Food Energy Water Nexus Workshop

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Panel 2: How to Measure All Three: Tools and Models

Oct. 7-9, 2015
Baltimore, MD

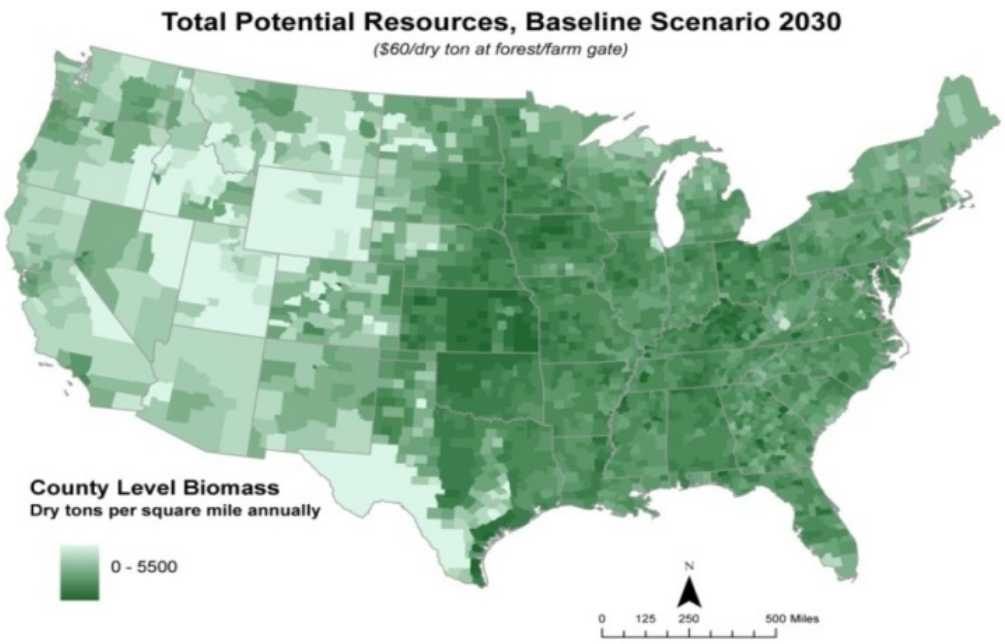
Food – Energy - Water*: The Context*

- Food, energy, and water are intertwined. Food crop production relies on water, land, energy, and climate; energy production requires water resource; and water supply needs energy.
- Competing demand for water resource in the production of electricity (from all sources), fuels (conventional, non-conventional, and renewables) and food, feed, and fiber.
  - Shale gas: Large volume of water required in short period of time during initial fracking
  - Agricultural crop and biofuel feedstock: Irrigation and crop growth
  - Thermoelectric power plant: cooling
- Dynamic relationship between energy and fuel production and water sustainability. Increased water stress could disrupt their production, and its ripple effect can be felt across various regions in multiple sectors.
- A growing population demands increased supply of food, energy, and water.

Food – Energy - Water*: The Context*

- Water issue is regional. The extent of water stress varies substantially with geographic regions.
- Water is valued differently from one region to another, depending on water resource richness, the potential disruptive impact of water shortage on economics can be substantial.
- According to the forecast, the world may experience increased flood and draught in various regions currently producing food, feed, and biofuel feedstock.
  - A shift of the frequency and intensity of precipitation and heating days
  - These changes are expected to be temporal
- The impact of climate change on water quality in agricultural landscapes varies with feedstock type, soil type, and geographic regions; the extent to which this change affects large-scale food-energy production can be complex.

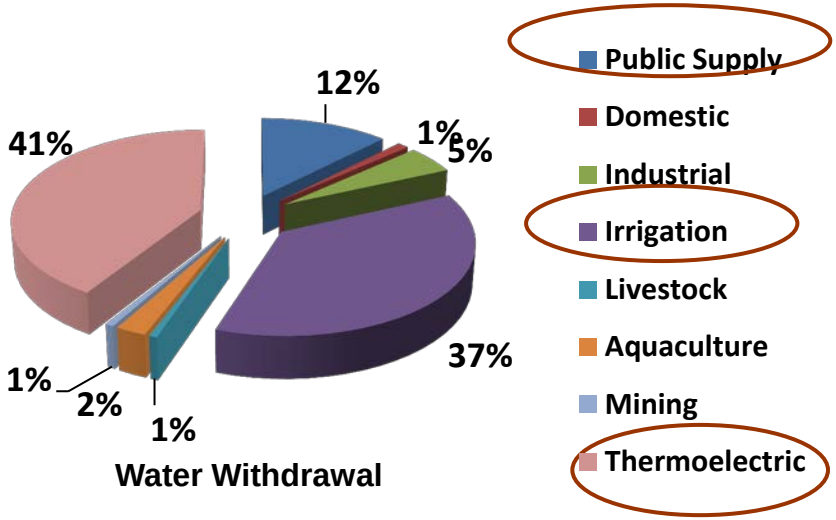
Water for BioEnergy / BioFuels

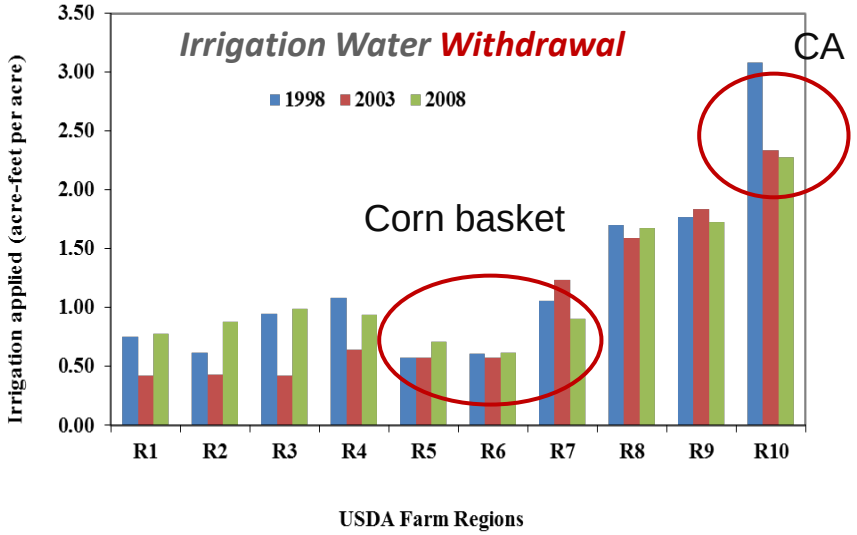


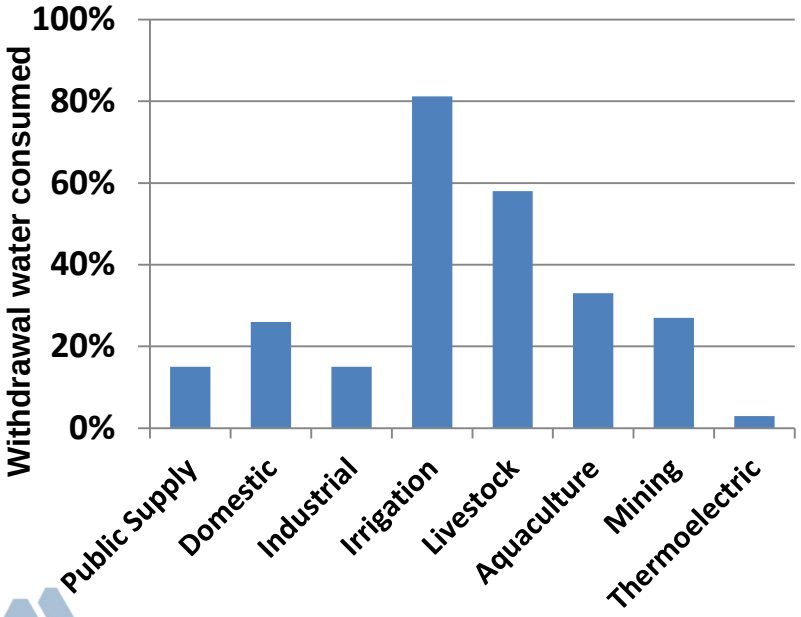
- Cellulosic biomass feedstock of 0.5 - 1.1 billion dry tons potentially available for biofuel production by 2030, to replace 30% of the nation's current petroleum consumption.
  - A majority of current biofuels consists of conventional crops, for which about 11-13% is irrigated.

