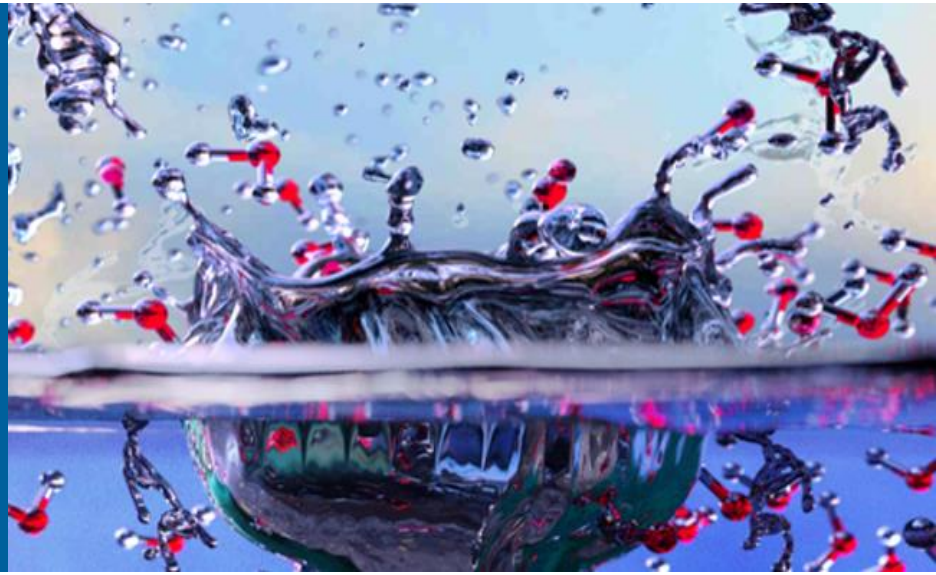
13TH CONCAWE SYMPOSIUM

Argonne NATIONAL LABORATORY

WATER SUSTAINABILITY OF RENEWABLE FUELS



MAY M. WU

Argonne National Laboratory

Radisson Blu Astrid Hotel
Antwerp Belgium

March 18-19, 2019

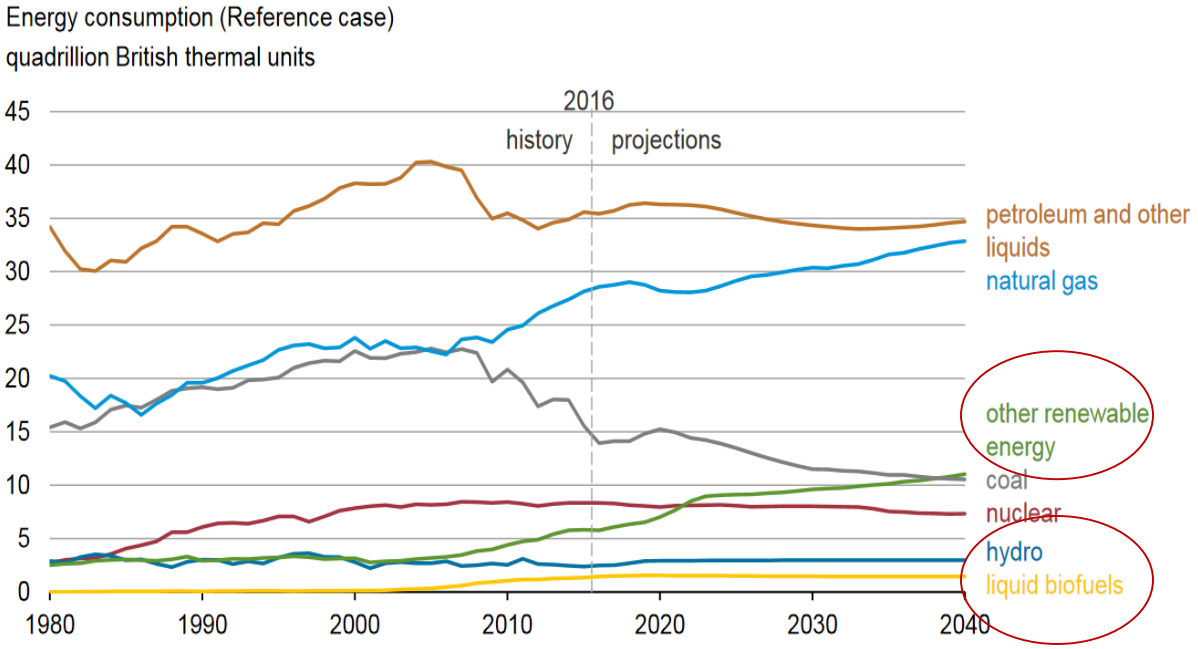
Attributes of Water Resources in Energy Production

- Water and energy are intertwined. Energy production requires water and water production and delivery requires energy.
- Competing demand for water and land in the production of electricity, fuels, bioenergy, food, and in urban development.
- A growing population demands increased supply of food, energy, and water.
- According to the forecast, the world may experience increased flood and draught in various regions currently producing food, feed, and biofuel feedstock.
- Decrease in water availability could disrupt their production, and its ripple effect can be felt across various regions in multiple sectors.
- 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.

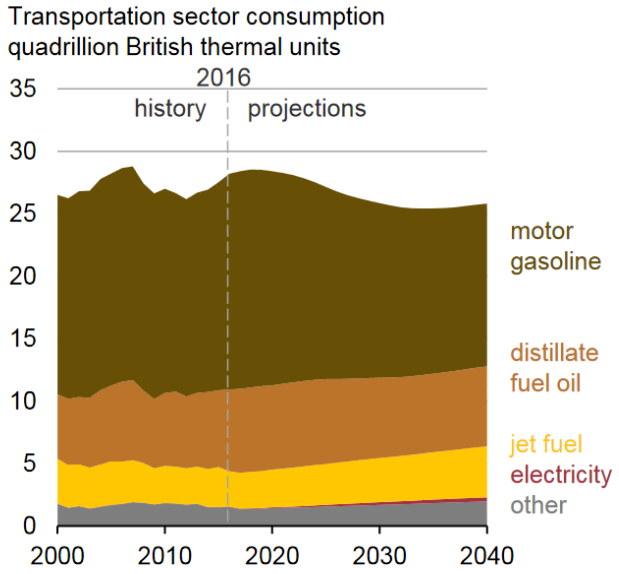
Impact of Renewable Fuel on Water Demand

- Water consumption in the production of renewable fuels
  - Solar
  - Wind
  - Hydro
  - Geothermal
  - Municipal waste
  - Biofuel
- Biofuel blend requirement
  - U.S.: Renewable Fuel Standard
    - More than 10% of total supply by 2017
    - Corn starch dominant, soy bean oil small fraction, cellulosic initial phase
  - E.U.: RED II
    - Oil seeds dominant, potential forest wood residue, ag. Residue, others

Renewable Energy Consumption Overview



Source: EIA, Annual Energy Outlook 2017

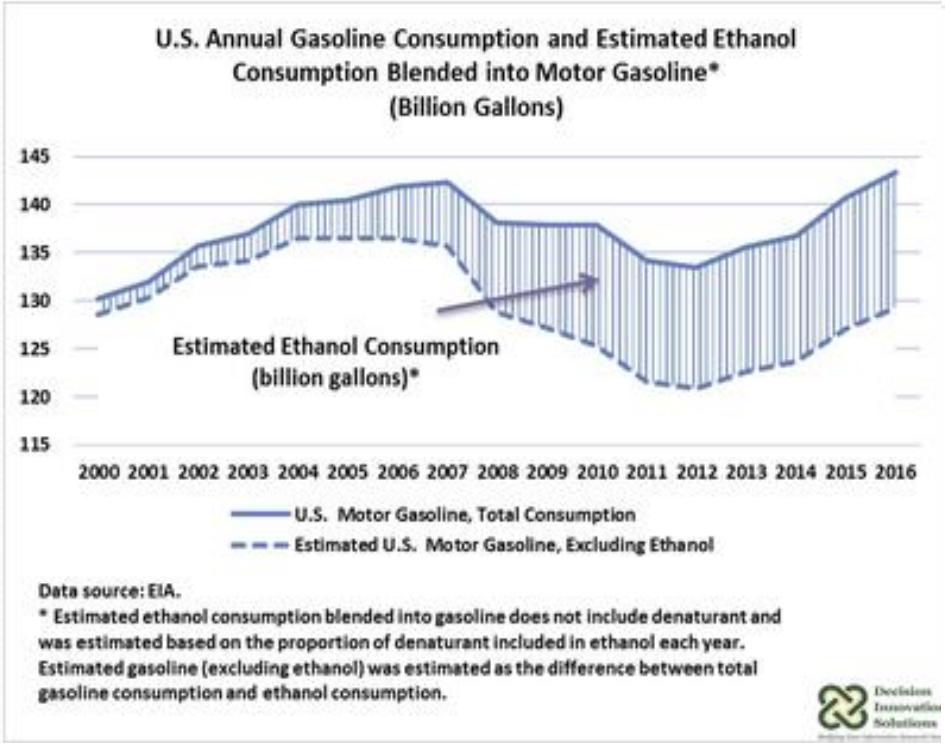


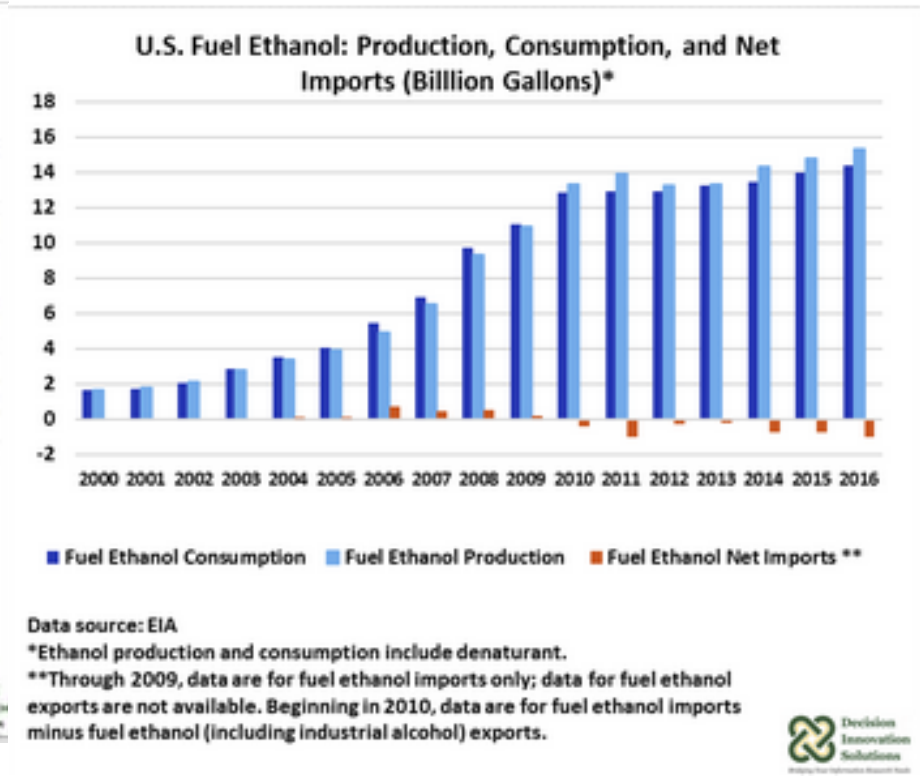
Source: EIA, Annual Energy Outlook 2017

- Industrial sector energy consumption is led by increases in petroleum and natural gas consumption.
- Replacement of crude oil by natural gas liquids and liquid biofuels.
- Energy consumption decreases for most major end uses in the residential and commercial sectors.

Motor Gasoline Consumption and Biofuel Blending

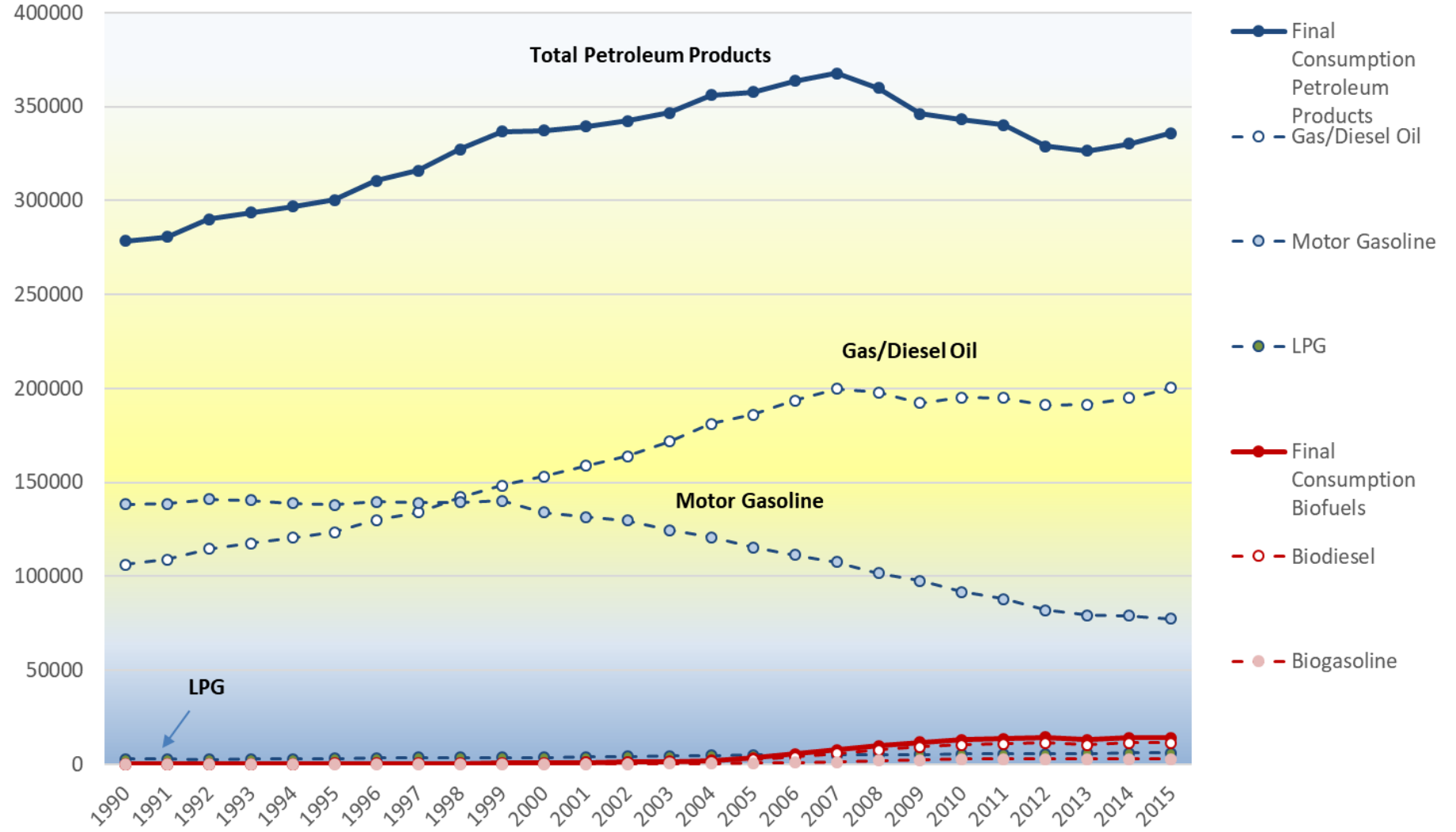
- United States consumed 9.3 million barrels of gasoline per day, 3.4 billion barrels in 2016.
  - Up to 10% of ethanol blended into motor gasoline
  - In 2016, biofuel production reached 15 billion gallons; consumption = 14 billion gallons (0.33 billion barrels)



