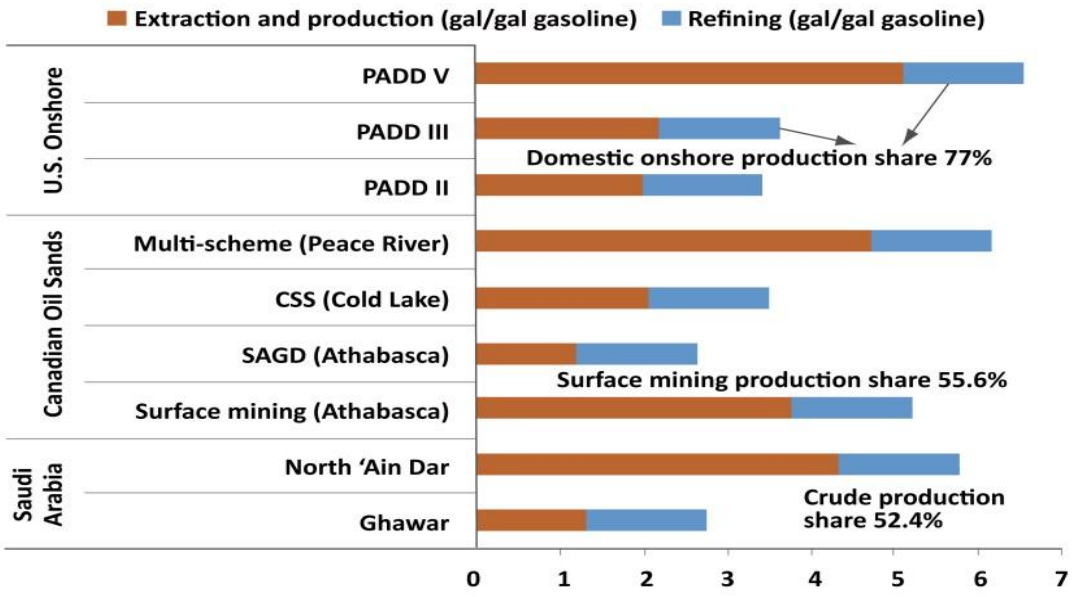
Sources: Wu and Peng, 2011



# Water Use for Energy Production from Petroleum Oil



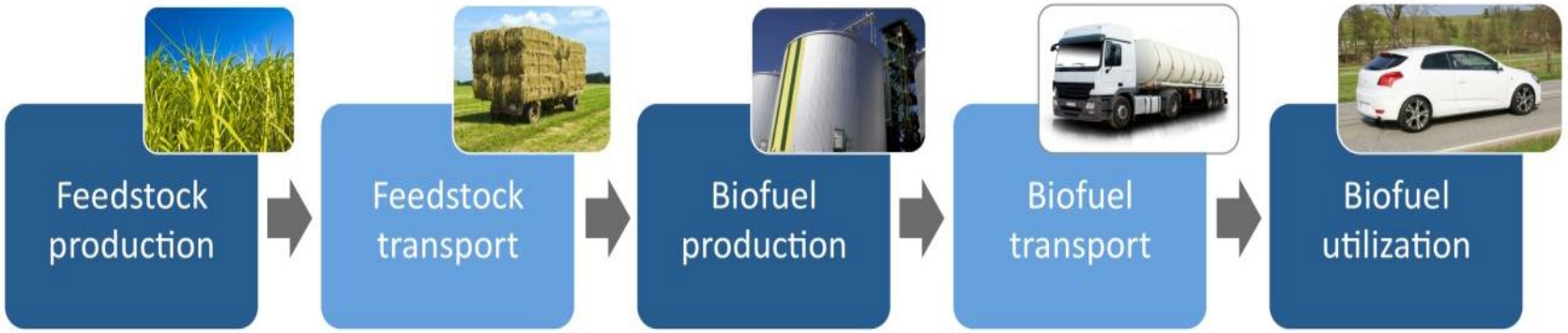




Sources: Wu et al. 2009

# Life-Cycle Water Footprint of Biofuels

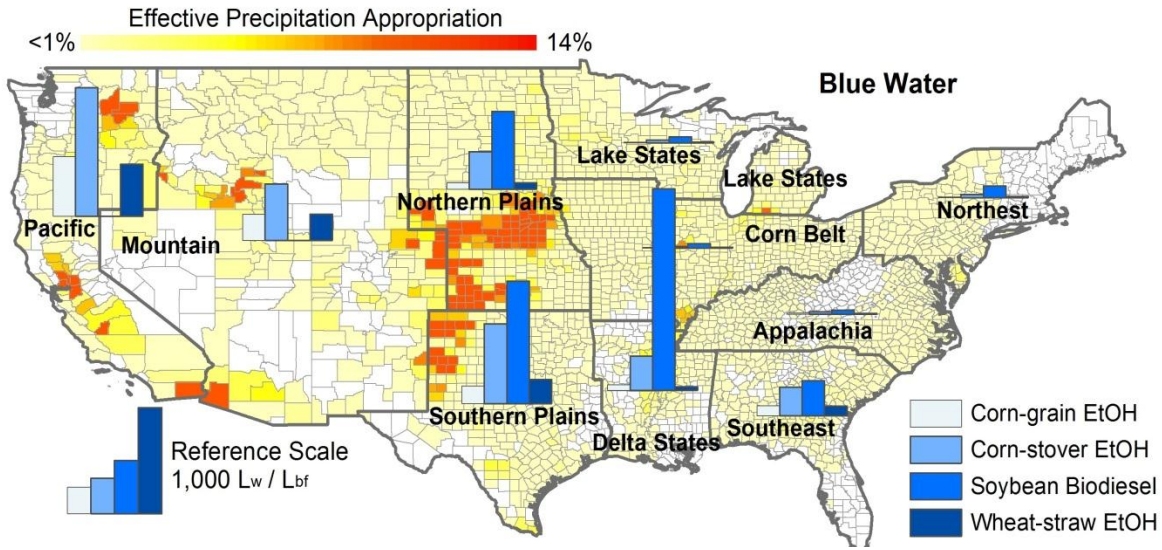
## Blue water consumed to drive a passenger car for a mile

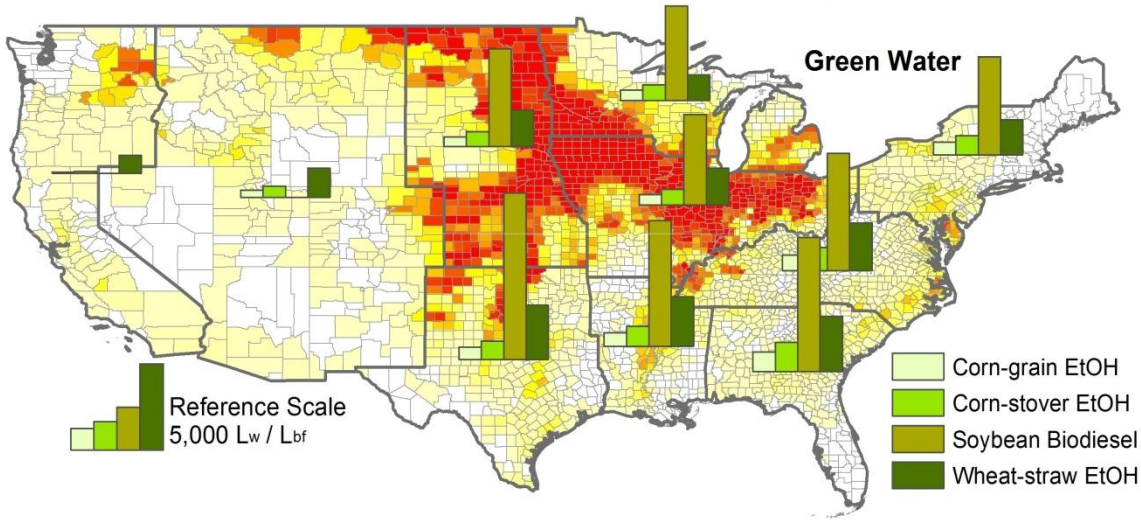
| | | |
|---|---|---|
| • Corn ethanol: | 0.7–10.4 gal | Midwest regions |
| • Cellulosic ethanol: | 0.1–0.3 gal | Non-irrigated perennial grass |
| • Algal biodiesel: | 3.7–53 gal | Open-pond algal biodiesel, with MWW, southern states |
| • Petroleum gasoline : | 0.1–0.3 gal | United States, Saudi Arabia, Canadian oil sand |




