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Analysis of Water Consumption in the Major Steps of Bioethanol Production

May Wu, Marianne Mintz, Michael Wang, Salil Arora

Center for Transportation Research
Energy System Division
Argonne National Laboratory

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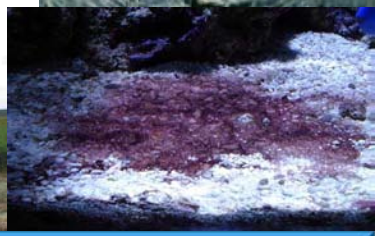
Office of Biomass Program

Addressing Environmental Sustainability of Biofuel Development

- Determine life-cycle impacts of a major scale-up in biofuels production, from feedstocks to end-use in vehicles
  - Greenhouse gas (GHG) emissions
  - Water use and quality
  - Air quality
- Evaluate environmental impacts of emerging biomass conversion technology and biofuel delivery infrastructure
- Improve understanding of regional climates, soil types, land use, and water issues as they relate to feedstock production



Analysis of water use is vital toward developing sustainable practices for biofuel production

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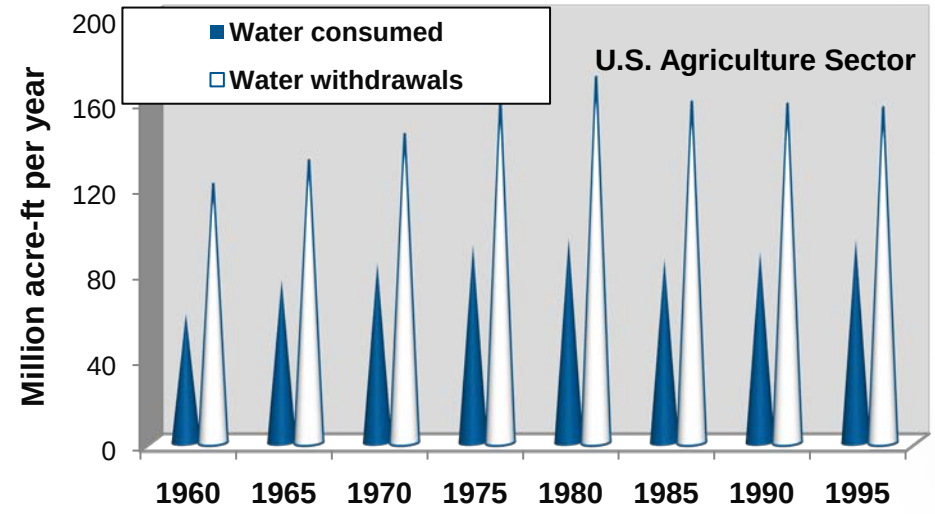
Key Considerations in Water Analysis for Biofuels

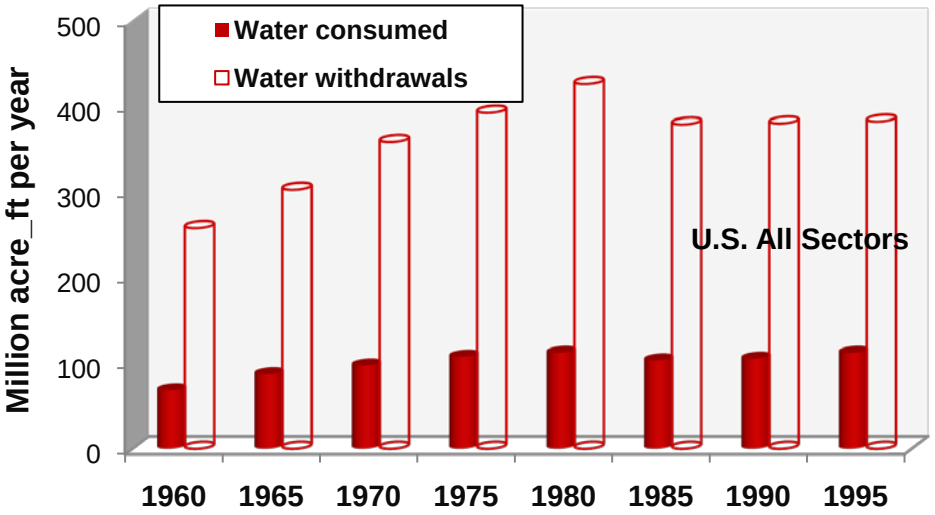
- Water is consumed by feedstocks through evapotranspiration and incorporation into the feedstocks.
- Irrigation is required when precipitation alone is not sufficient for growth.
  - Water-stressed areas demand more irrigation
- Groundwater use for irrigation may be more of a concern in areas where groundwater is depleting.
- Certain feedstock is often concentrated in several regions.
- Water management practice affects total water withdrawal.
- Water quality requirements for biofuel feedstocks differ from other products.