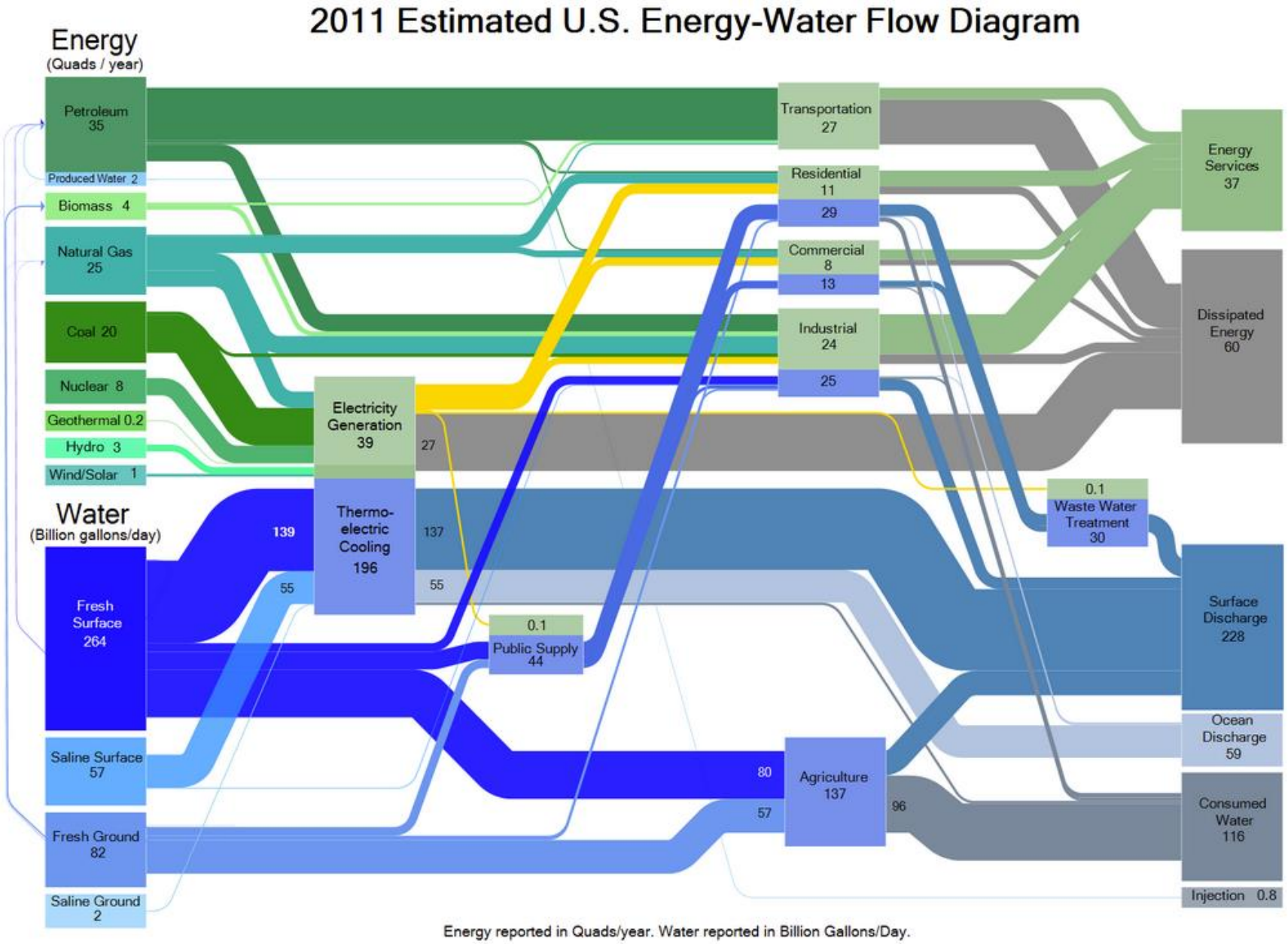


Source: Decision Innovation Solutions, http://www.decision-innovation.com/

EU Transportation Sector



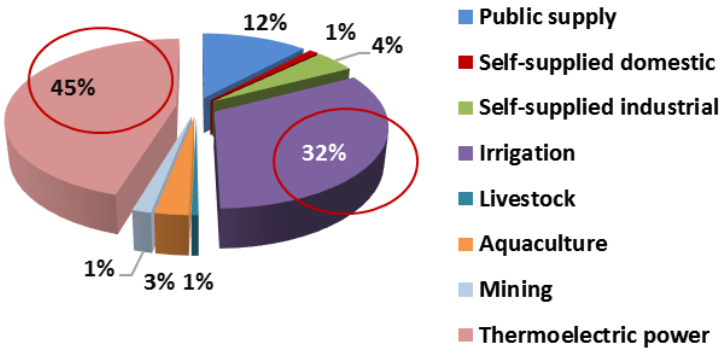
Source: Eu Energy in Figures: Statistical Pocketbook, 2017. ISBN 978-92-79-70449-9 ISSN 2363-247X, doi:10.2833/80717 MJ-AB-17-001-EN-N



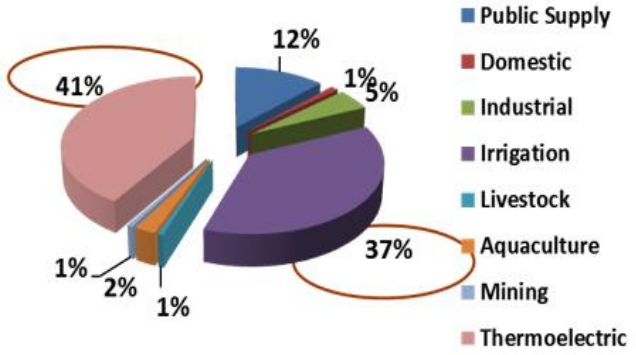
Source: The Water-Energy Nexus: Challenges and Opportunities, DOE, June 2014. https://www.energy.gov/downloads/water-energy-nexus-challenges-and-opportunities.

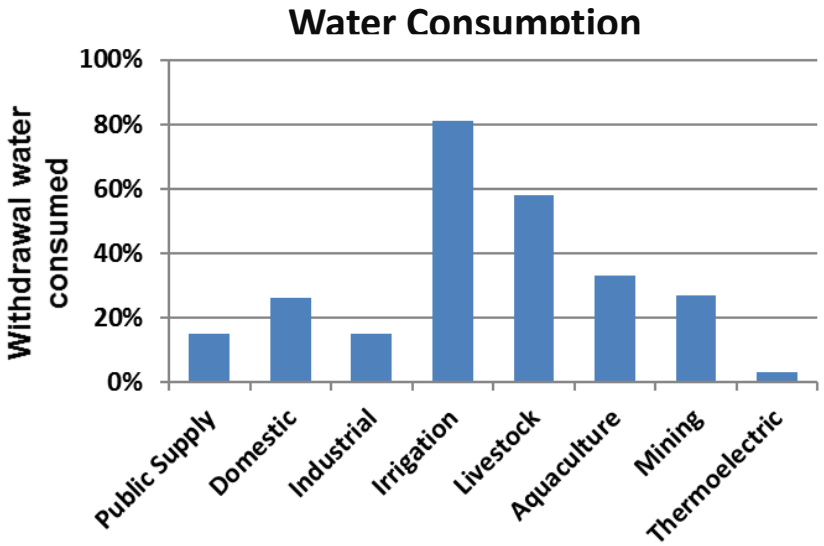
Water Resource Use: Major Players

2010 Withdrawals (Million gal. per day)



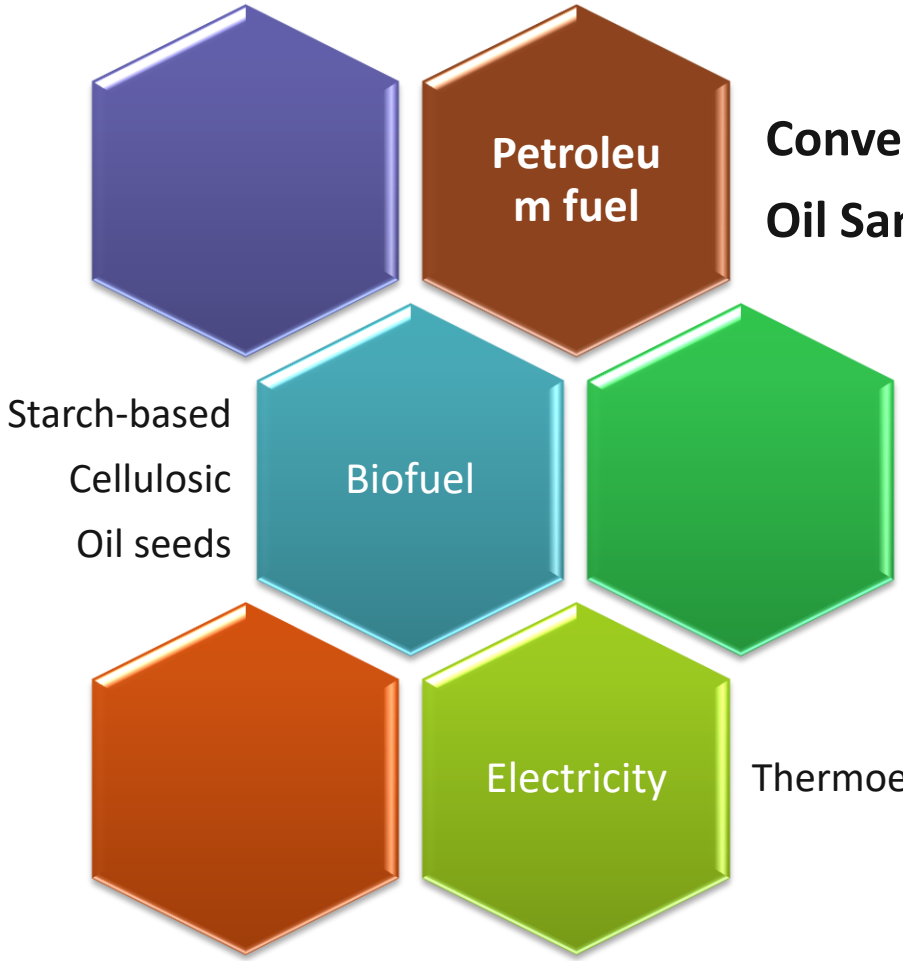
2005 Withdrawals (Million gal. per day)



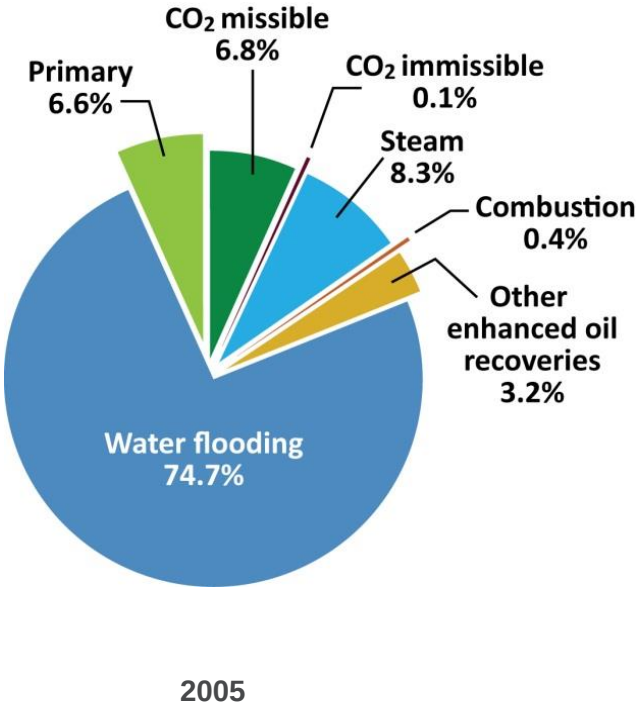


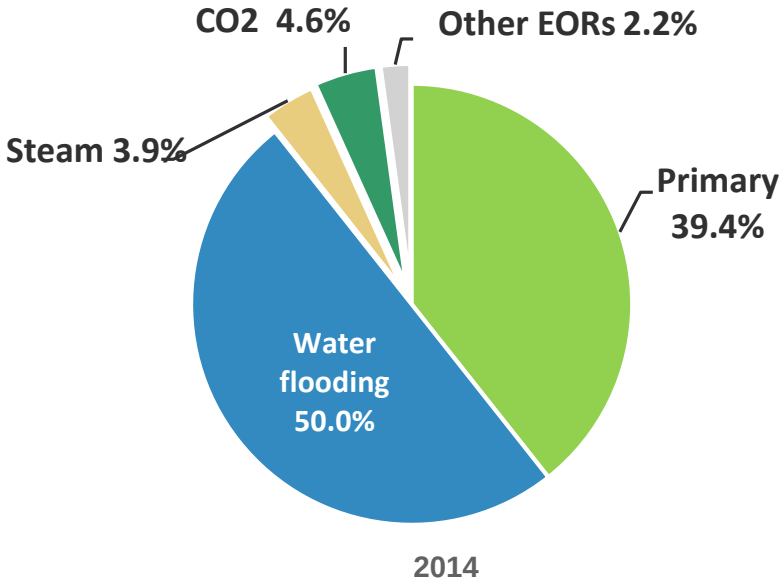
Sources:
- USGS
- http://greet.es.anl.gov/publication-watertool