Sources: Wu et al. 2009

# Impact on Water Resource: Annual Appropriation



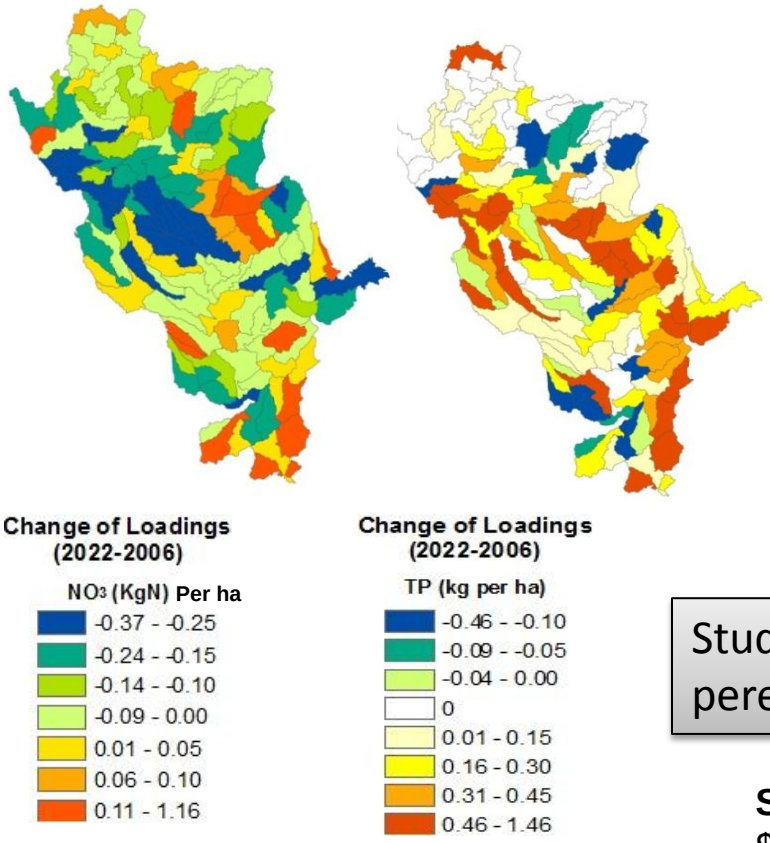

Sources: Chiu and Wu 2012

# Water Quality and Quantity Changes in Upper Mississippi River Basin under a Selected Billion Ton Scenario

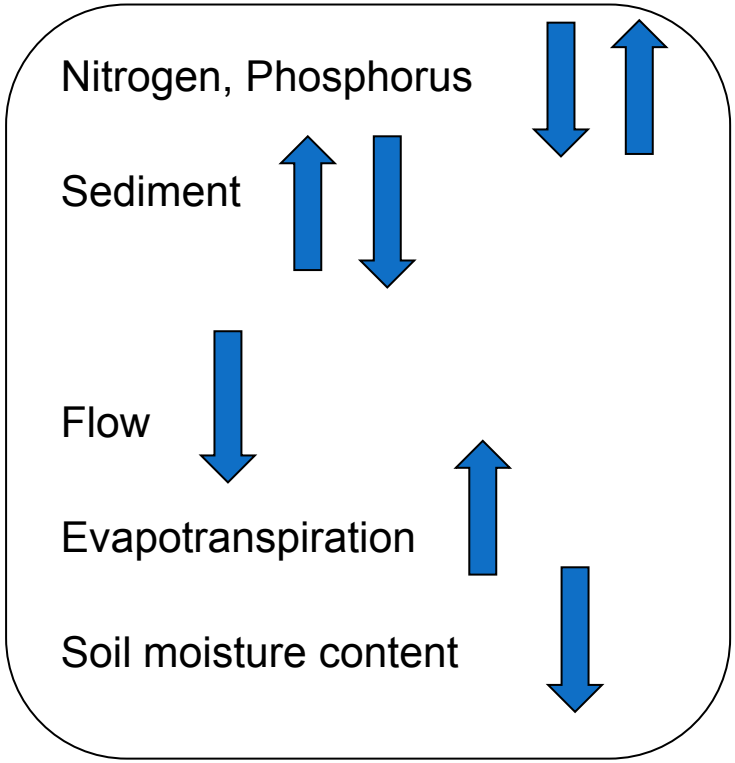
***SWAT modeling***

Change of Nitrate ($NO_3$)