Scope And Approaches

- Estimate net water use (consumption)
  - Irrigation water, process water, cooling water
- Focus on representative regions and compare with baseline fuels
  - 89% of corn and 95% of ethanol in United States
  - 90% of onshore crude and 81% refinery gasoline output in United States
  - 100% of oil sands production in Canada and 52% of oil production in Saudi Arabia
- Consider technology share and water use factor
  - Water use factor for each technology is synthesized by technology share to derive a weighted average
- Takes into account regional variations and historic trends
- Data sources
  - USDA FRIS, USDA NASS, USGS, and other open literatures
- Results were reviewed internally and externally by industries, NGOs, academia, and national labs

Historical Irrigation Water Withdrawal, Returning Flow, and Consumption



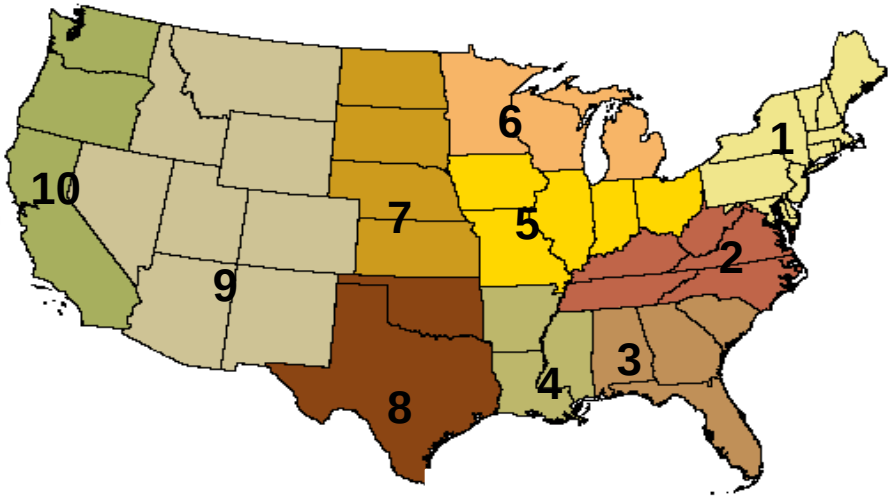


- Water withdrawal
  - Agriculture sector accounts for 34% of total freshwater withdrawal by all sectors in 2000
  - Power sector water withdrawal: 48% of total in 2000
- Returning flow
  - 30–50% of withdrawal water returned to water body
- Water consumption
  - Agriculture consumes 50–70% of its total water withdrawal
  - Agriculture sector accounts for 85% of total consumption by all sectors