Water Use in Energy and Fuel Production



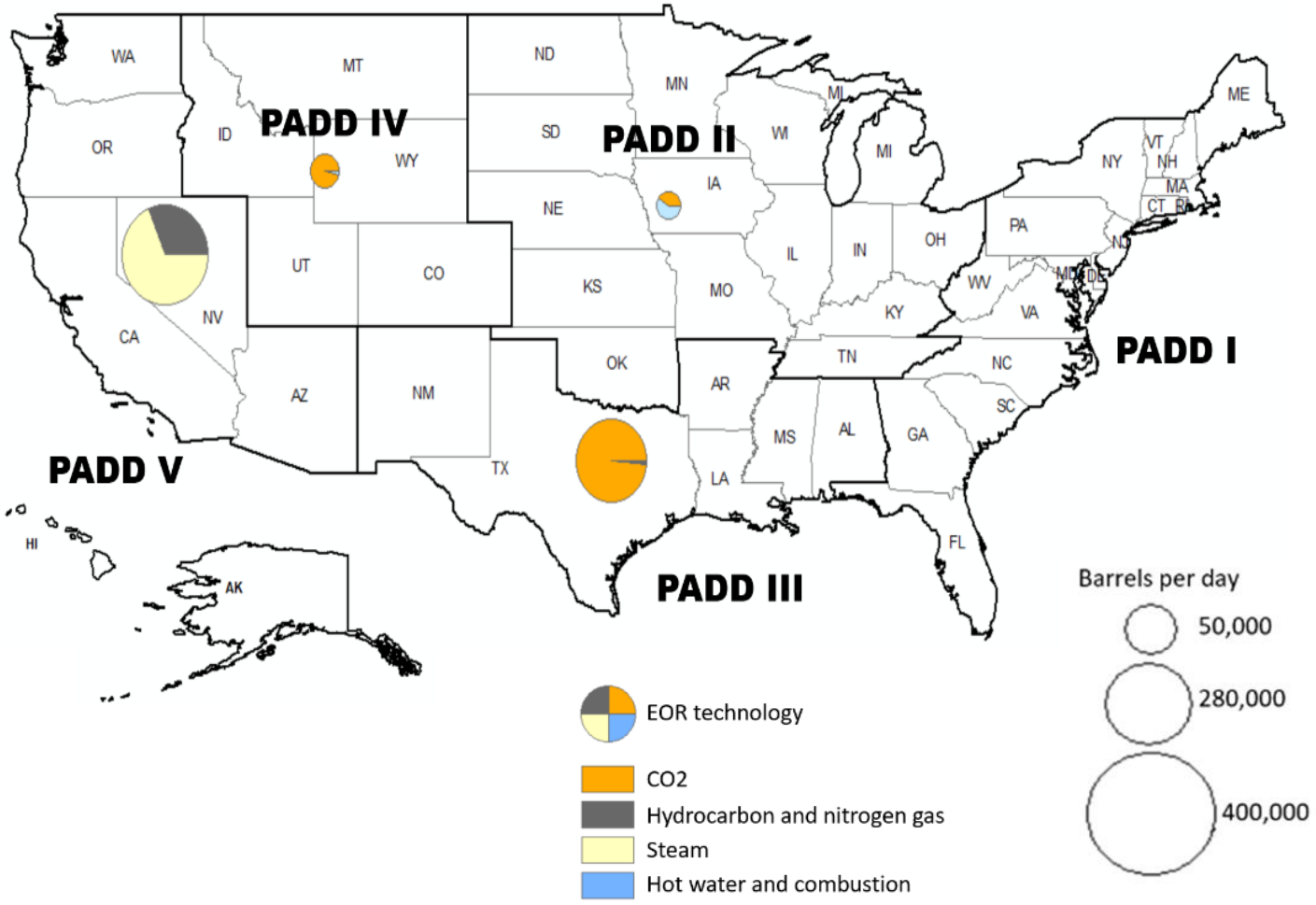
Production Technology





Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

EOR Technology Regional Distributions



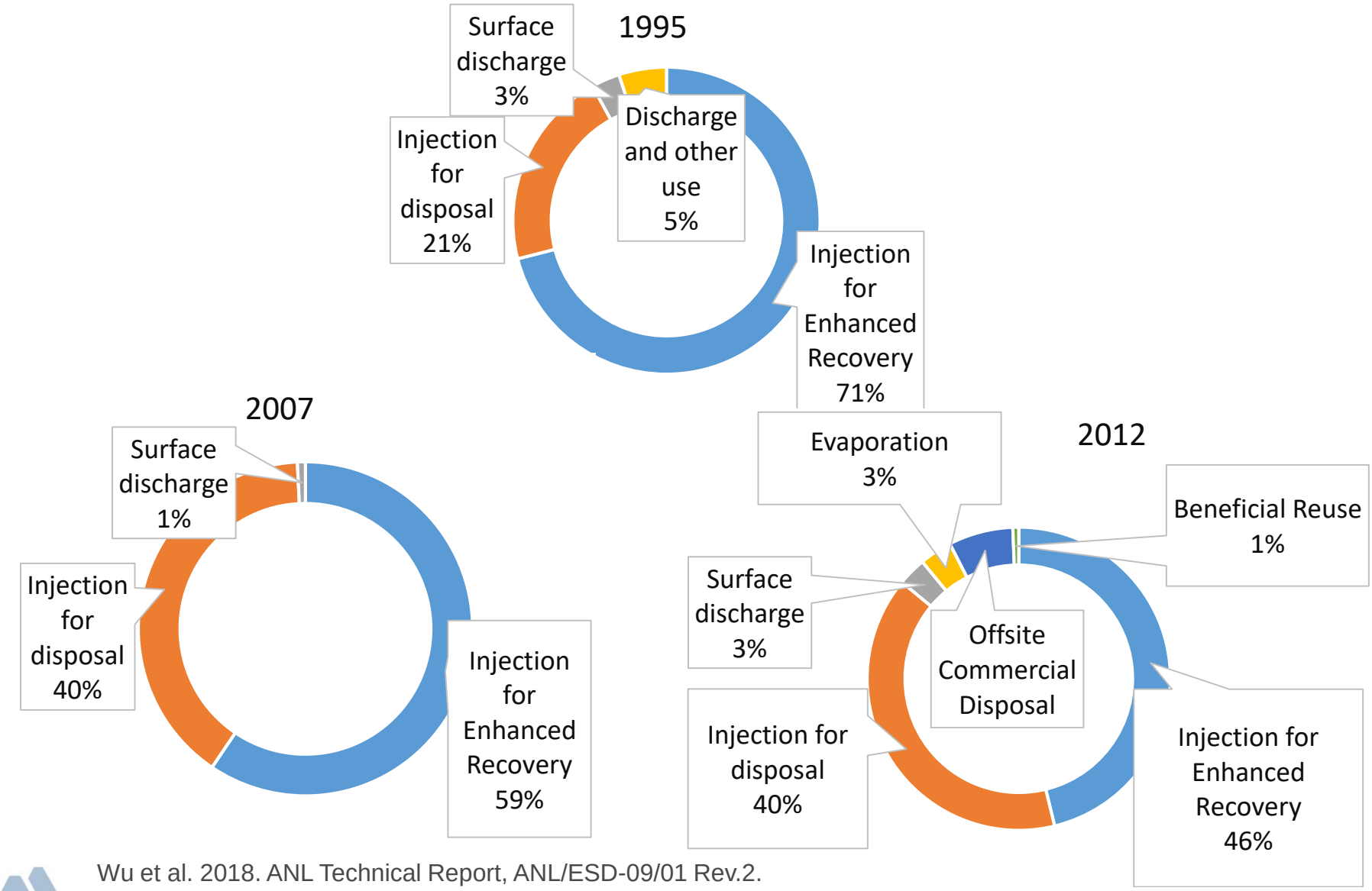
Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

Water Intensity Varies Significantly with Technologies

Recovery Technology	Water intensity (gal/gal)
E&P, Drilling	0.005
Primary	0.21
Water flooding[4]	15.69
Steam	4.90
Combustion	1.93
Hot water[1]	4.55
Hydrocarbon miscible/immiscible [1]	4.55
CO_2 miscible/immiscible	4.26
Nitrogen[1]	4.55

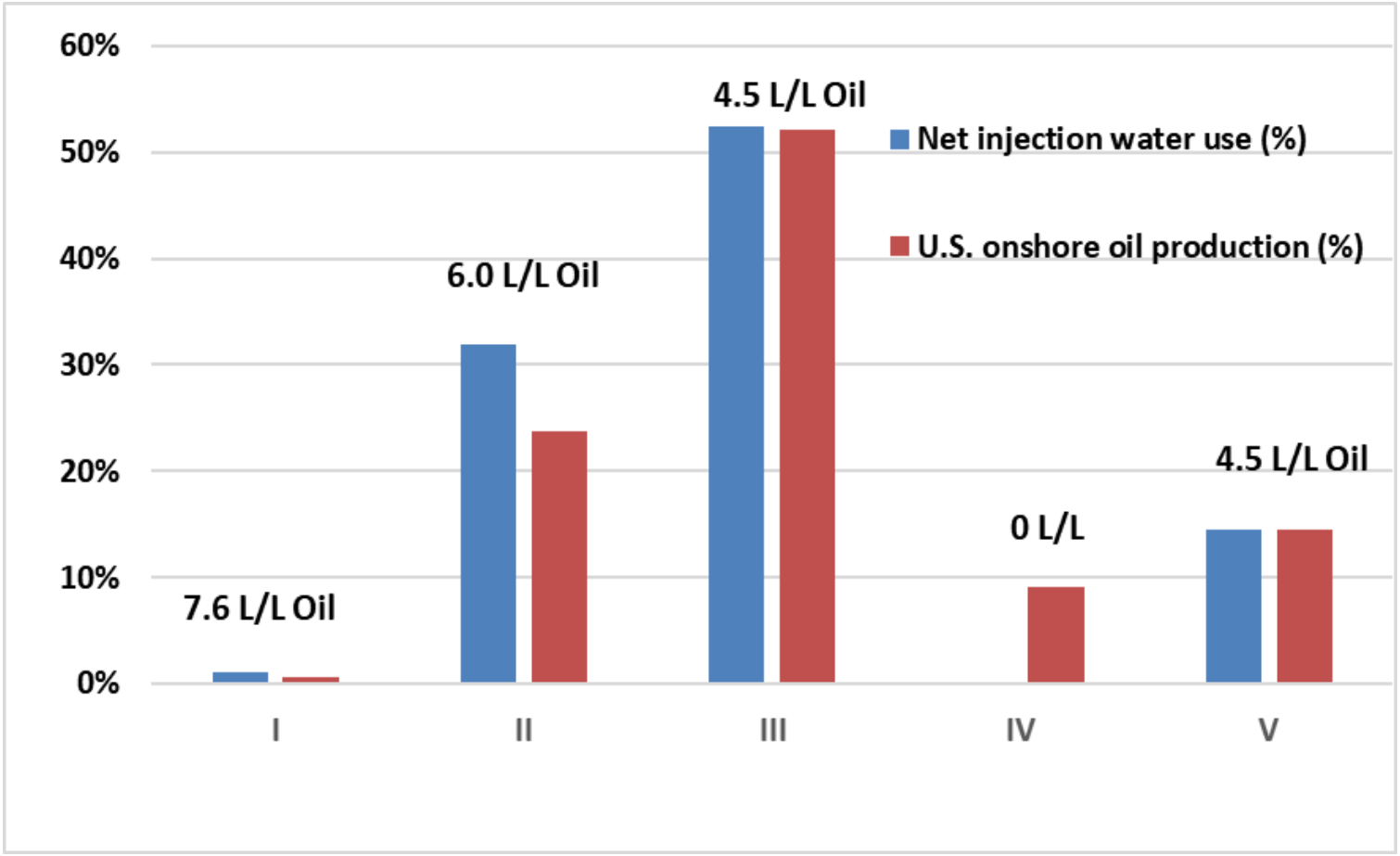
Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

Fate of Produced Water from Oil Recovery



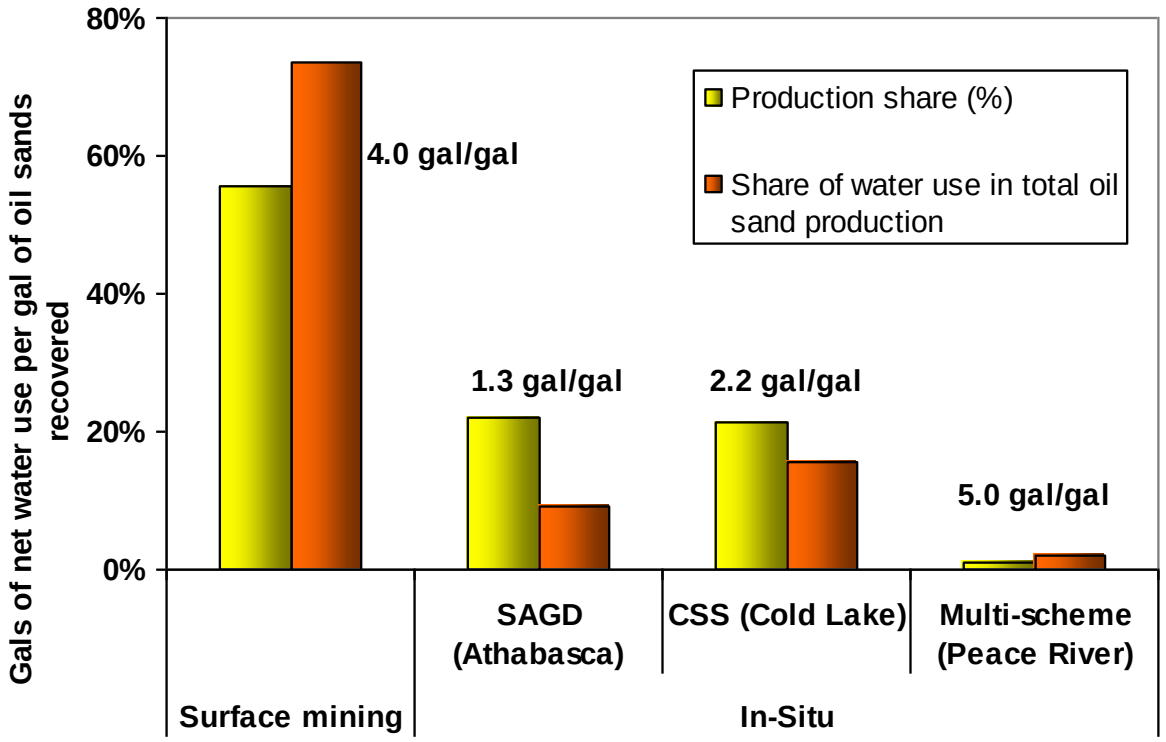
Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

Onshore Oil Production and Water Consumption for U.S. On-Shore Oil-Producing Regions



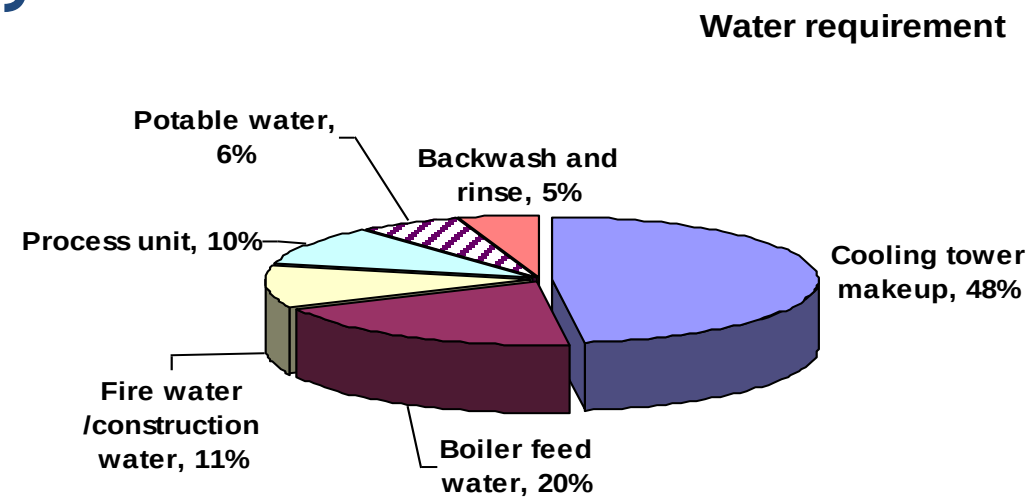
Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

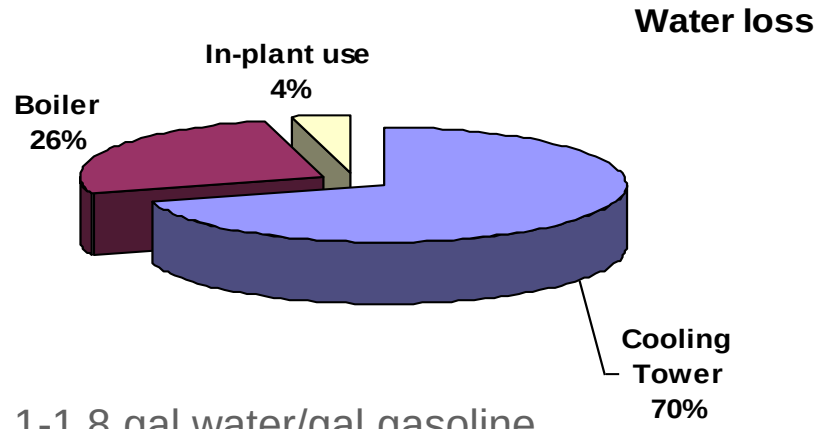
Water Use in the Production of Oil from Canadian Oil Sands



Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

Oil Refinery Water Use

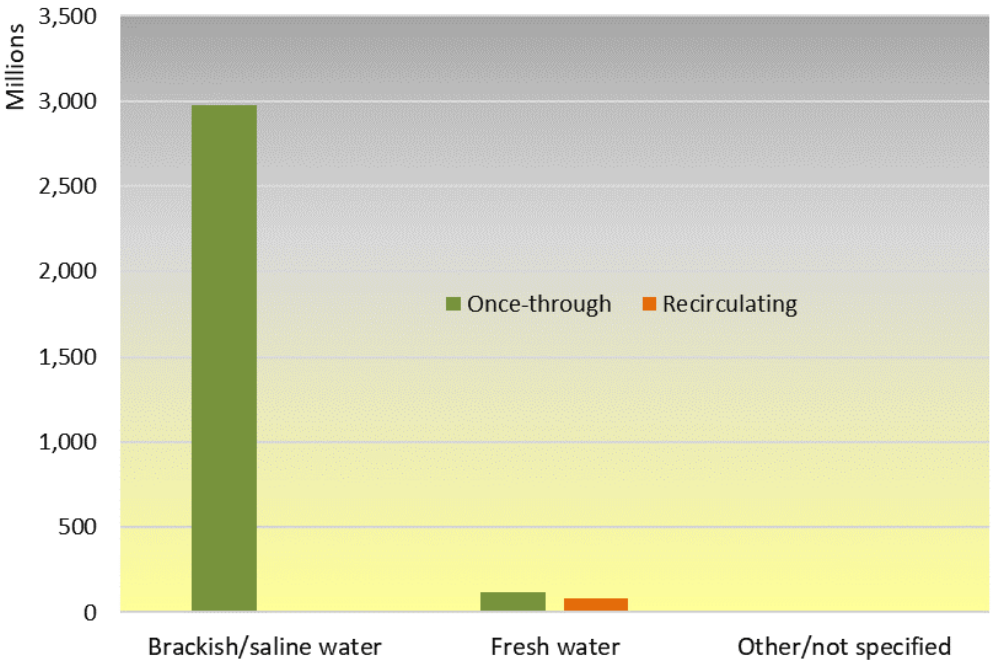


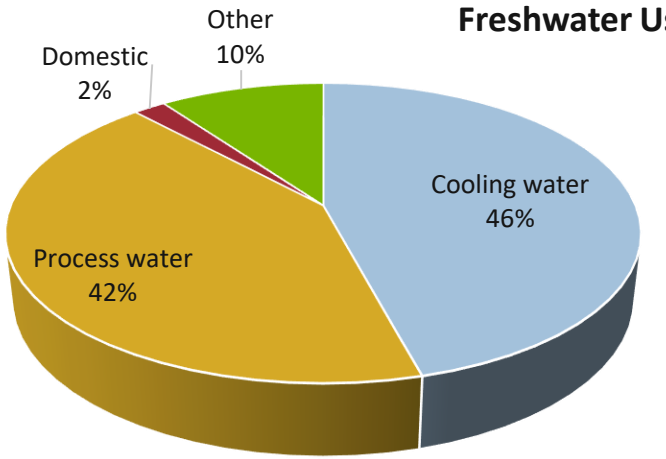


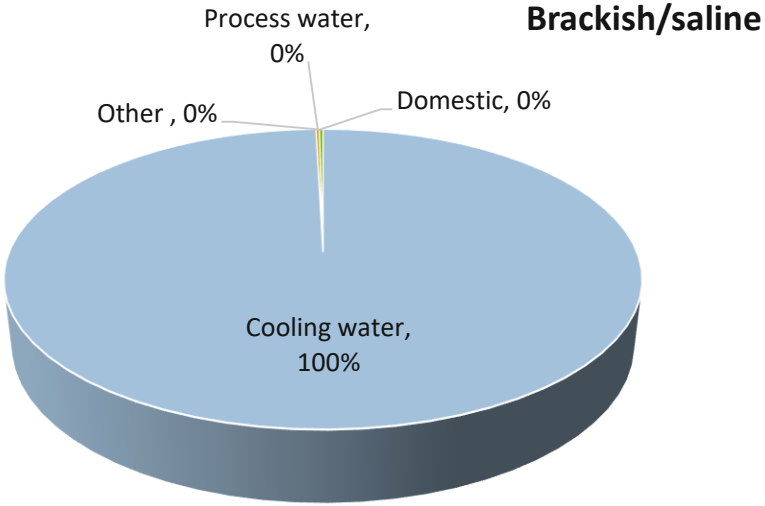
Freshwater consumption: 1-1.8 gal water/gal gasoline

Wu et al. 2009. ANL Technical Report, ANL/ESD-09/01.

EU Oil Refinery Water Use



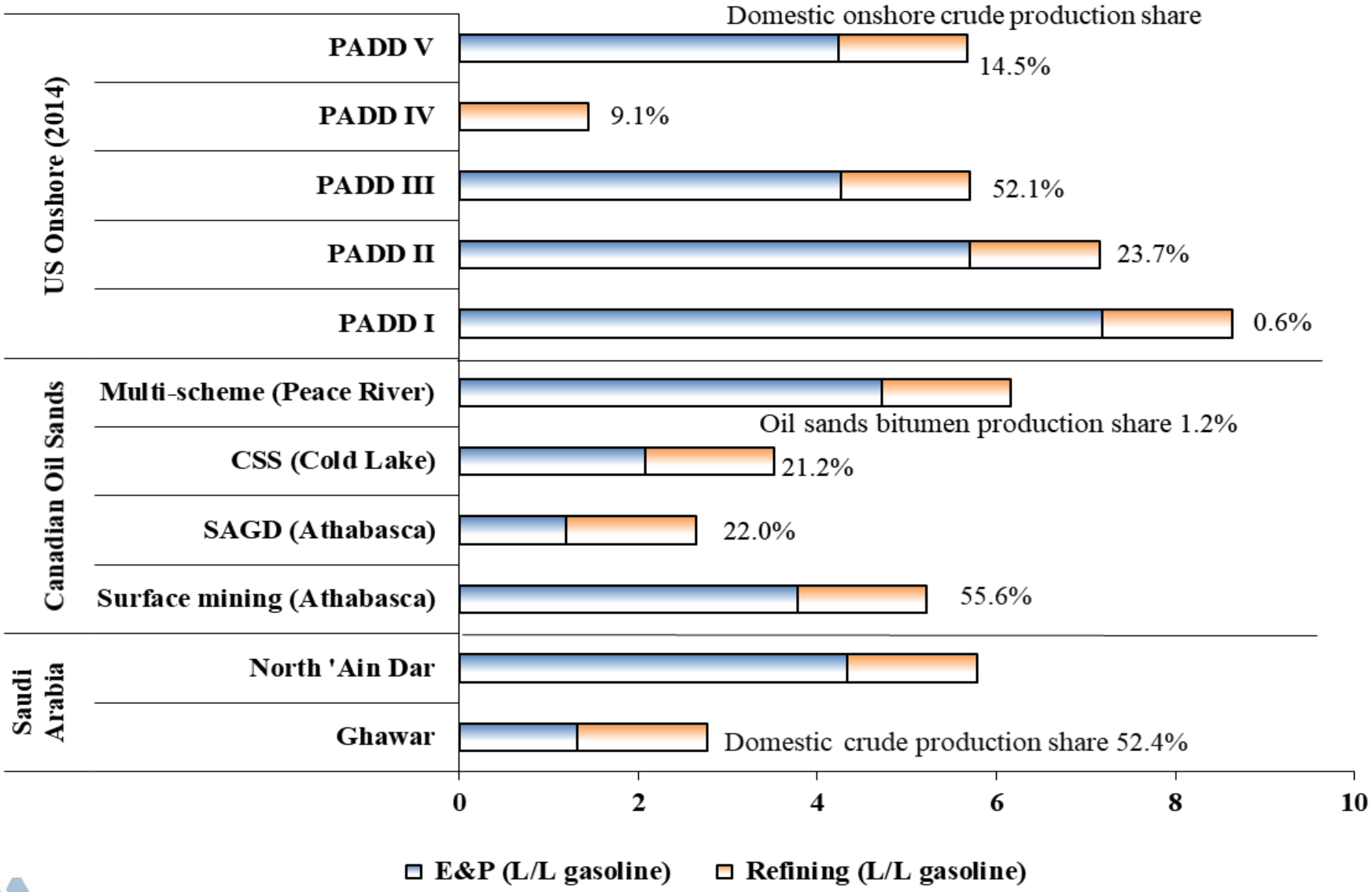




Freshwater consumption: ~180 – 780 m^3/kTonne

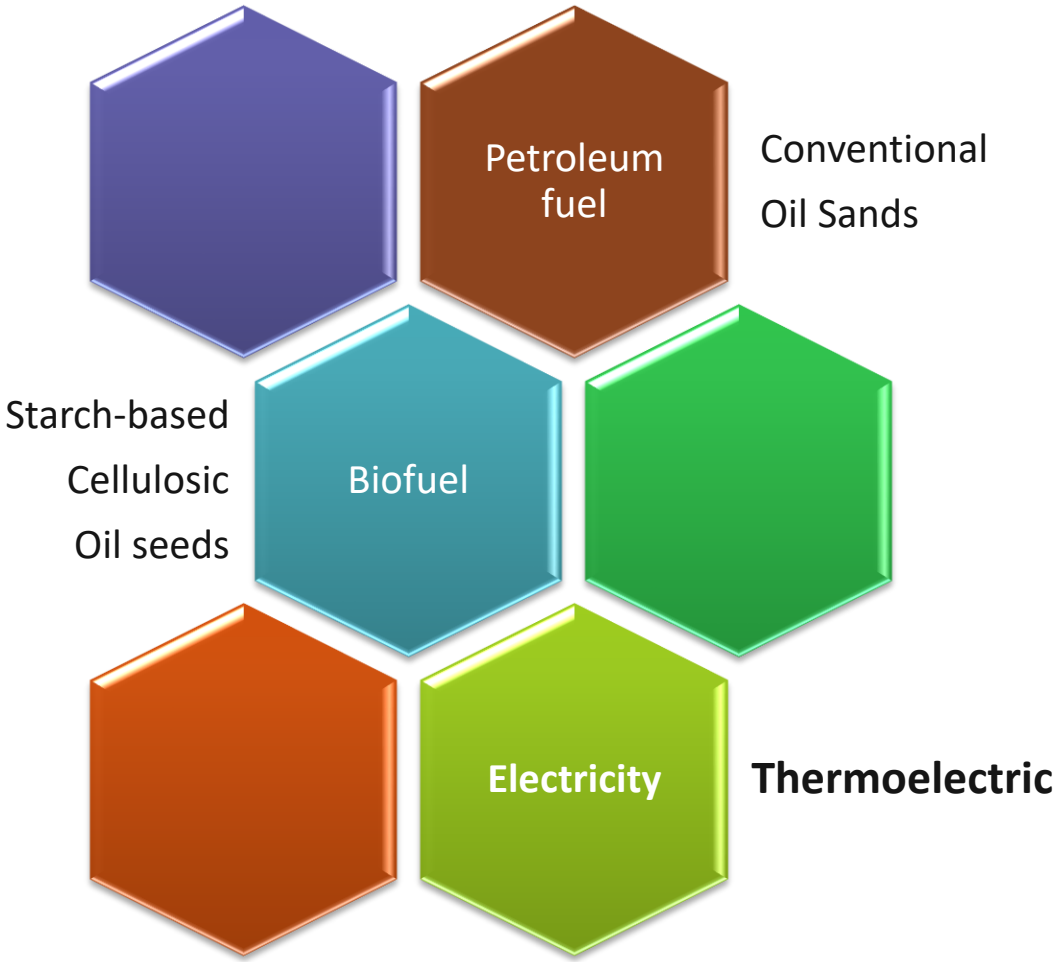
Source: Concawe, 2013 survey of effluent quality and water use at European refineries, report number 12/18, www.concawe.eu.