Change of Total Phosphorus (TP)




Sources: Demissie et al. 2012

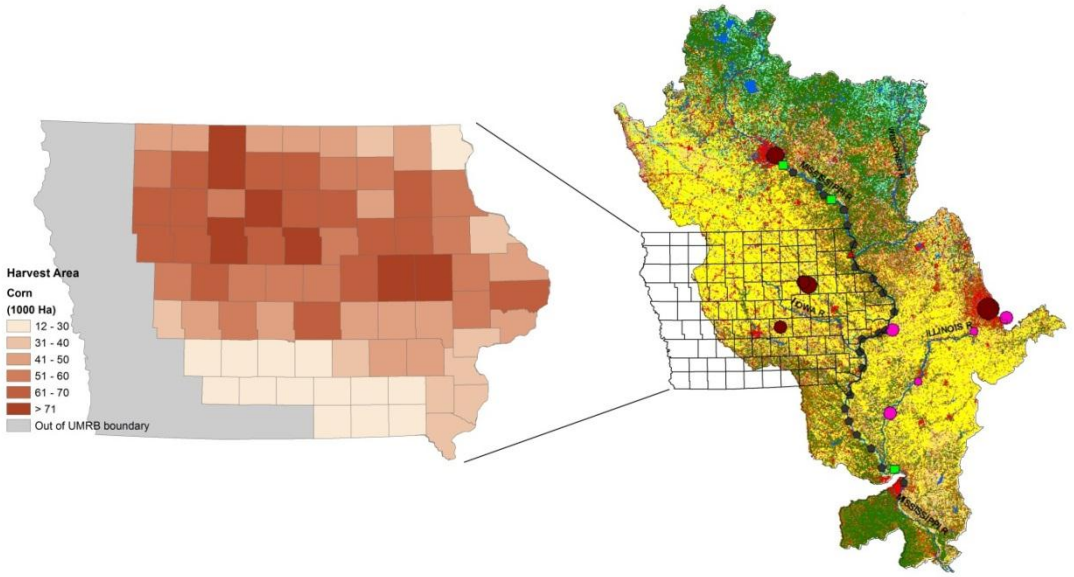


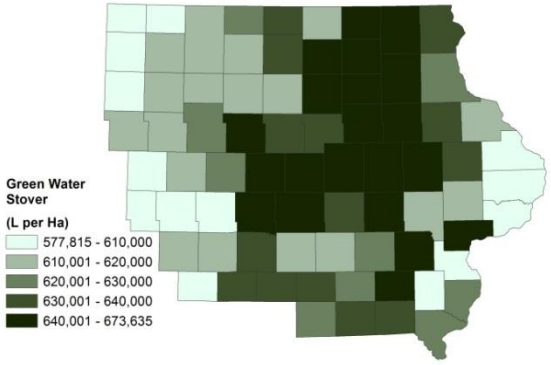

Study demonstrated reduced nutrient loss by growing perennial grass to produce cellulosic biofuel

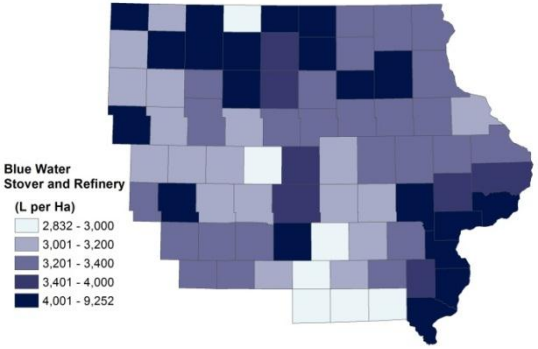
**Scenario**:
$50 per dry ton, 2022, with sustainable agricultural residue harvest, USDA baseline

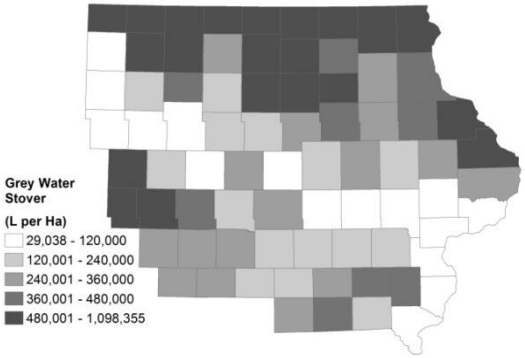
# *Case Study: Corn Stover Scenario*
# *Biofuel Produced from Corn Stover in Iowa Counties*