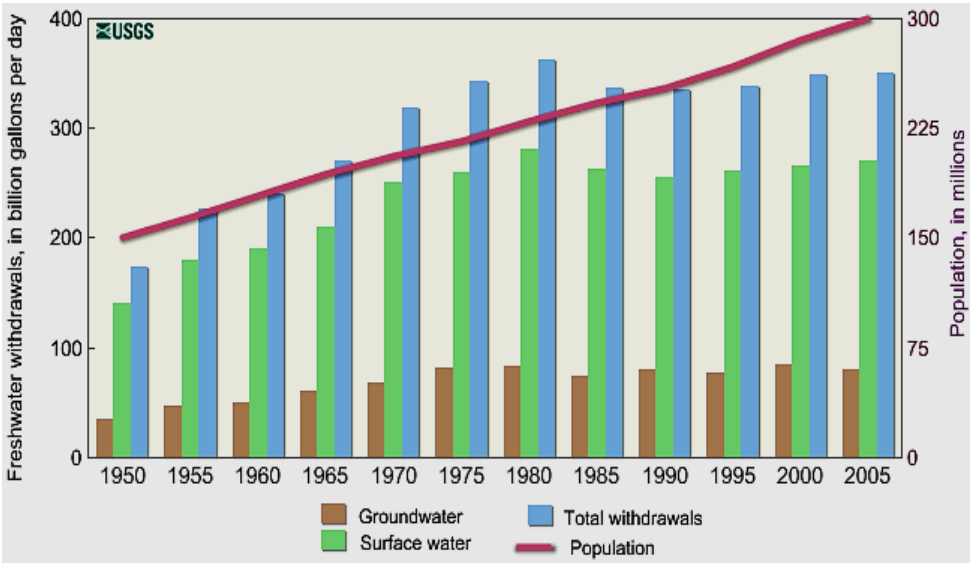
- Current research incorporate local water resource constraints, in addition to economic and infrastructure considerations, in feedstock production and biorefinery siting.

Historical Water Use Overview – Dominant Sector and Regional Variations







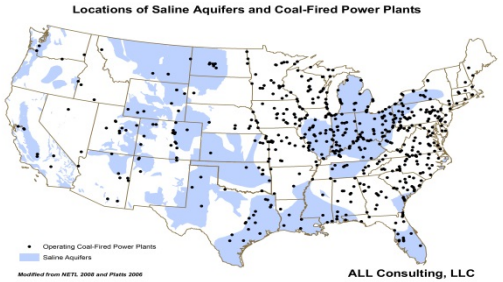


https://greet.es.anl.gov/publication-consumptive-water

Alternative Water Resources

- Municipal wastewater from POTW
  - Biological in nature, presence of nutrient (nitrogen, phosphorus)
  - Irrigation and industrial application in the west of U.S. has been practiced
  - Extensive use for cooling in the Western of U.S.

- Saline ground water and sea water
  - TDS level dependent application (treatment required)
  - Electricity generation in some thermoelectric power plant
  - Salt tolerate crops
  - Salt tolerate biological process

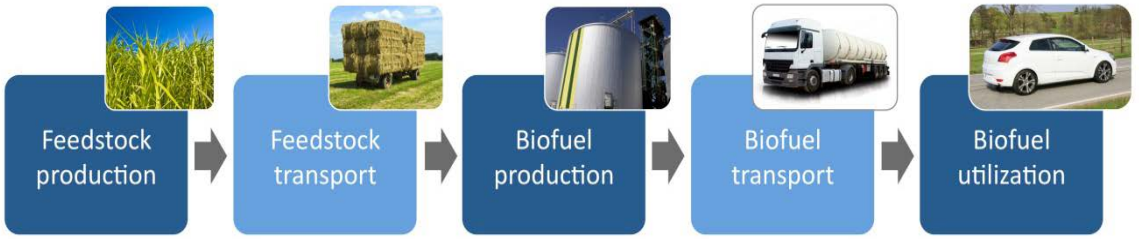


- Coal-mine water
  - High sulfur content
  - Application in oil/gas field exploration and production has been investigated

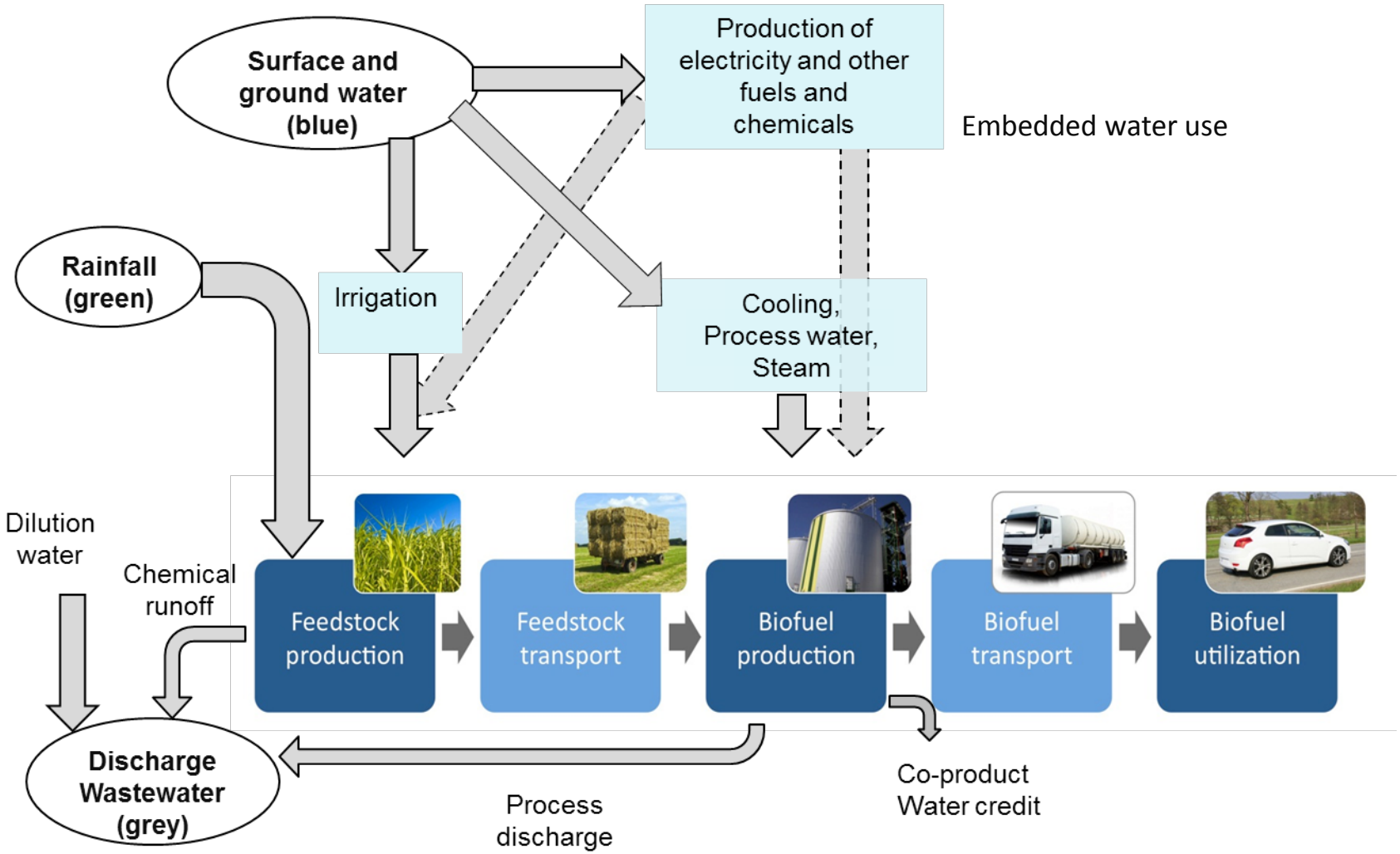
Investigate Water - Energy – Food Relationship from Biofuel Perspective