Water Use for Petroleum Oil Production

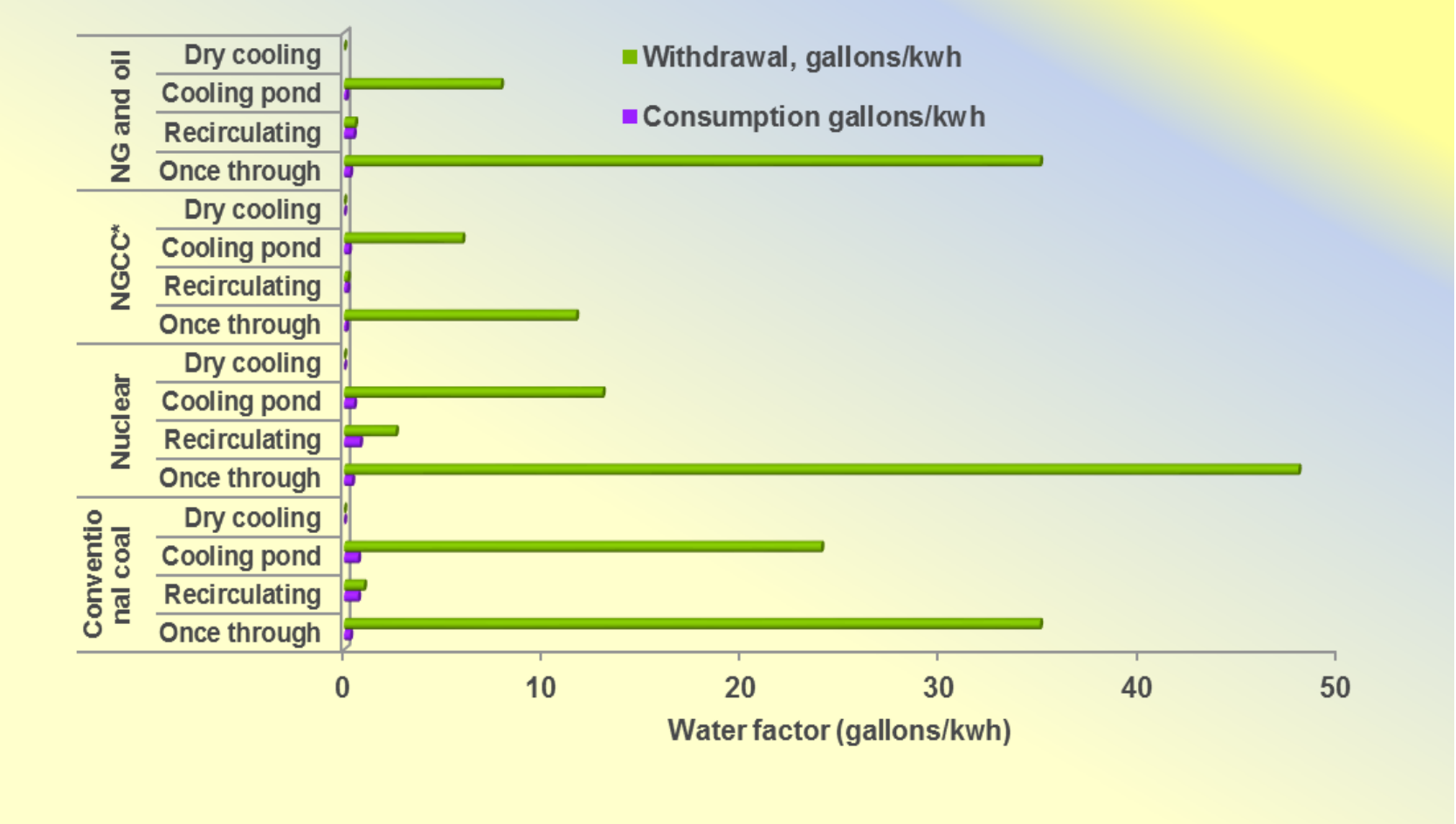


Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

Water Use in Energy and Fuel Production



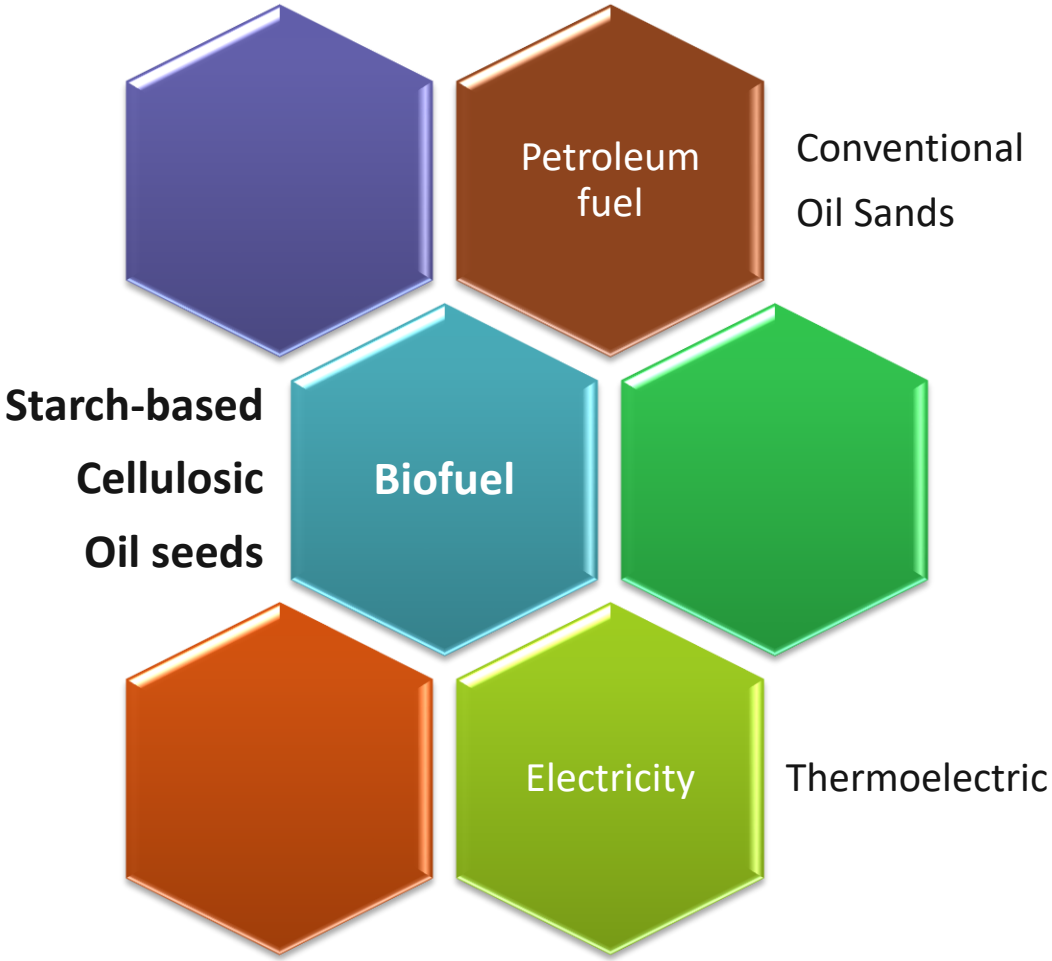
Water Intensity in Thermoelectric Power Generation

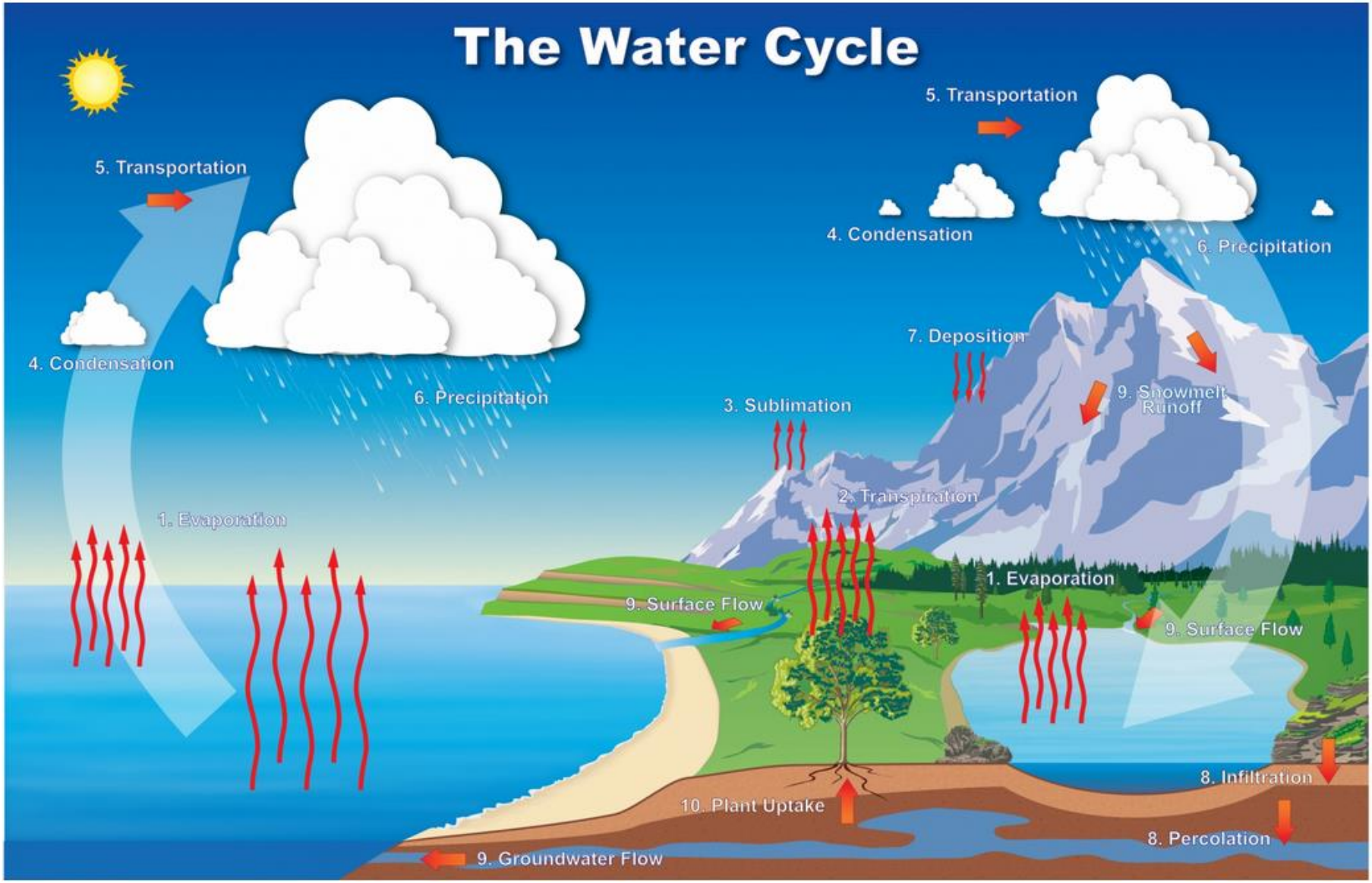


Source:

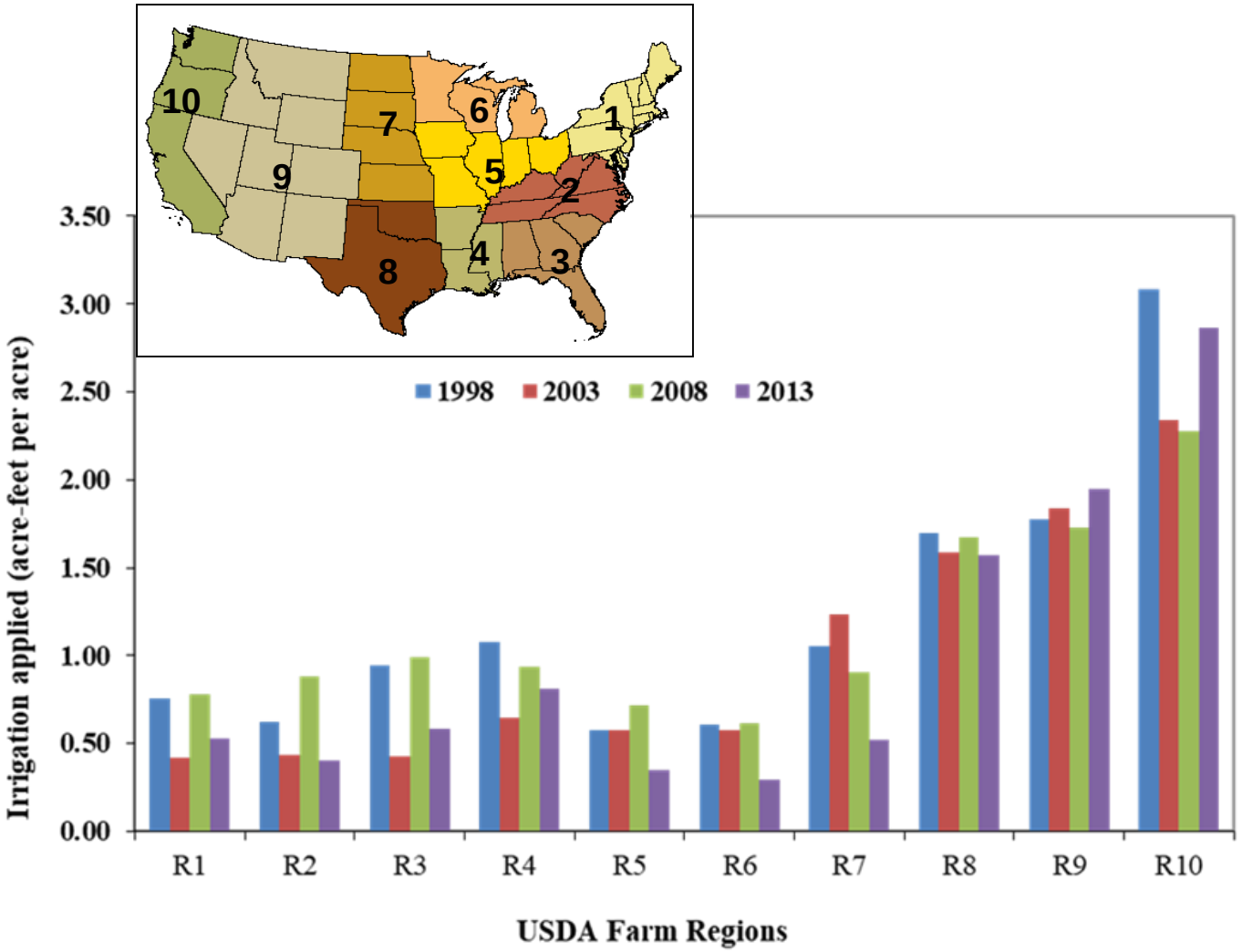
- http://greet.es.anl.gov/publication-watertool

Water Use in Energy and Fuel Production



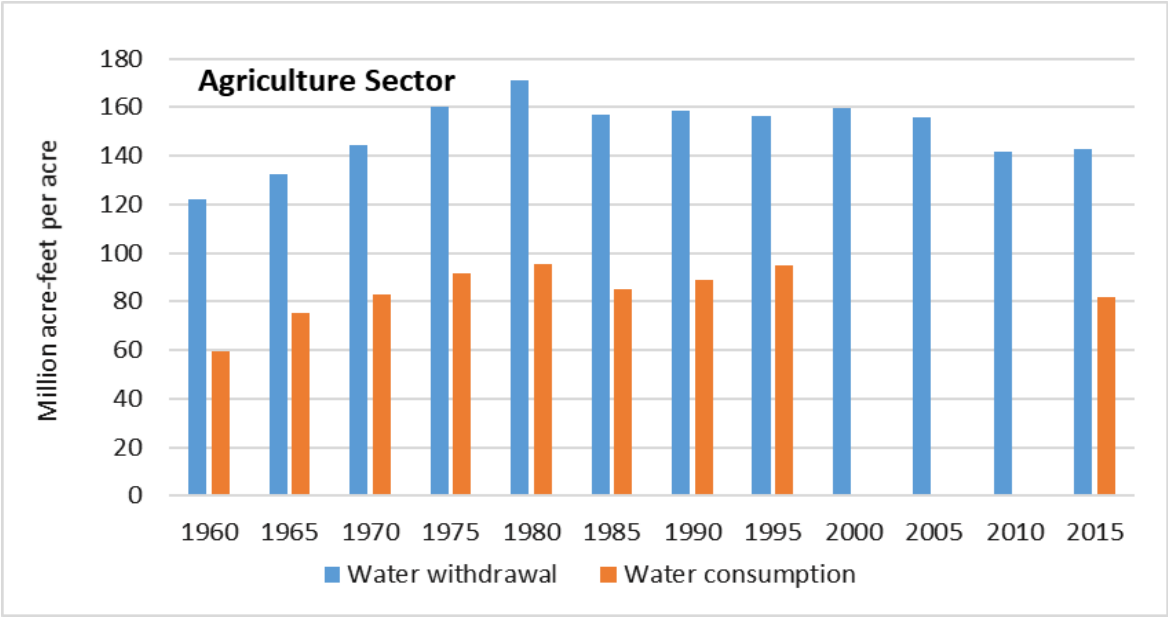

The Water Cycle
5. Transportation
4. Condensation
6. Precipitation
1. Evaporation
5. Transportation
4. Condensation
6. Precipitation
7. Deposition
3. Sublimation
9. Snowmelt Runoff
2. Transpiration
1. Evaporation
9. Surface Flow
9. Surface Flow
8. Infiltration
10. Plant Uptake
8. Percolation
9. Groundwater Flow

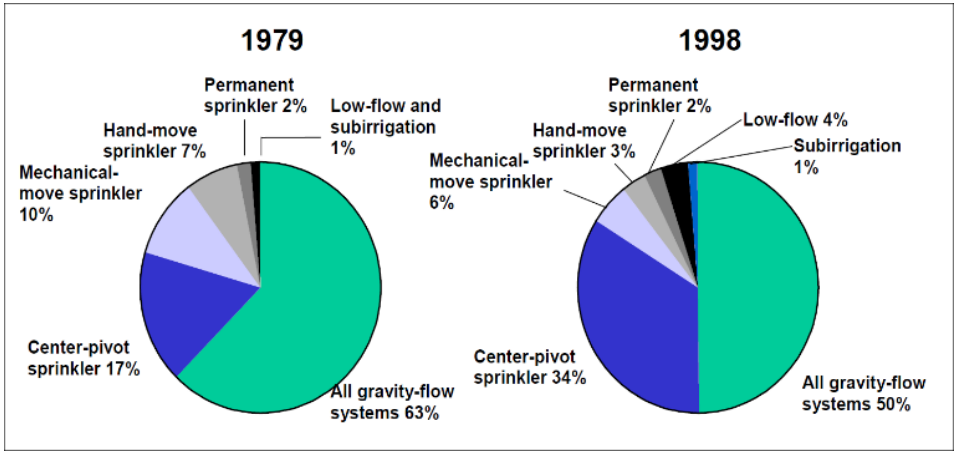
A Majority of Biofuel Water Use is Irrigation



Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

Trend of Historical Irrigation Water Use



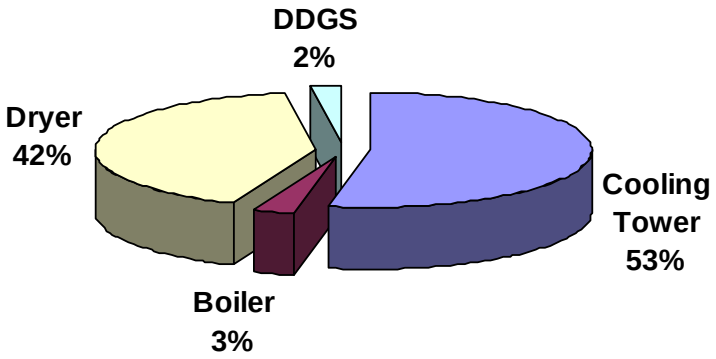


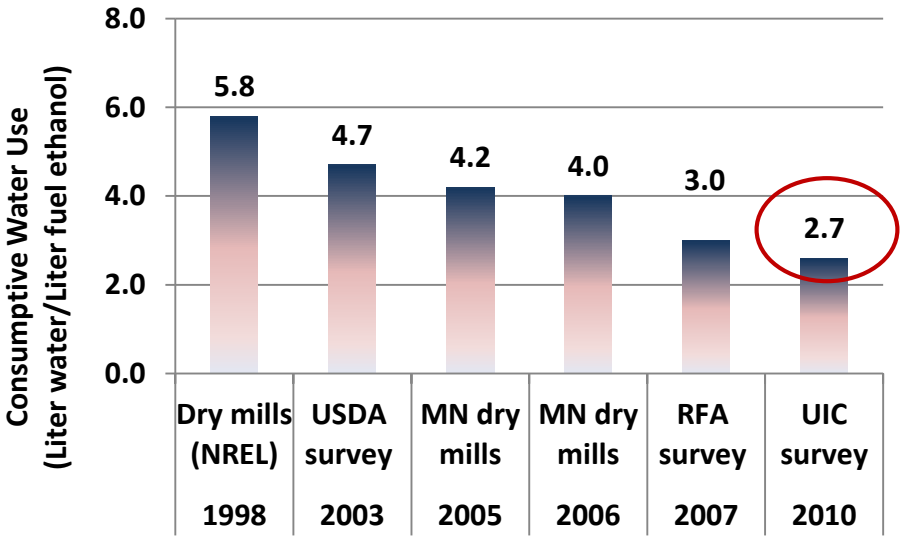
Irrigation Technology Improvement

Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

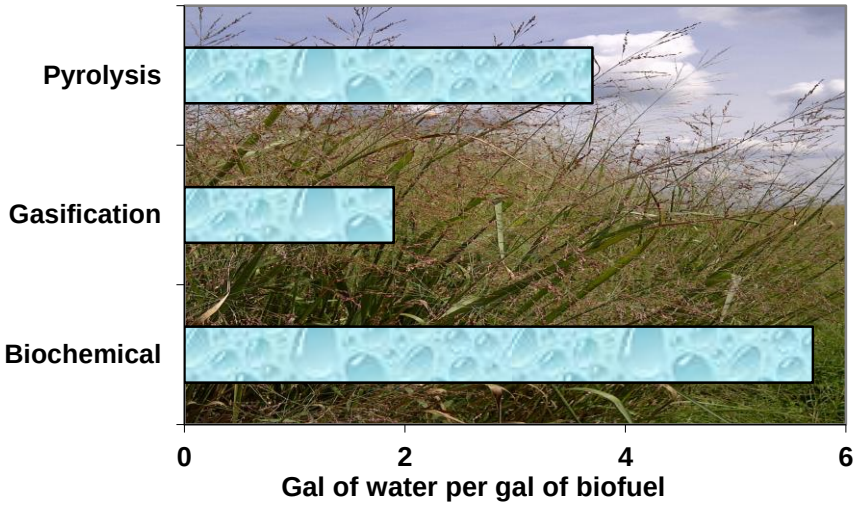
Biofuel Plant Water Use

Conventional biofuel - Corn dry mill





Cellulosic biofuel - Biorefinery



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

Factors Affecting Water Footprint of A Fuel Mix

- Biofuel
  - Type of feedstock
  - Where it was grown
  - Conversion technology
  - Feedstock mix of the biofuel
- Petroleum Fuel
  - Energy feedstock type and region
  - Production technology
  - Produced water management
  - Refinery technologies

Water Consumption in Production of Biofuel and Petroleum Fuels

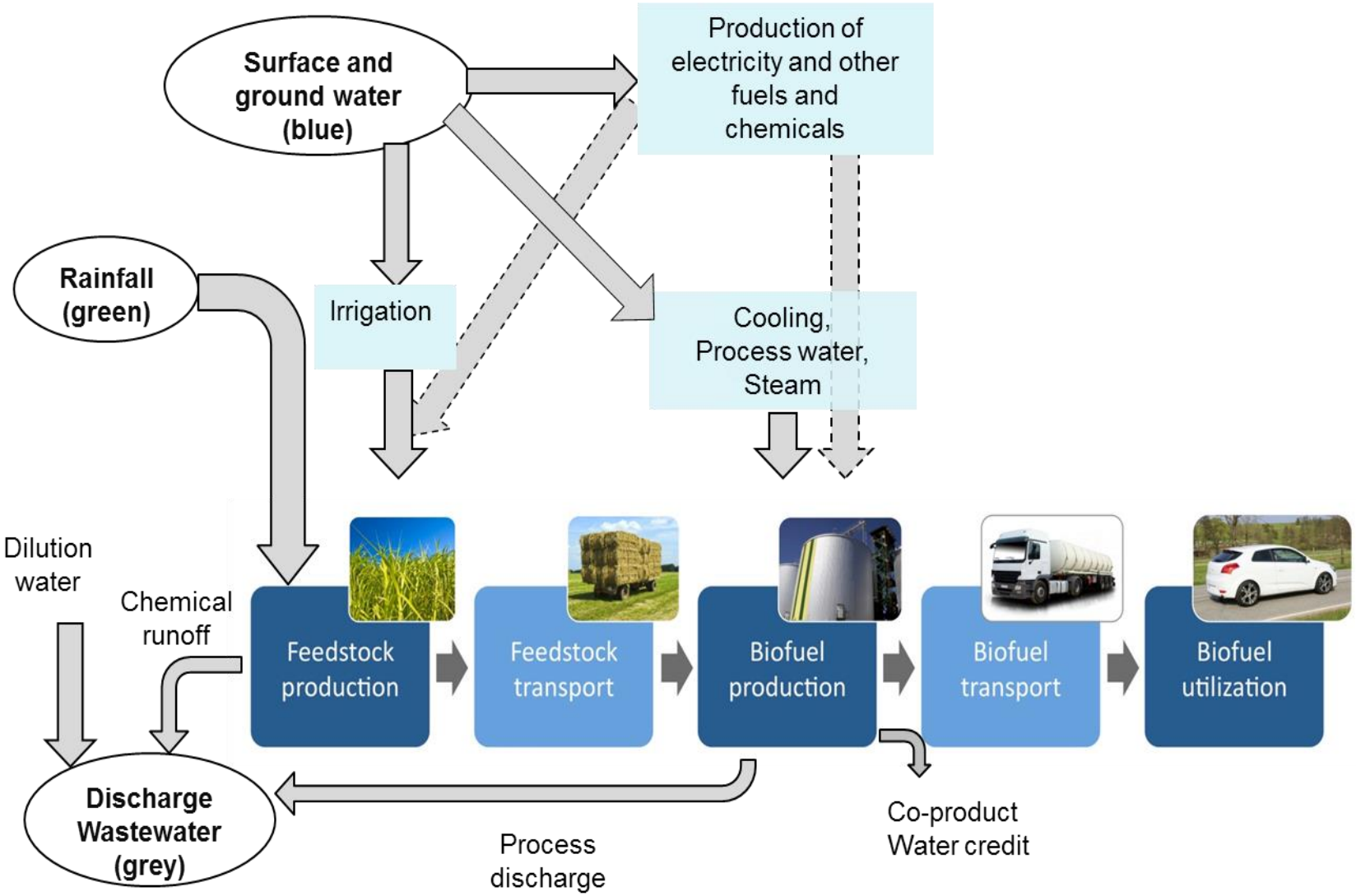
Fuel (Feedstock)	Net Water Consumed	Major Factors Affecting Water Use
Corn ethanol	8.7–160 L/L ethanol	Regional variation caused by irrigation requirements due to climate and soil types
Switchgrass ethanol	1.9–4.6 L/L ethanol	Production technology
Gasoline (U.S. onshore conventional crude)	1.4–8.6 L/L gasoline	Age of oil well, production technology, and degree of produced water recycle
Gasoline (Saudi conventional crude)	2.8–5.8 L/L gasoline	Same as above
Gasoline (Canadian oil sands)	2.6–6.2 L/L gasoline	Geologic formation, production technology

Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

Water Footprint

Water Footprint Accounting

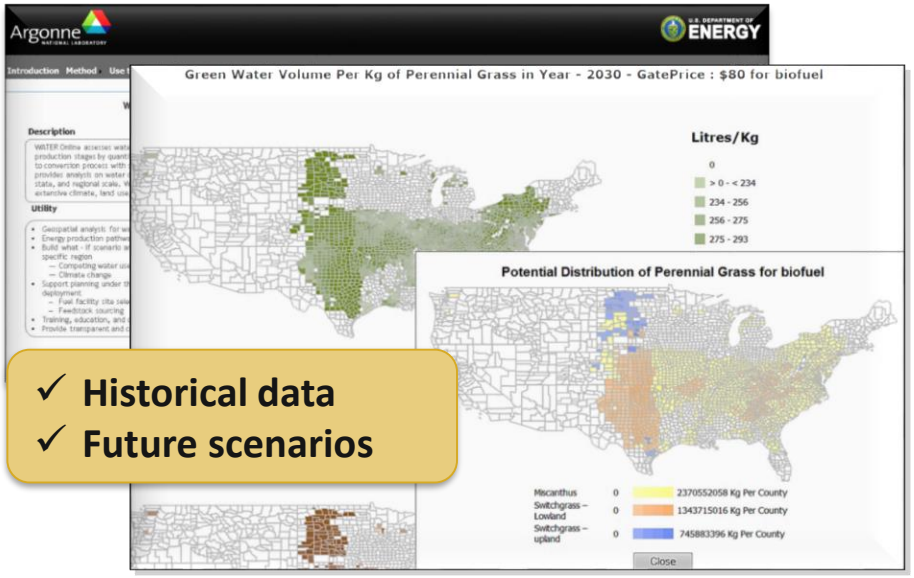
http://WATER.es.anl.gov



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

WATER (Water Analysis Tool for Energy Resources)

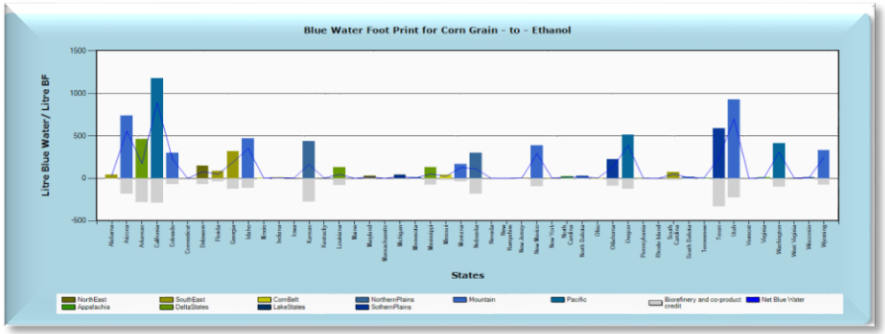
http://WATER.es.anl.gov



✓ **Historical data**
✓ **Future scenarios**

Feature

- Blue, green, and grey water footprint
- Water Availability Index
- County, state, region
- Metric: fuel product, feedstock, land use



Feedstock

- Corn, Soybean
- Crop residues
- Switchgrass and Miscanthus
- Forest wood resource
- Short rotation woody crops
- Electricity
- Petroleum, Natural gas

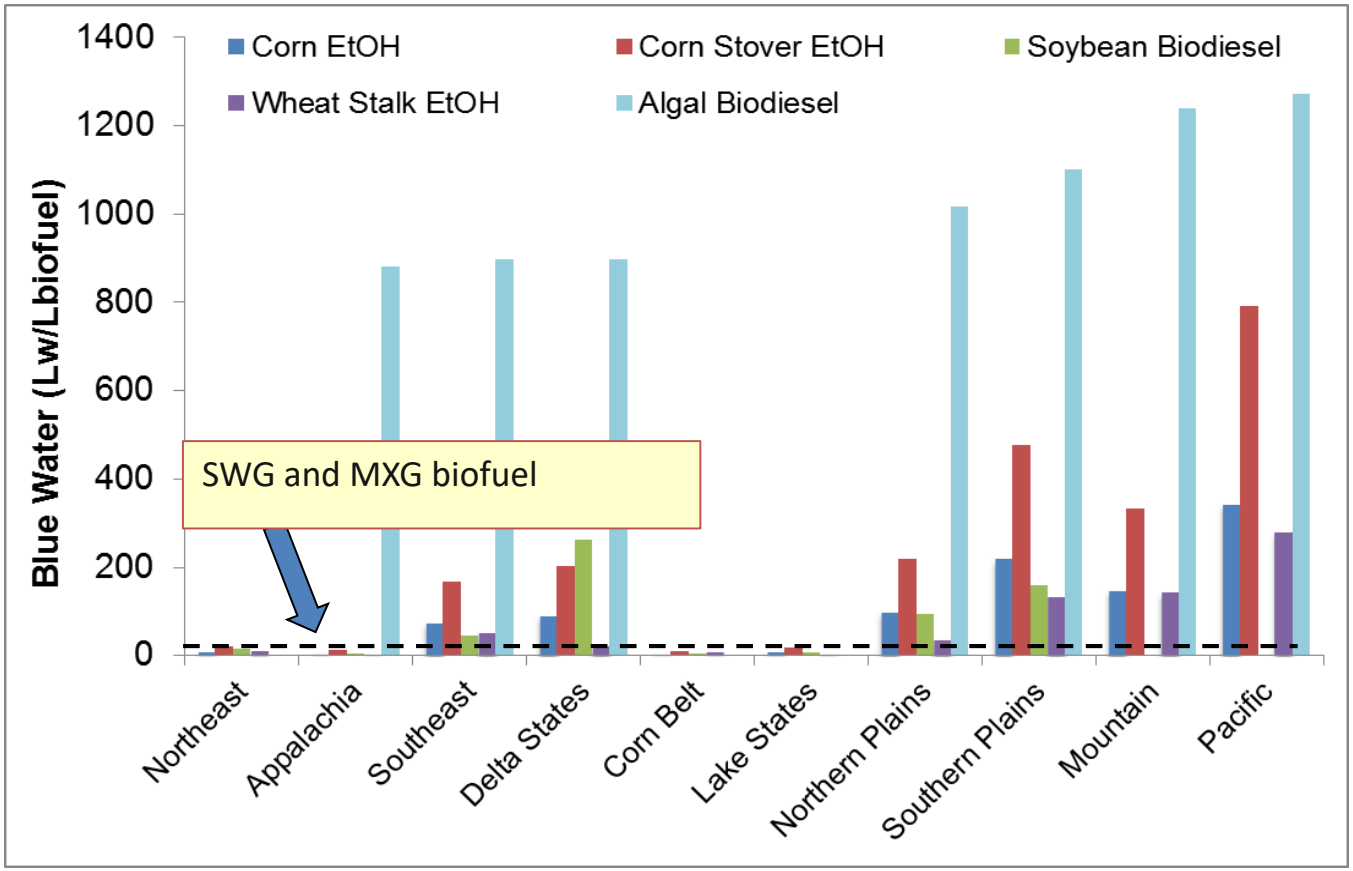
Conversion process:

- Biochemical
- Thermal chemical
- Chemical

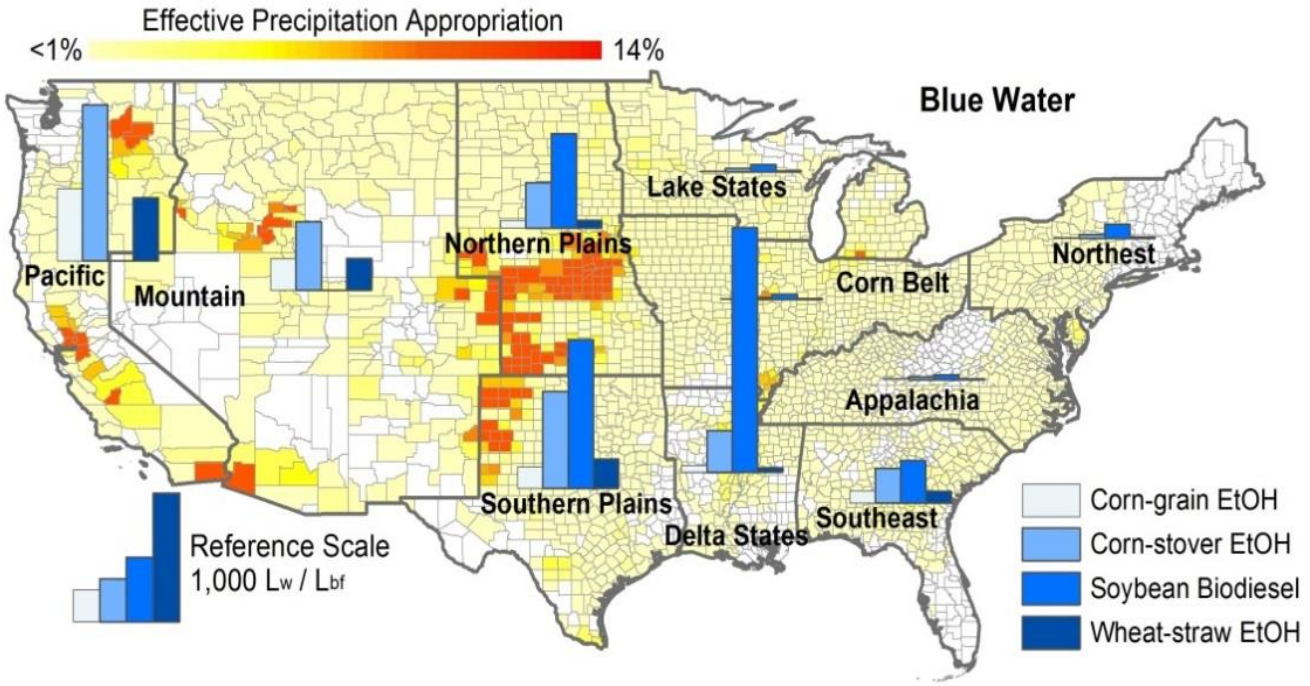
Application

- Enables stake holders to analyze trade-offs among fuel production, water resource, and other environmental impacts at regional level in conjunction with other tools

Substantial Variation in Biofuel Water Footprint



Geographic Distribution of Blue Water Footprint of Biofuel Production



Implication of Water Consumption on Resource Availability

Chiu and Wu, 2012, ES&T

Water Consumption in Production of Biofuel and Petroleum Fuels

Fuel (Feedstock)	Net Water Consumed	Major Factors Affecting Water Use
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Wu et al. 2018. ANL Technical Report, ANL/ESD-09/01 Rev.2.

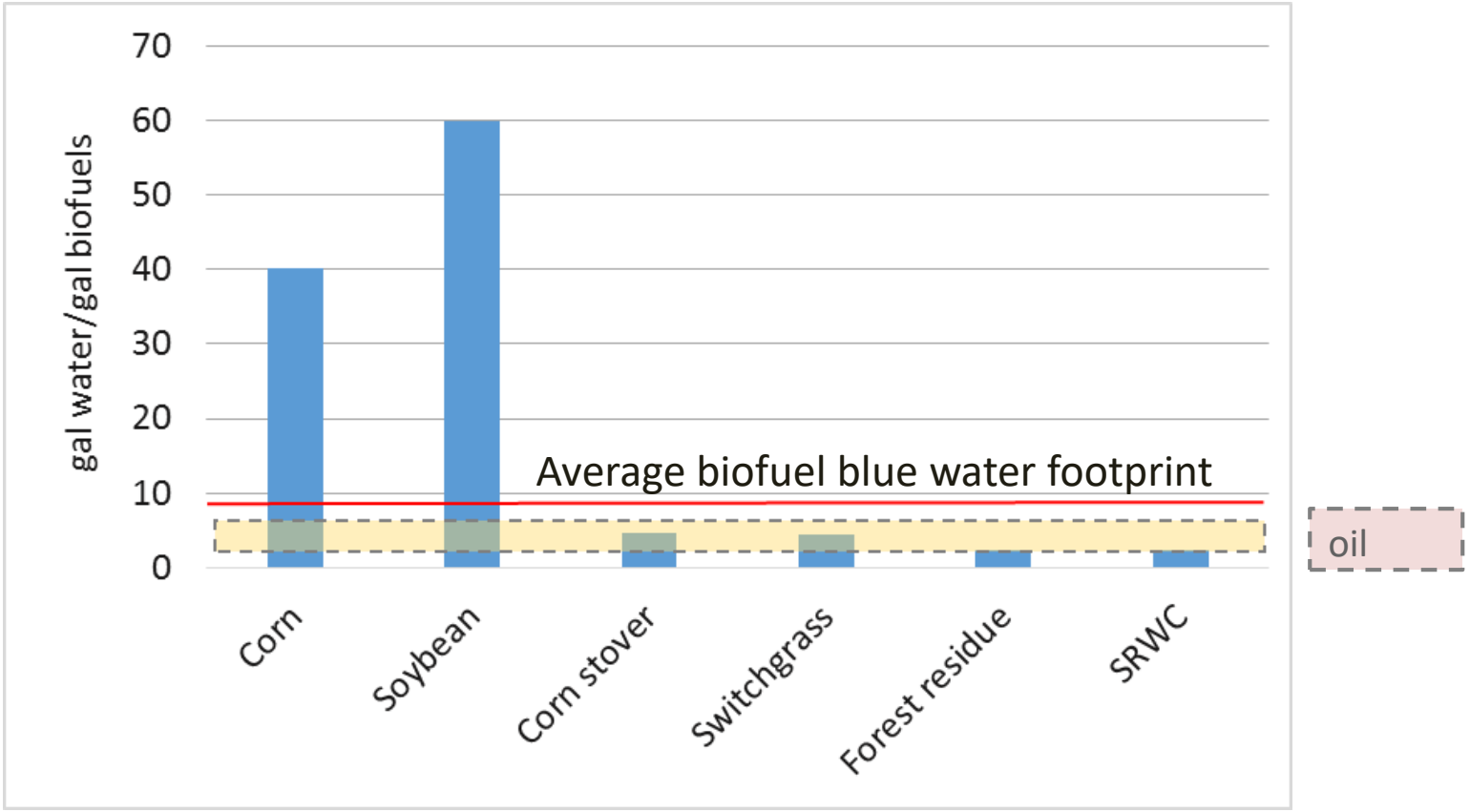
WATER Application: Analysis of the Role of Cellulosic Feedstock

- A future scenario: 920 Million dry tons of feedstock
  - 15% conventional
  - 30% crop residue
  - 11% perennial grass
  - 39% wood residue
  - 5% SRWC (MSW not included in water assessment)
- Major regional feedstock
  - Wood resources: Southeast U.S.
  - Switchgrass: South, Midwest U.S.
  - Corn stover, corn, soybean: Midwest U.S.

Rogers, et. al.. 2016, *Biofpr*. (2016), doi/10.1002/bbb.1728/

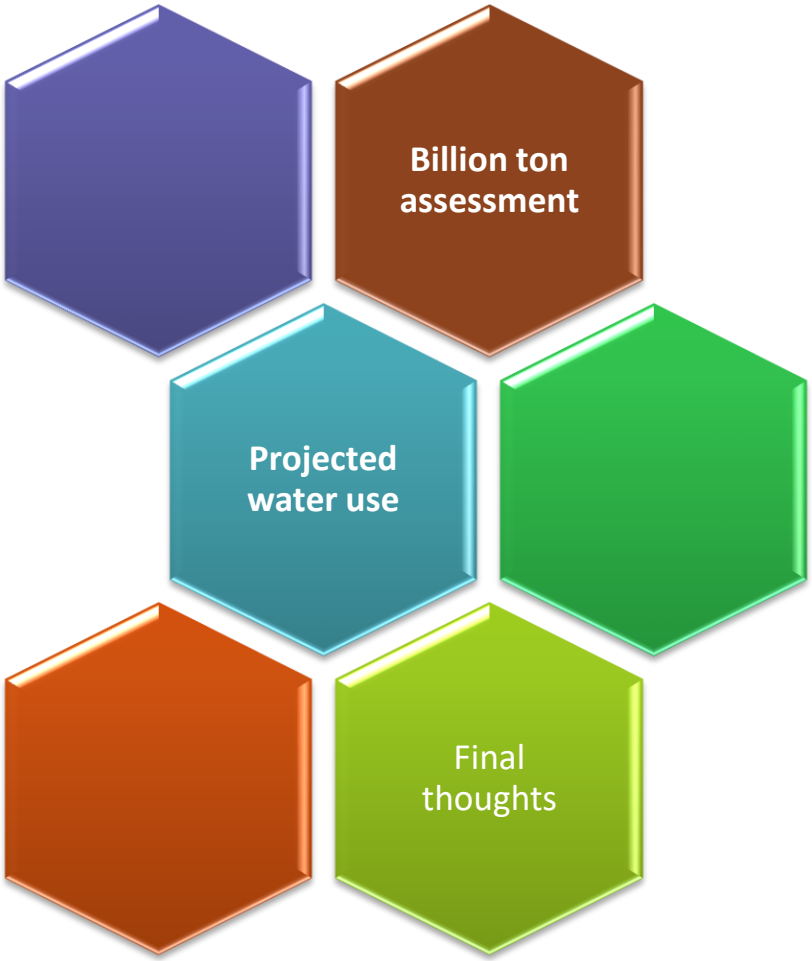
Approach to Reach Water Sustainability

Weighted Average Water Footprint Decreases As Cellulosic Share Increases



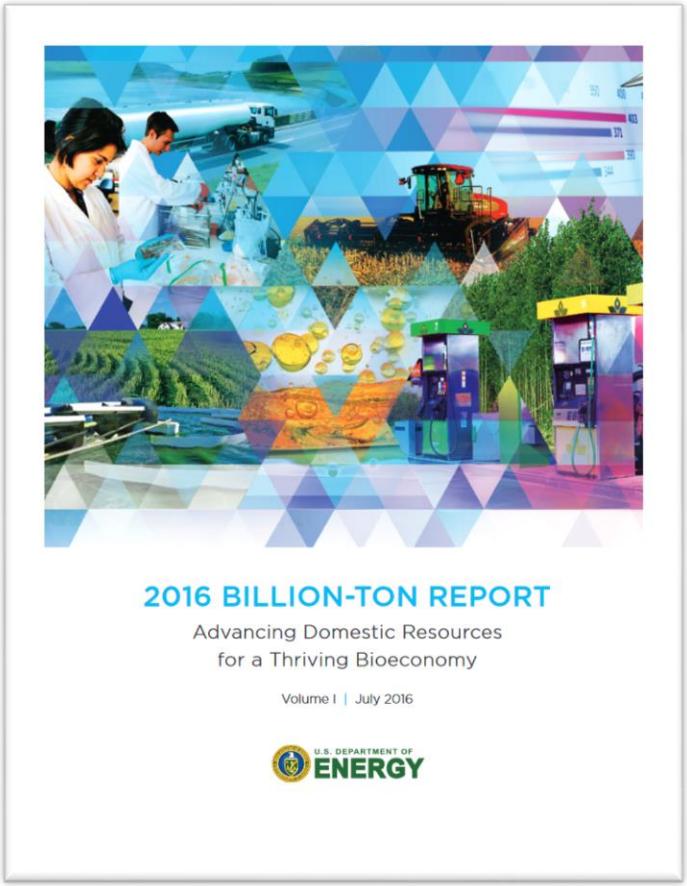
Rogers, et. al.. 2016, *Biofpr*. (2016), doi/10.1002/bbb.1728/

Potential Water Use in Future Production



Biomass Resource Assessment

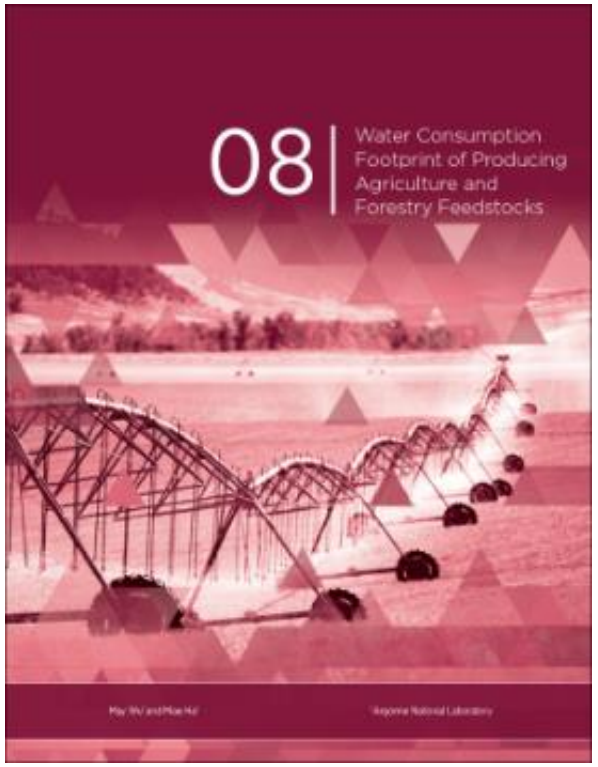
- Between 2005-2016, U.S. Department of Energy launched a study to assess biomass resource available in the United States to produce bioenergy.
- The study found that approximately more than one billion tons of biomass are available in the conterminous United States.
- Three reports were issued:
  - Billion Ton Study (2005)
  - Billion Ton Update (2011)
  - Billion Ton 2016 (2016)
- The biomass includes: corn grain, soybean, crop residues, perennial grass, forest wood residue, sorghum.