- Corn stover based cellulosic ethanol production via hydrolysis and fermentation
- Portions of stover removal based on soil sustainability requirement



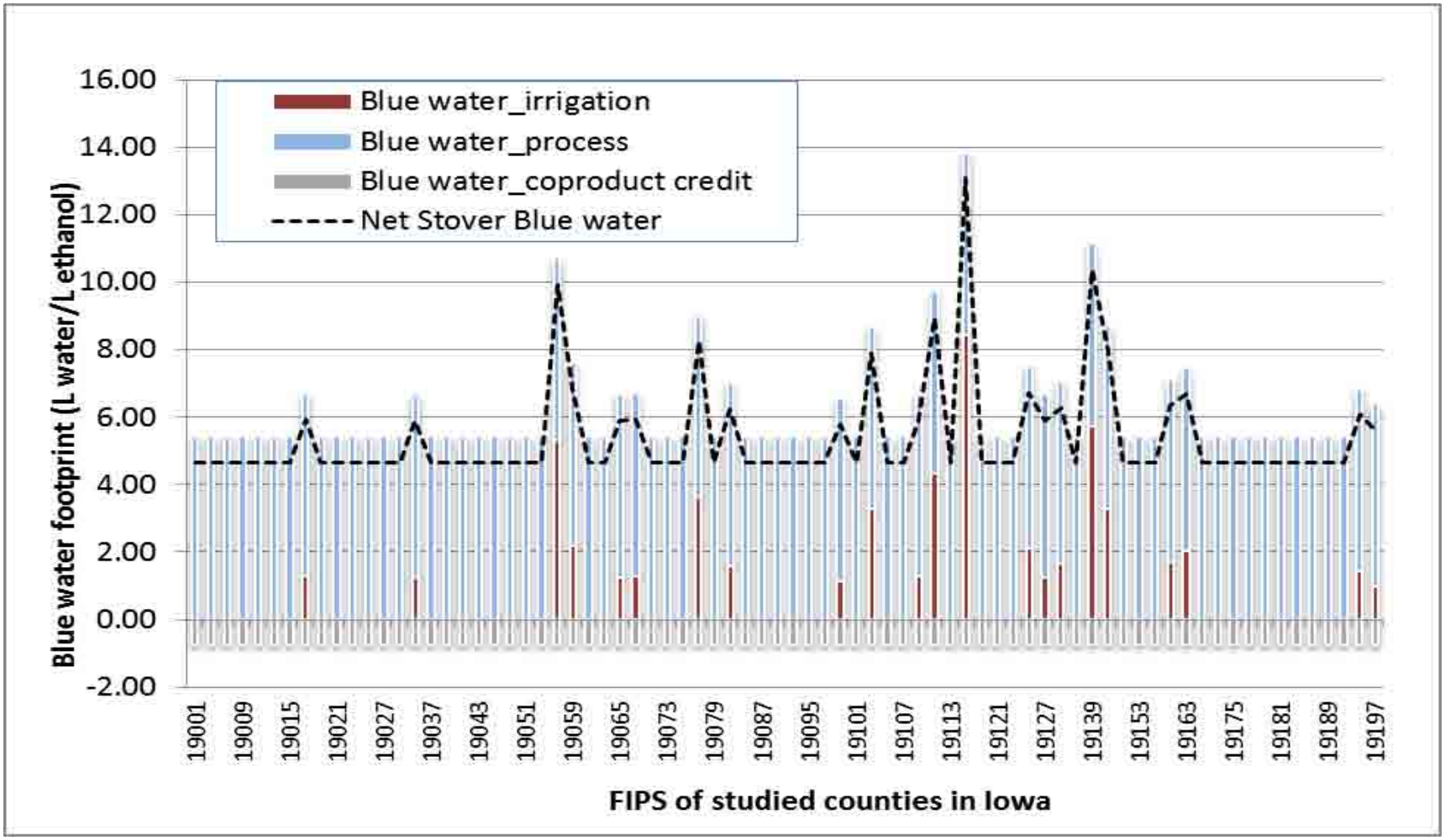




Sources: Wu et al. under review with WRR

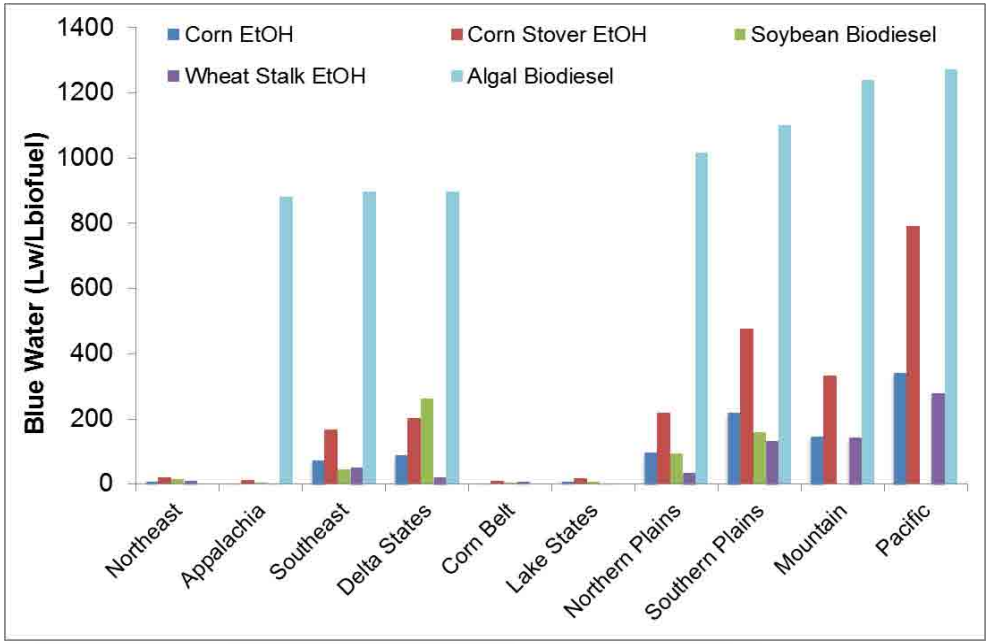
# Blue Water Footprint Affected by Irrigation, Process Water, and Biorefinery Co-product

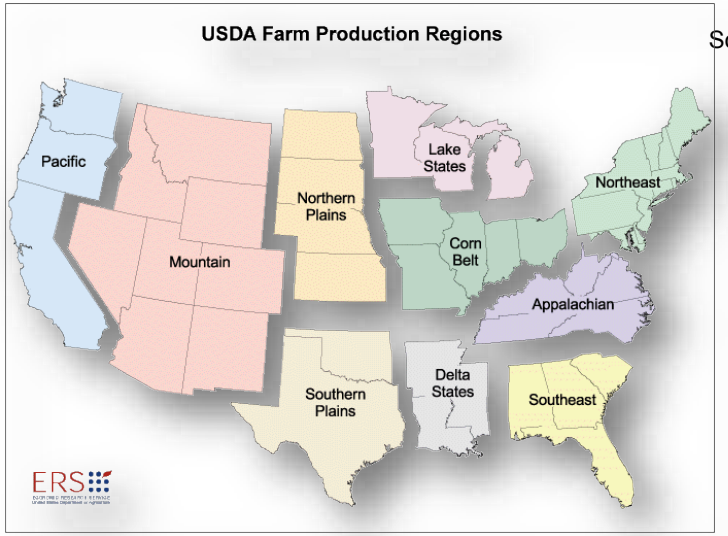



Sources: Wu et al. under review with WRR

# Develop Water Sustainable Biofuel Production through Multiple Resource Planning

- Water-biofuel nexus must be examined on regional basis to account for land availability, climate, soil, and **water resource** factors.
- Development of a region-specific biofuel feedstock mix (starch, cellulosic, sugar, and oil crops) is essential for a water-sustainable biofuel production.
- Biorefinery site selection should incorporate local water resource constraints, in addition to economic and infrastructure considerations.
- Using perennial grass as feedstock can assist soil runoff control and reduce nutrient loss to water body while producing additional biofuels.




Source: Chiu and Wu 2012

# Thank you !

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# Thank you !

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