- Water use
- Water quality
- Water resource availability
- Region-specific crop mix
- Baseline, future scenario assessment
- Sustainability indicators
- Potential competing water use

- Agricultural data and knowledge
- Climate, hydrology, soil, land cover
- Geospatial analysis at watershed, county, state, region scale
- Across production supply chain with a focus on feedstock production and processing



Water Footprint Framework



Water Footprint Pathways for Energy/Fuel Production

- Corn
- Corn stover
- Soybean
- Wheat straw
- Switchgrass and Miscanthus
- Forest wood resource, short rotation woody crops
- Algae, rapeseeds, camelina, others

Conversion process:

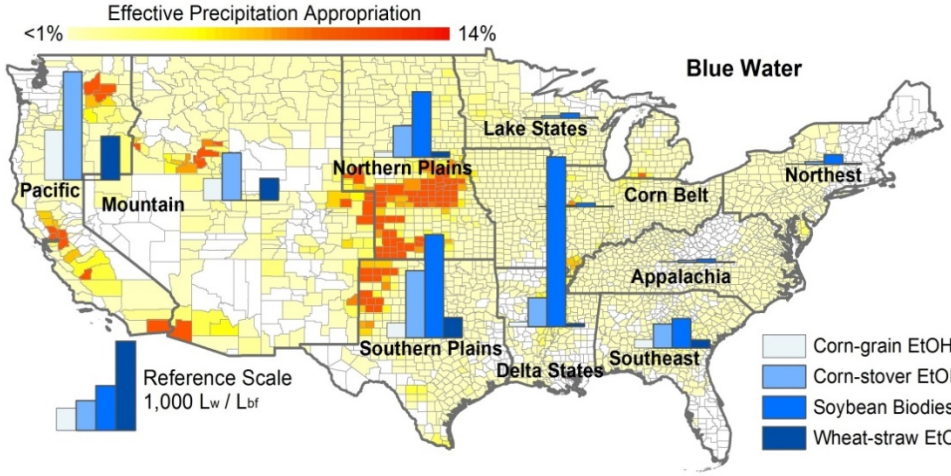
- Biochemical
  - hydrolysis, fermentation
- Thermal chemical
  - gasification, pyrolysis
- Chemical
  - trans-esterification
- Process water
  - management and treatment

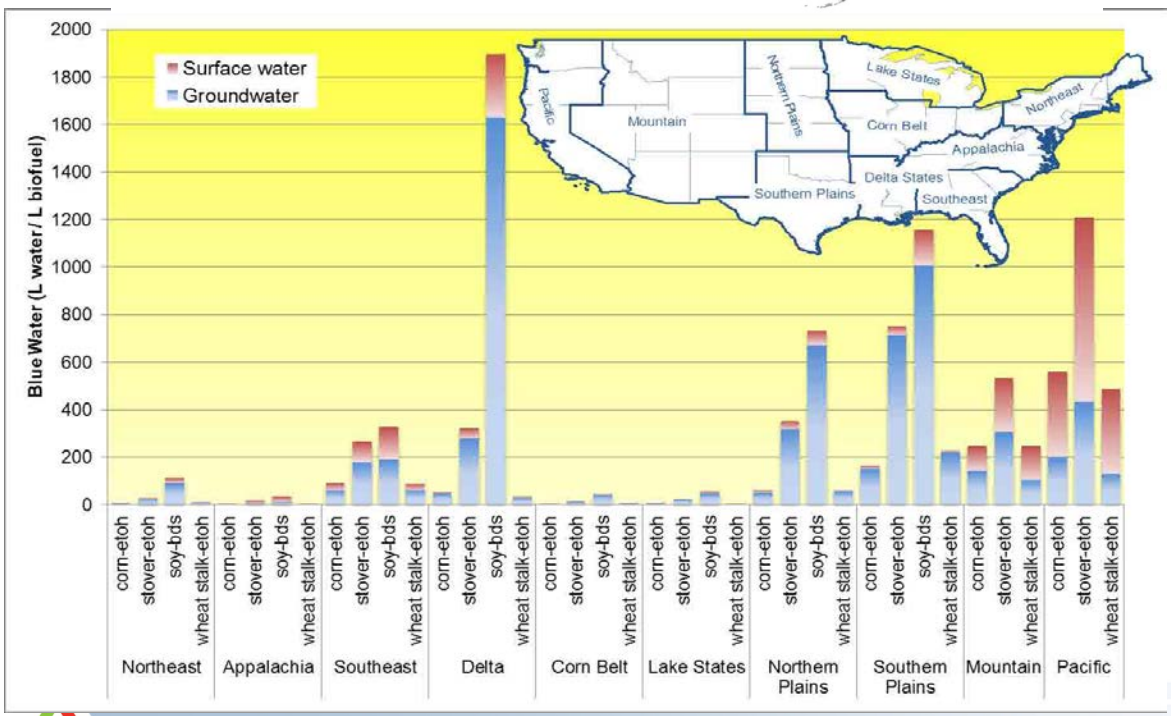
- Petroleum gasoline and diesel
  - U.S. on-shore wells
  - Canadian oil sands
  - Oil shale
- Natural gas
  - Conventional
  - Shale
- Electricity
  - Coal, NG, Nuclear
  - Solar, wind, geothermal, biomass
  - Cooling systems
  - Generation technologies

Spatial resolution:
County, state, USDA regions – biofuel
State level – power
PADD, Canadian regions – oil
Play – shale gas

Alternative water resources

Water Intensity of Biofuel Produced from Corn, Corn Stover, Soybean, and Wheat Straw