Data source: USGS

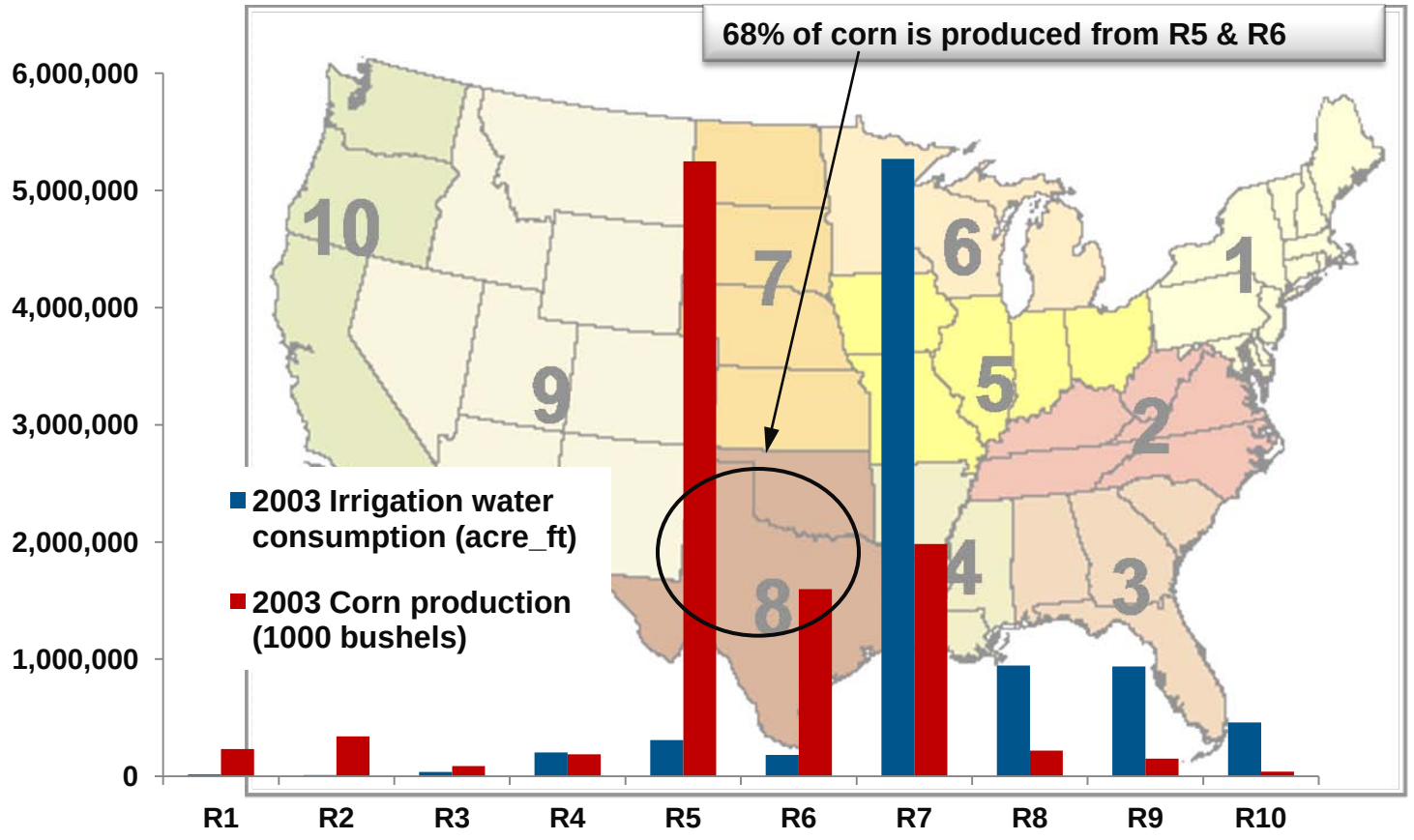
Irrigation Water Withdrawal and Consumption for Corn in 10 USDA Farm Regions

- In 2003, a total of 11,830,725 acre_ft of freshwater was withdrawn for corn irrigation in the United States
- Regions 7, 8, and 9 account for a majority of irrigation requirements