DOE, 2016 https://www.energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf

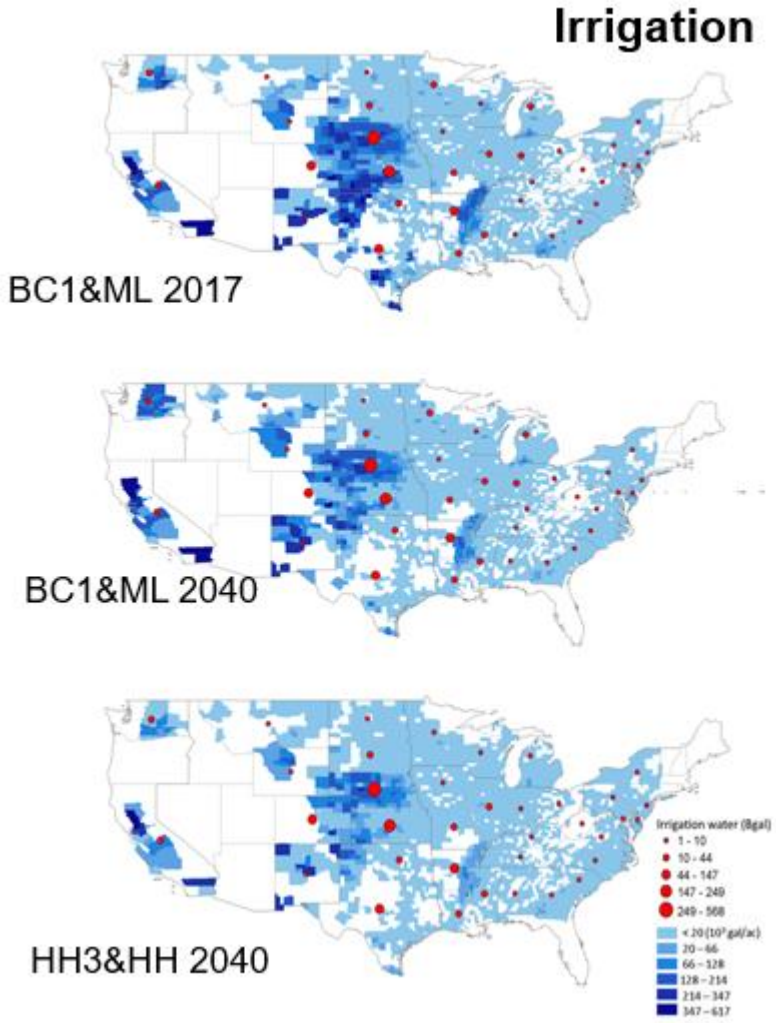
Water Sustainability Assessment for BT16

- The BT16 scenarios incorporate feedstock selection and land management to reduce irrigation demand for biomass production.
- The feedstock portfolio changes from mostly starch-based material to mostly cellulosic-based material.
- Biomass growing area changes from irrigated land to rain-fed land in various regions.
- Focuses on reducing groundwater irrigation in areas facing ground water depletion.



Wu, M. and M. Ha, 2017.
https://energy.gov/sites/prod/files/2017/02/f34/2016_billion_ton_report_volume_2_chapter_8.pdf

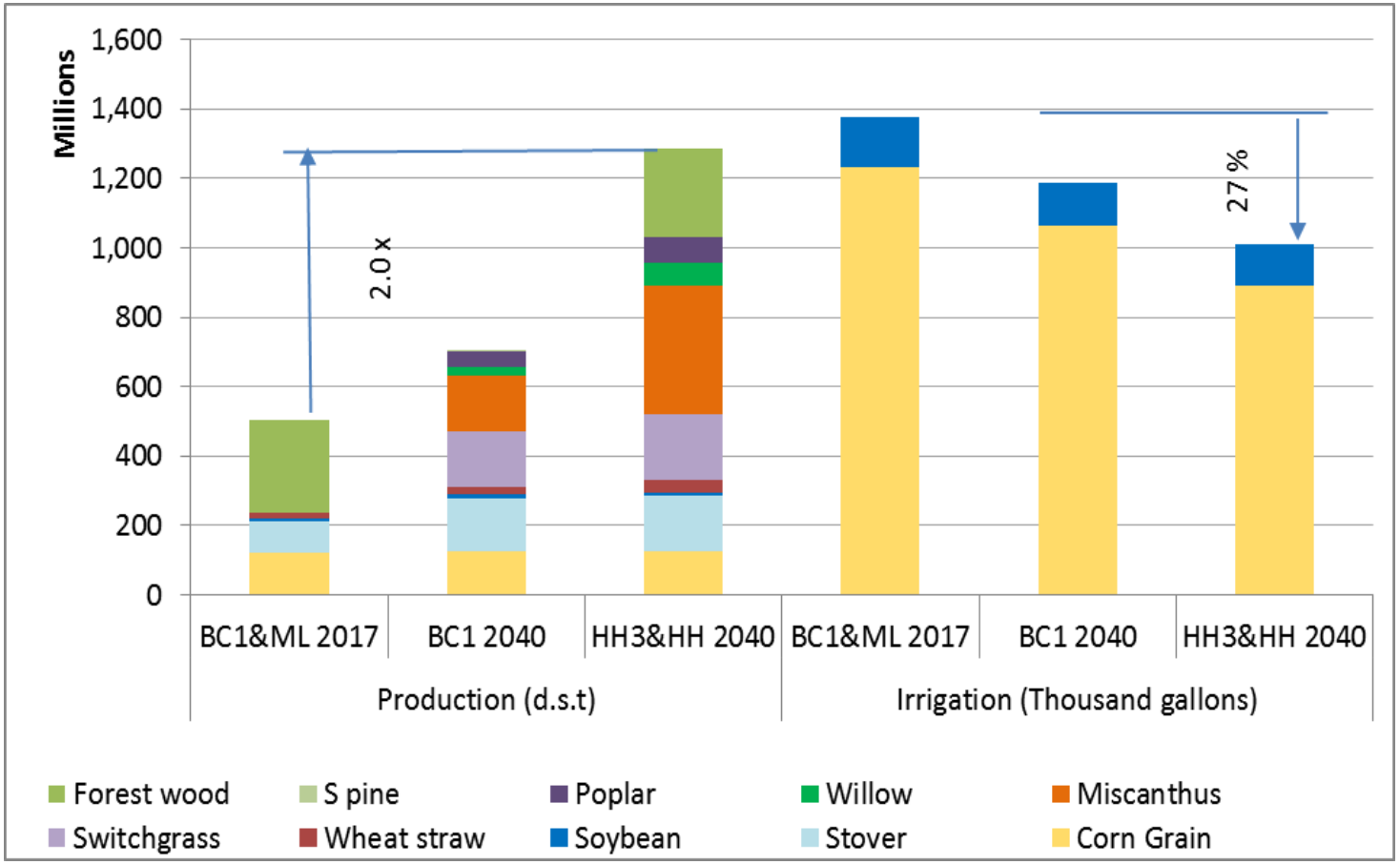
Blue Water Demand for Biomass Production under Potential Scenarios



- *Total consumptive irrigation water intensity on per acre basis would decrease from BC1&ML 2017 to HH3&HH 2040; the changes are significant in Northern Plains and surrounding states.*
- *The reduction is primarily resulted from*
  - *Decrease in irrigated land that grows annual biomass, and*
  - *Increase in acreages that grow perennial grass and other cellulosic.*

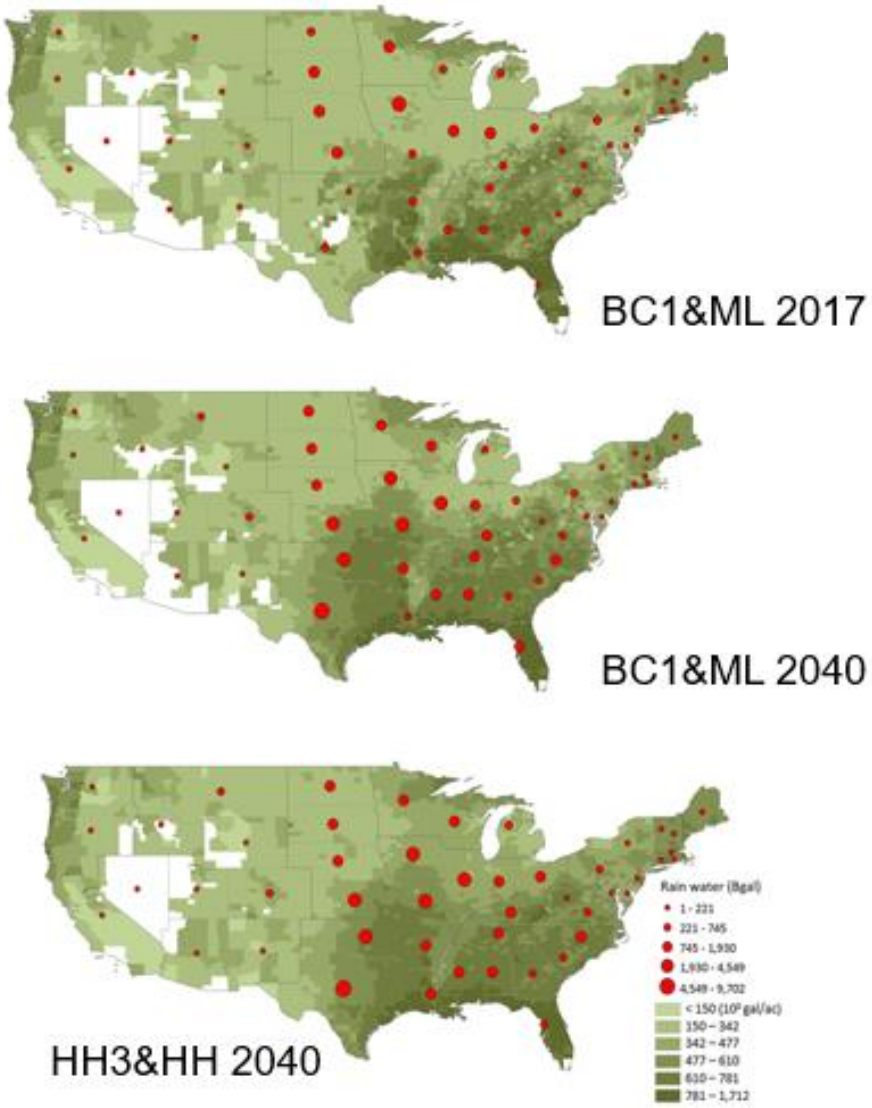
Wu and Ha, 2017.
https://energy.gov/sites/prod/files/2017/02/f34/2016_billion_ton_report_volume_2_chapter_8.pdf

Road Map to Increased Production with Decreased Irrigation Water Use



Wu, M. and M. Ha, 2017.
https://energy.gov/sites/prod/files/2017/02/f34/2016_billion_ton_report_volume_2_chapter_8.pdf

Green Water for Biomass Production under Potential Scenarios

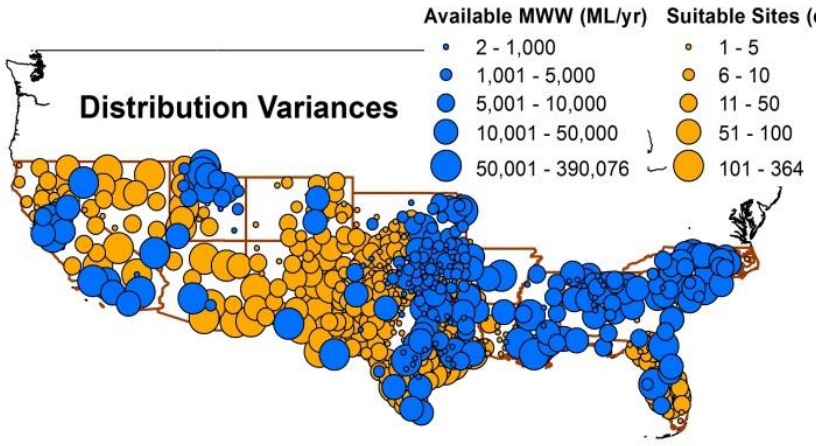


- *Demand for effective rain would increase per acre of land from BC1&ML 2017 to HH3&HH 2040.*
- *The changes are*
  - *Concentrated in south and southeast states.*
  - *Resulted from increase in acreages of rain-fed biomass production.*
  - *Substantial in some areas*
- *Green water available to other economic sectors is likely to decrease*

Wu and Ha, 2017.
https://energy.gov/sites/prod/files/2017/02/f34/2016_billion_ton_report_volume_2_chapter_8.pdf

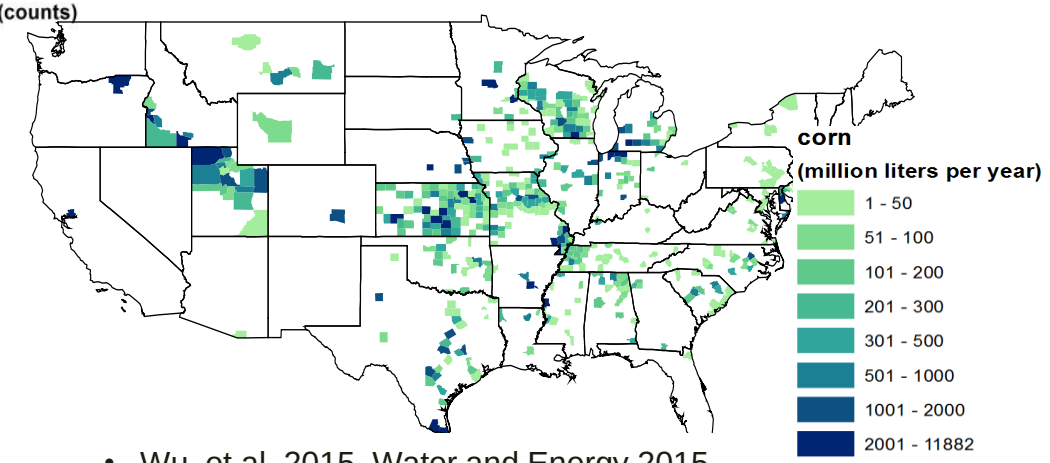
Reclaimed Water Reuse for Crop Irrigation and Growing Algae

Algae biofuel production



- Chiu and Wu, 2013. *BioFPR*.

Irrigation volumes can be replaced by reclaimed water



- Wu, et al. 2015. Water and Energy 2015 WEF.

- Geospatial analysis showed that reclaimed wastewater is available in substantial amount for irrigation.
- Geographic mismatch between the alternative water source and potential user because of land footprint constraint, which suggests an infrastructure challenge

Concluding Remarks

- Water footprint of a fuel mix that contains petroleum and biofuel can be optimized (minimized) by
  - Comparing feedstock type, feedstock production region, management options, and processing technology
  - Select a fuel blend and the blending level of individual fuel to reduce overall water footprint
- WATER
  - Supply chain-based analysis model
  - Multiple feedstock and conversion pathways
  - Water consumption footprint
  - Water availability
- Support informed decision making for water sustainable energy production by providing downloadable geospatial data of biomass production, water footprint under historical and potential scenarios.
  - Biofuel: Future land use and production scenarios
  - Petroleum oil (Database for major pathways available)
  - Electricity (Database for major pathways available)

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