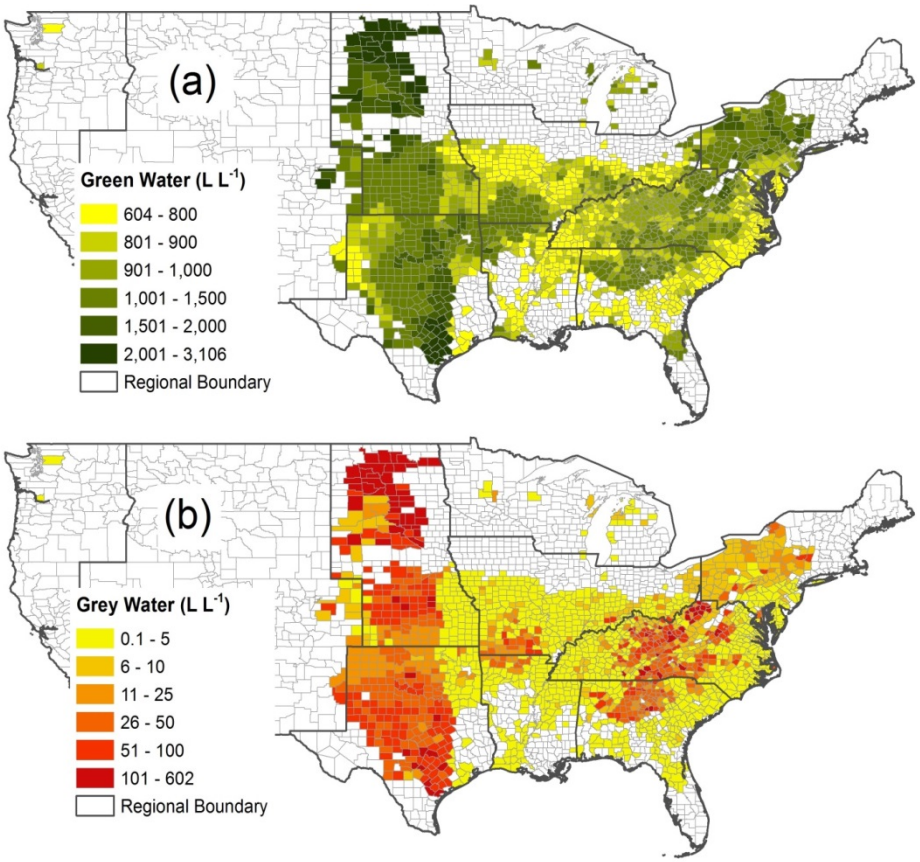
- Substantial variability in water footprint across feedstock and regions
- Identify water stress hot spot to address water availability issue
- Ground water is the major water resource for irrigation and processing

http://dx.doi.org/10.1021/es3002162

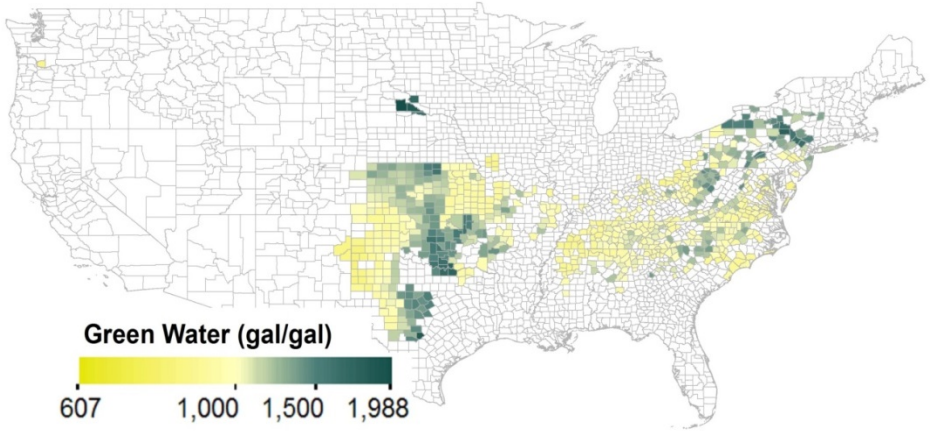
http://dx.doi.org/10.1029/2011WR011809

Water Footprint of Biofuel Produced from Switchgrass and Miscanthus

2030 $80.00/dry ton



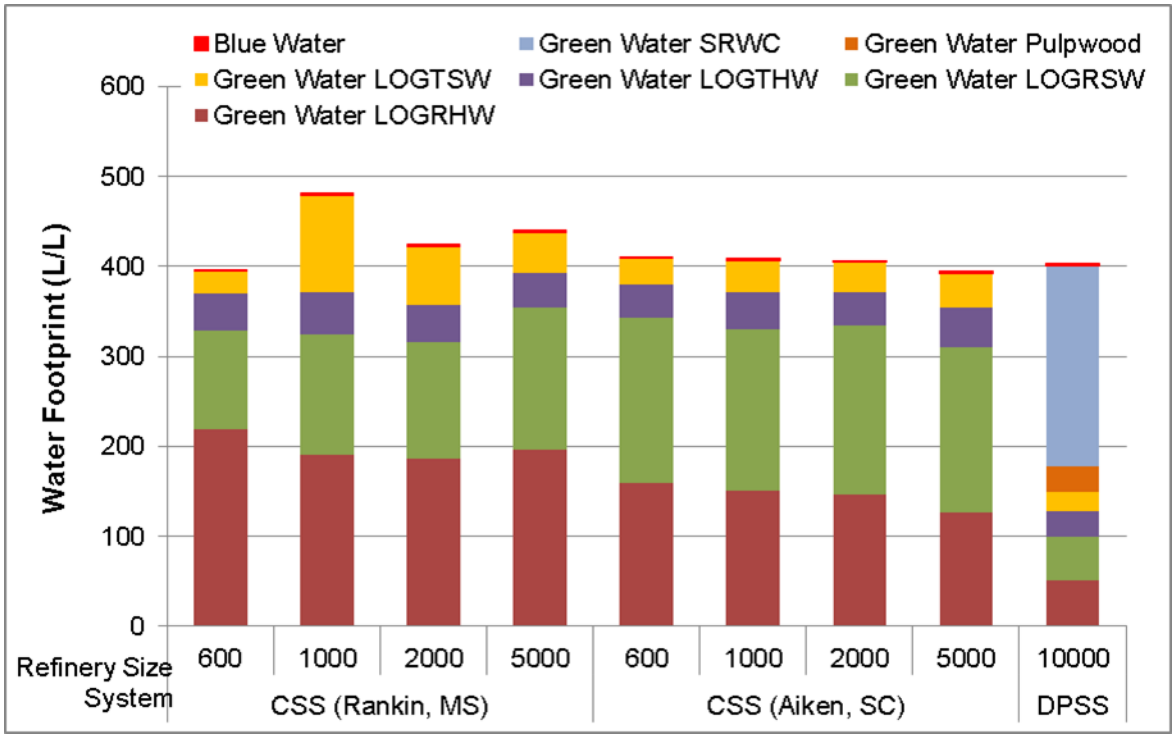
2022 $50.00/dry ton



- Blue water
  - Footprint is solely dependent on conversion process
  - No irrigation
  - Water use ranged from 2-6 gal/gal
- Green and grey water
  - Area with low WF identified

https://greet.es.anl.gov/publication-country-level-water-footprint

Impact of Feedstock Mix, Refinery Sizing, and Logistic Design



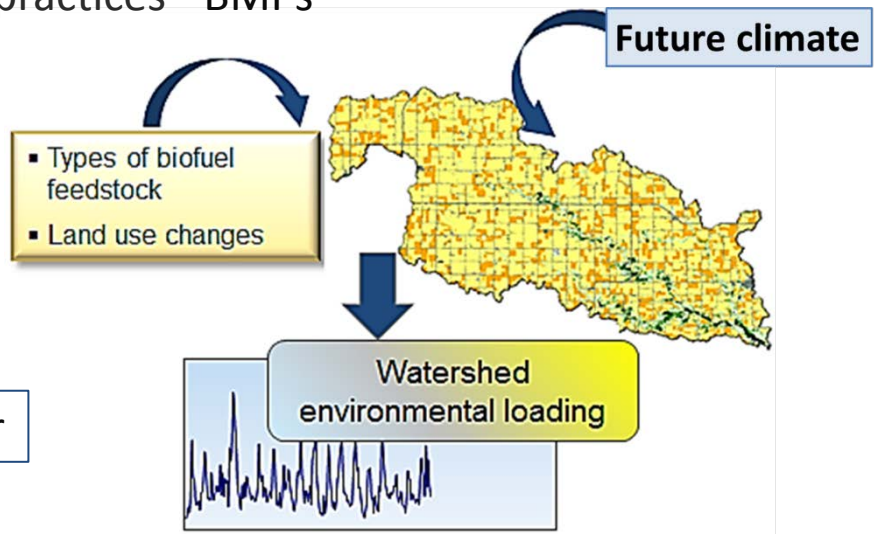
- Representative forest resources in SE of U.S.
  - Hardwood: sweet gum
  - Softwood: loblolly
  - SRWC
- Selected counties.
- No irrigation.
- Fertilizer applied for softwood.
- Gasification-mixed alcohol process.

- Estimated WF from forest feedstock mix (S.E.of U.S.)
  - Refinery sizing and logistic design scenario analyses (*Multi-lab collaboration*)
  - Feedstock mix is the determining factor for WF of mixed alcohol biofuel pathway
  - *Fertilizer grey water at watershed scale is scarce*.

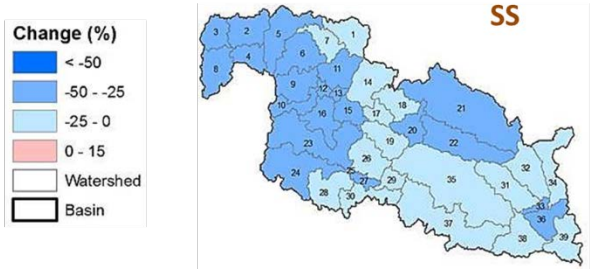
http://stacks.iop.org/1748-9326/8/i=3/a=035015

Impact of Land Use on Water Quality for Agricultural System

- Characterizing response of nutrients, stream flow and suspended sediments to various agricultural factors:
  - Land use change
  - Agricultural cropping system
  - Land management and cropping practices - BMPs
    - Riparian buffer
    - Cover crop
    - High efficiency irrigation
    - Tillage
    - Fertilizer application



Effect of riparian buffer

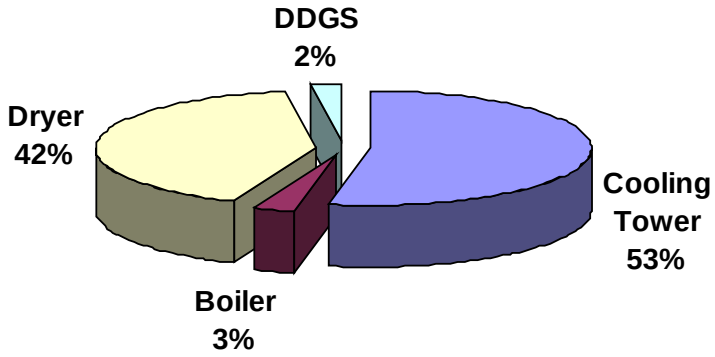


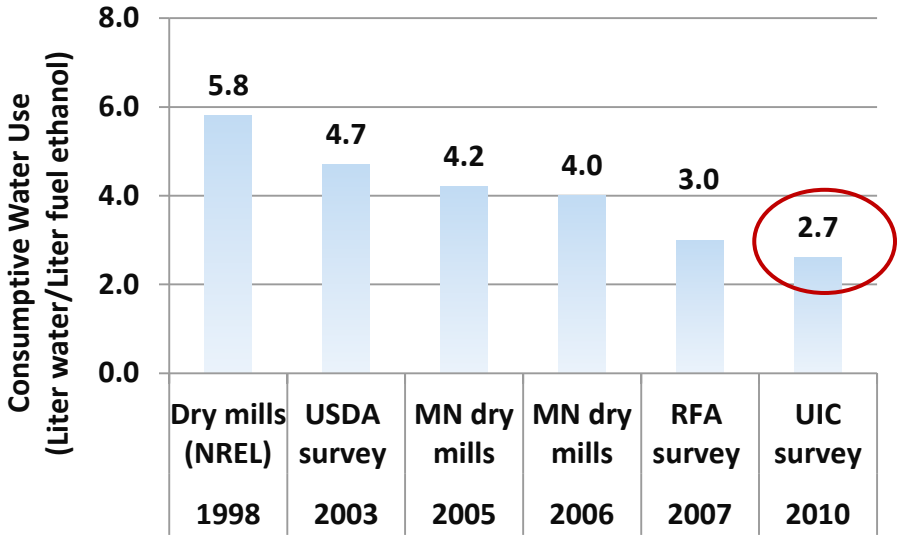
Adopting landscape design and management strategies to minimize undesirable impacts of climate change on water quality.

Ha and Wu, 2015. *BioFPR*

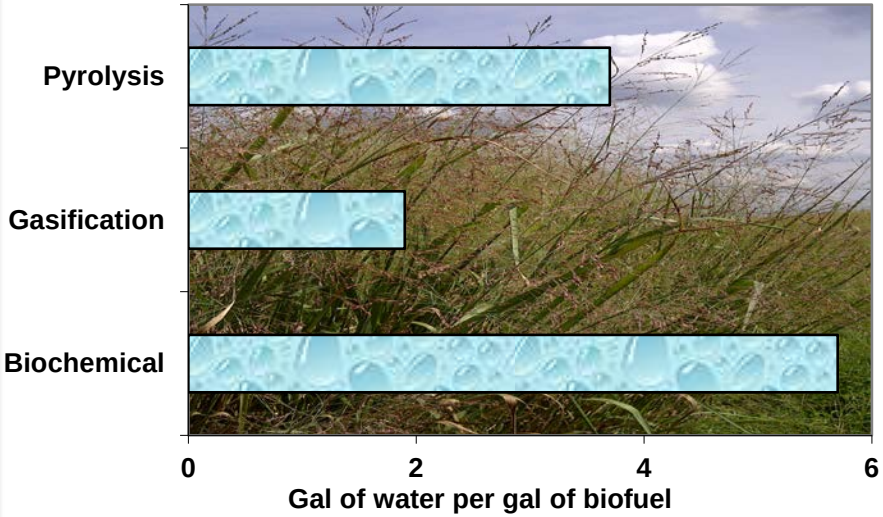
Water Use in Biorefinery Varies with Feedstock and Conversion Process

Conventional biofuel - Corn dry mill



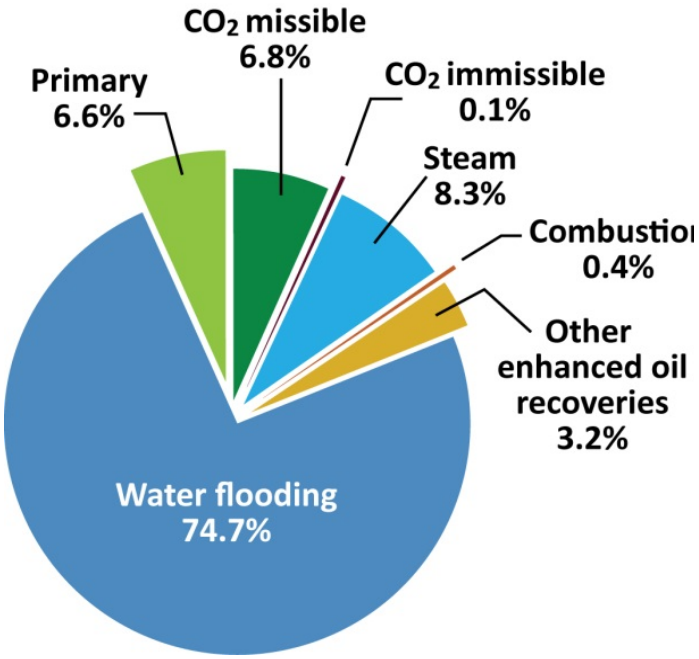


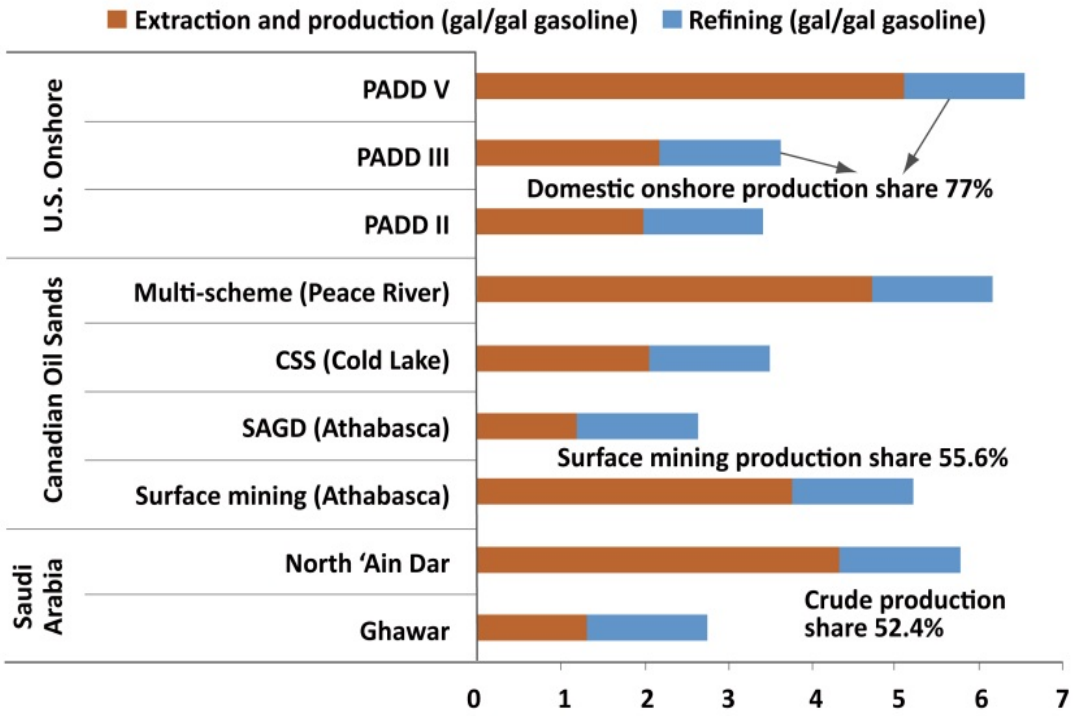
Cellulosic biofuel - Biorefinery



http://link.springer.com/article/10.1007%2Fs00267-009-9370-0

Water Use for Petroleum Oil Production





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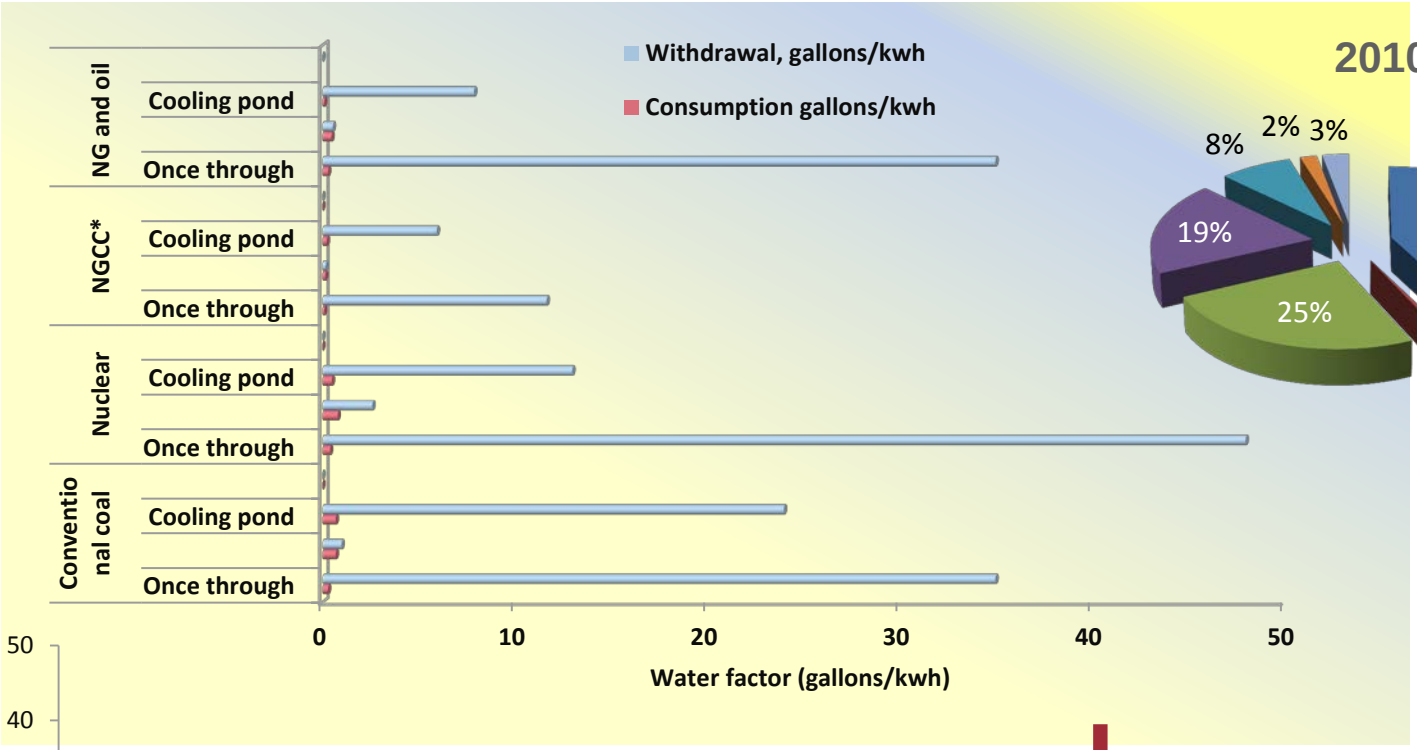
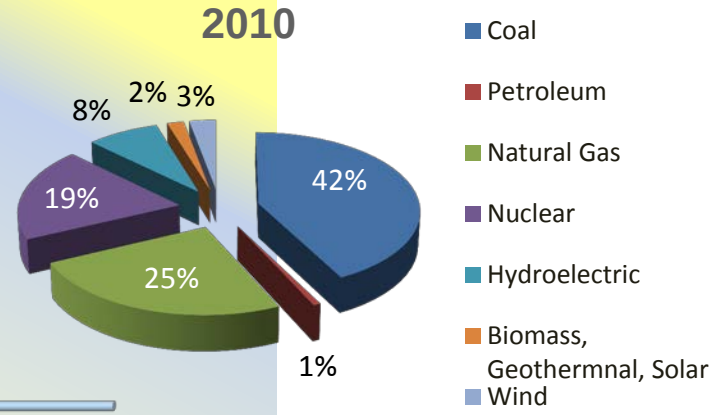
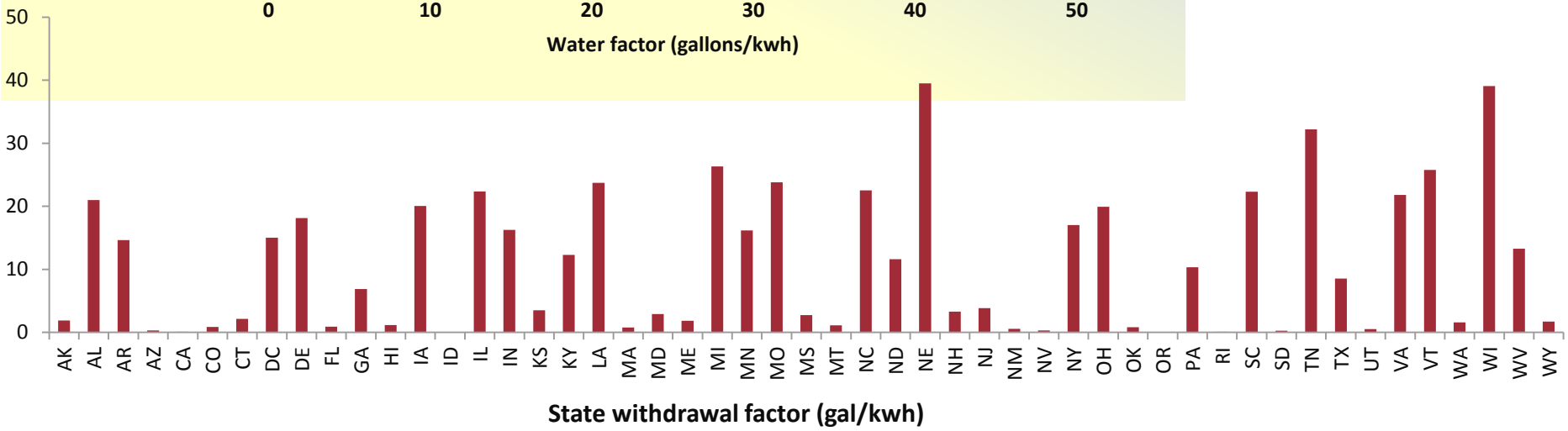
Water Intensity in Electricity Generation



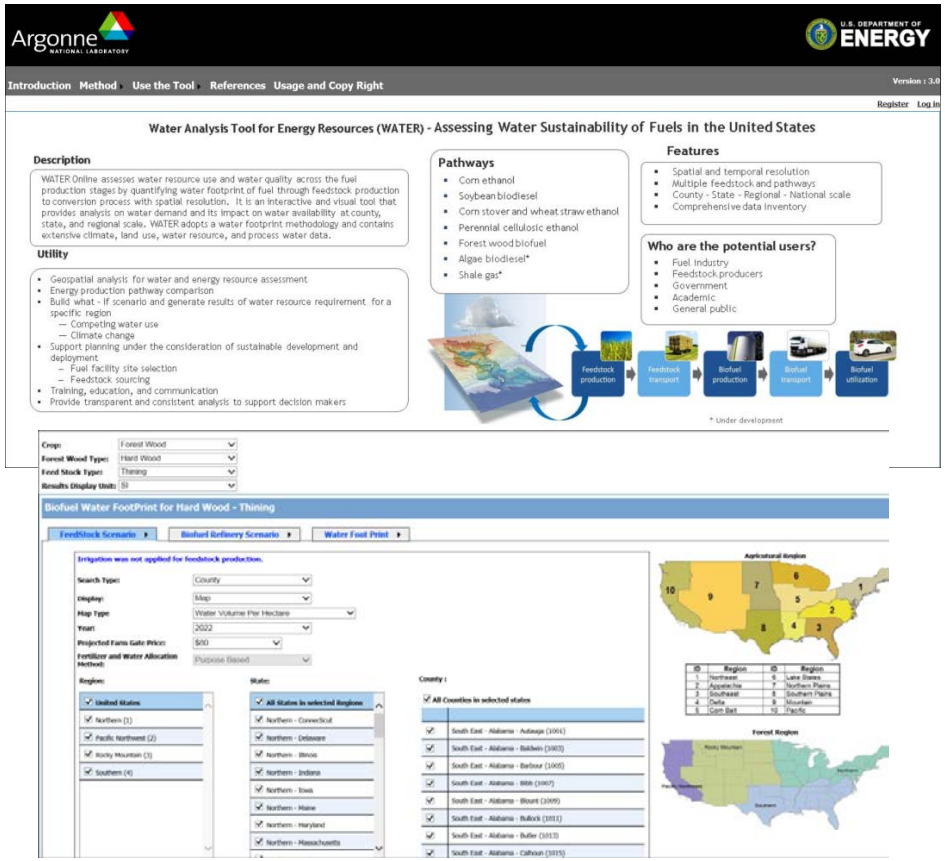




http://greet.es.anl.gov/publication-watertool

WATER (**W**ater **A**nalysis **T**ool for **E**nergy **R**esources)

http://WATER.es.anl.gov

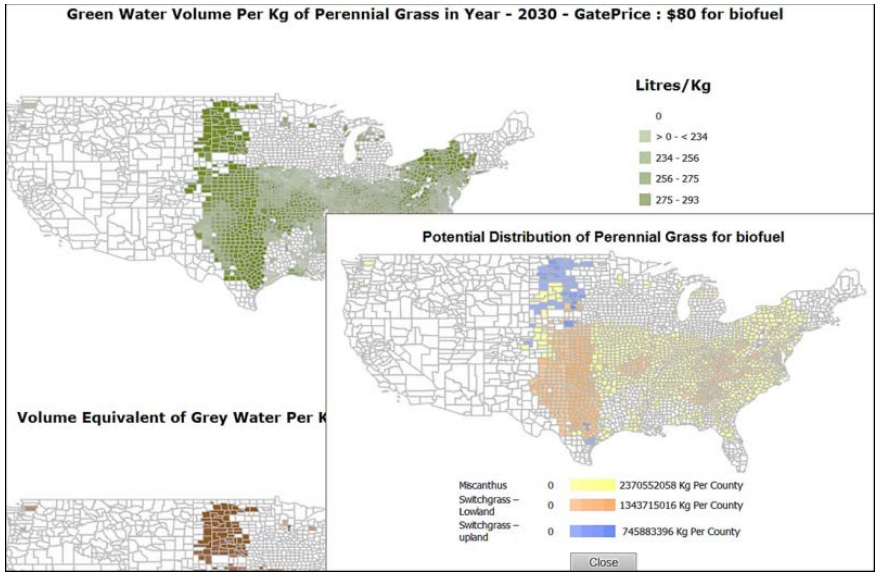


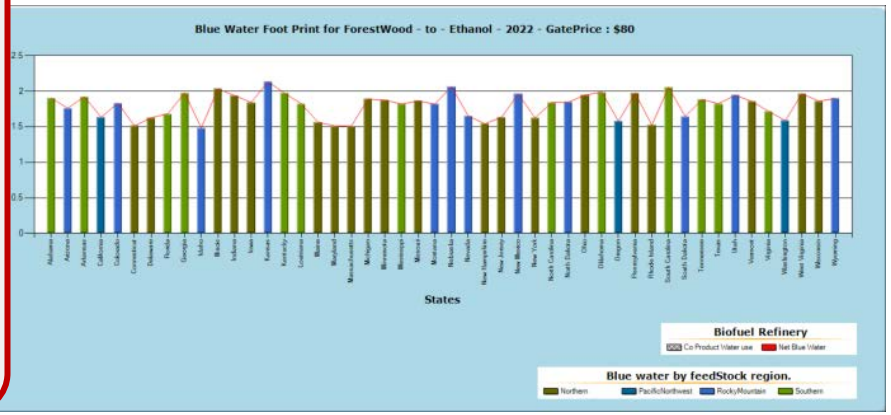
An on-line interactive visual tool for water use, water resource, and water quality assessment

- Launched May, 2013 (grain, beans, residue)
  - WATER V. 2.0 : May 2014 (grass, biochemical process)
  - WATER V. 3.0 : Jan. 2015 (forest resource, thermochemical processes)
- Multiple production pathways; feedstock production and conversion stages
- Selection of feedstock and biorefinery location at state level
- Metric: fuel product, feedstock, land use, blue, green, and grey water footprint

WATER Application

- Enables **compatible spatial resolution with POLYSYS and LEAF**, which allows for regional environmental sustainability assessment for a defined biofuel production scenario.
- Provides flexible structure for simulating multiple feedstock production in a region. Process plug-in available.
- Enables potential analysis of the interplay of impacts from multiple sectors on water use when used in conjunction with other models.
- Provide support to bioenergy industry, government, academia, and community for informed decision making.

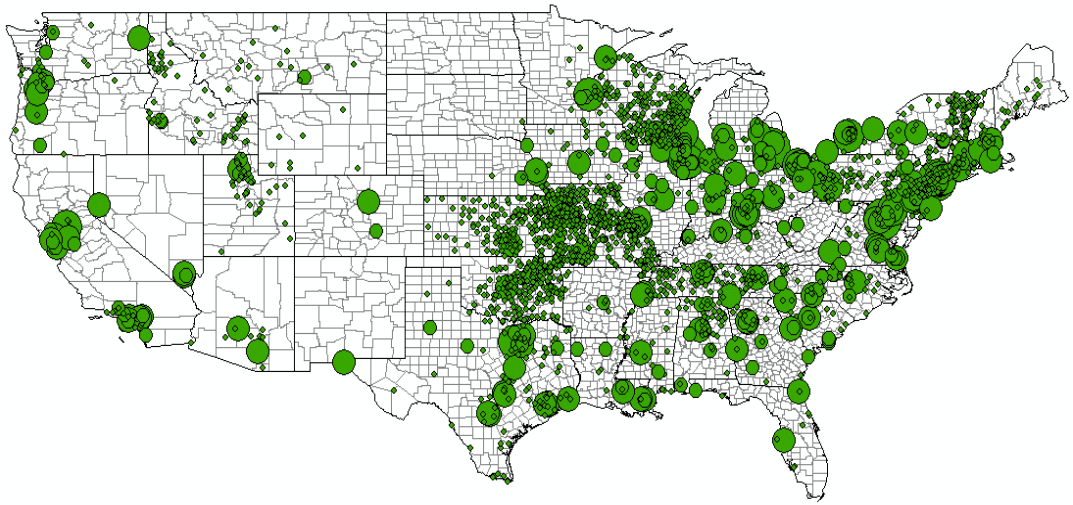




Presented at National Science and Technology Council's CENRS (Committee on Environment and Natural Resources), Subcommittee on Water Availability and Quality SWAQ meeting in Nov. 2014.

Reclaimed Water Reuse

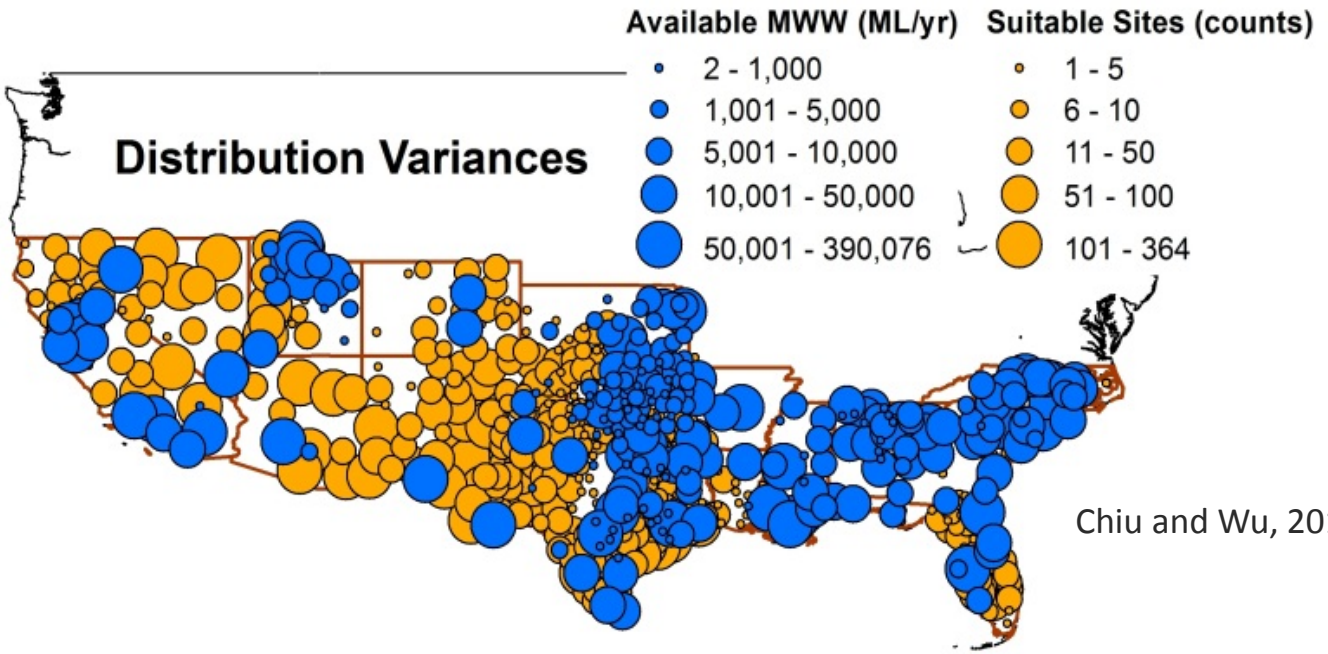
Current POTW Facilities in the U.S.



- POTWs treat a total of 38.9 trillion liters of wastewater annually in the U.S.
- Large facilities has a clustered distribution.
- High density small facilities in Minnesota, Missouri, Kansas, Oklahoma, Pennsylvania, and New England states.
- Significant amount of reclaimed water were used for cooling in thermoelectric facilities in U.S.
- Extensive use of reclaimed water in the Western of U.S. and FL.

Manuscript is in preparation

Reclaimed Water Use in the Production of Algae-based Biofuel

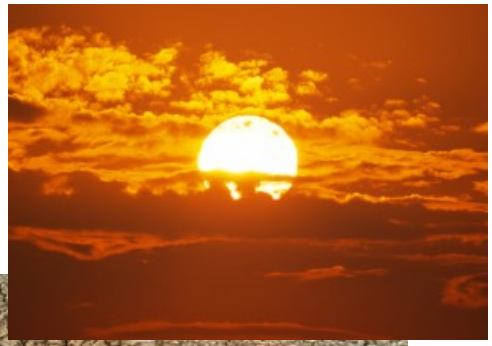


Chiu and Wu, 2013, BioFPR

- Explore wastewater effluent use in open-pond algae cultivation in southern 17 states in U.S.
- Geographic mismatch between the alternative water source (MMTW effluent) and potential refinery location; algae pond may not be able to located near urban area because land footprint constraint
- Process wastewater /grey water footprint from biorefineries are under investigating.

Future Applications

- Argonne's WATER modeling
  - Can be configured to various scales in other regions in the world (climate, land)
  - Can include different types of crops and production process
  - Can incorporate other water related parameters (cost, alternative water)
- Address FEW nexus by examining interplay between agricultural sector and energy sector from water perspective
- Quantify impacts on agriculture/energy availability by
  - Climate change
  - Water resource quality and quantity
  - Technology advancement
  - Policy
  - Population



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NREL, PNNL, ORNL, INL
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Univ. of Alberta

EERE, Bioenergy Technologies Office

EERE, VTO, Clean Cities Program

To learn more about water research at Argonne, please visit
http://www.anl.gov/energy-systems/group/water-quality-resources-and-technology
http://water.es.anl.gov/

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