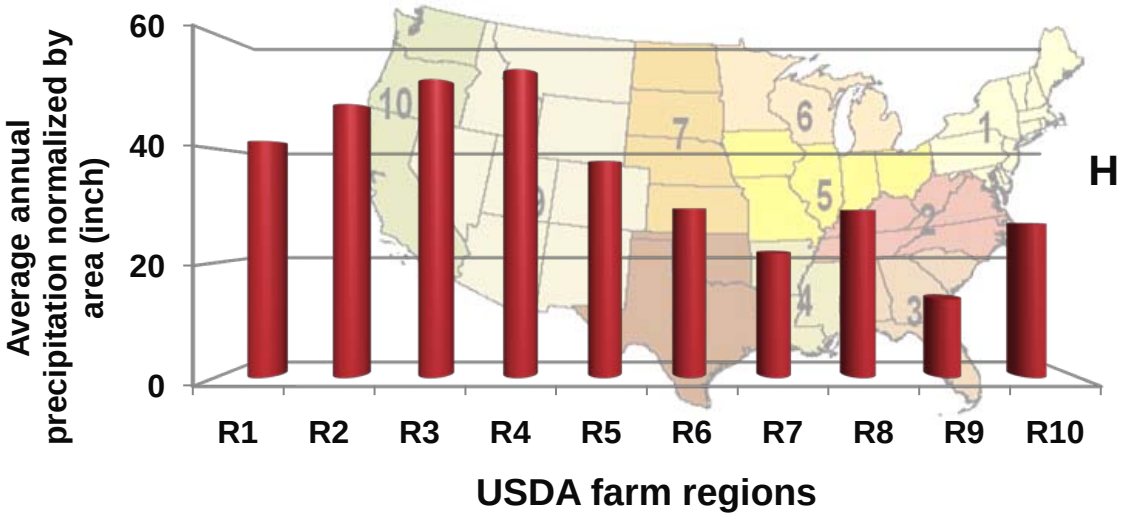


USDA regions	1	2	3	4	5	6	7	8	9	10
Percent of total U.S. irrigation water applied for corn	0.2%	0.1%	0.5%	2.4%	3.7%	2.2%	62.9%	11.3%	11.2%	5.5%

Substantial Variations in Corn Production and Irrigation among the 10 Regions

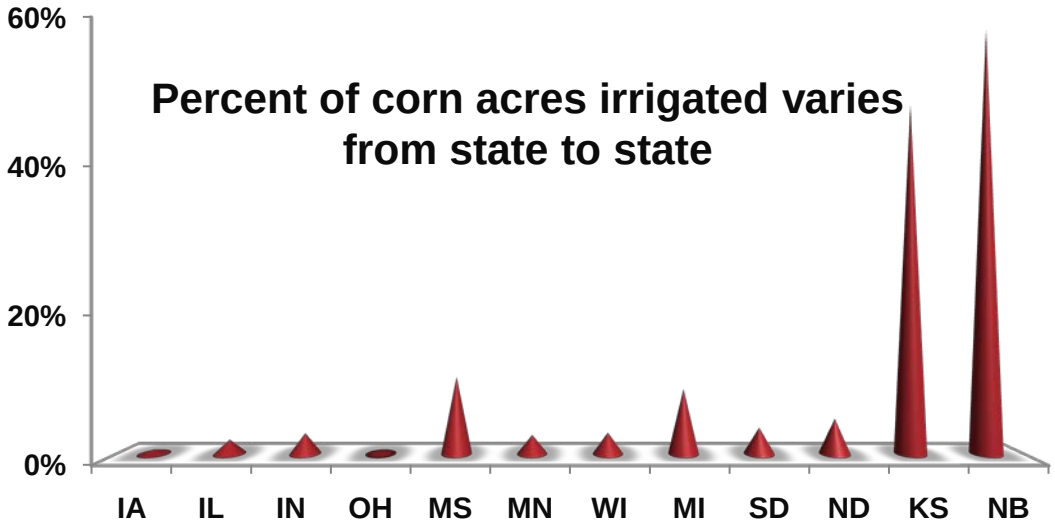


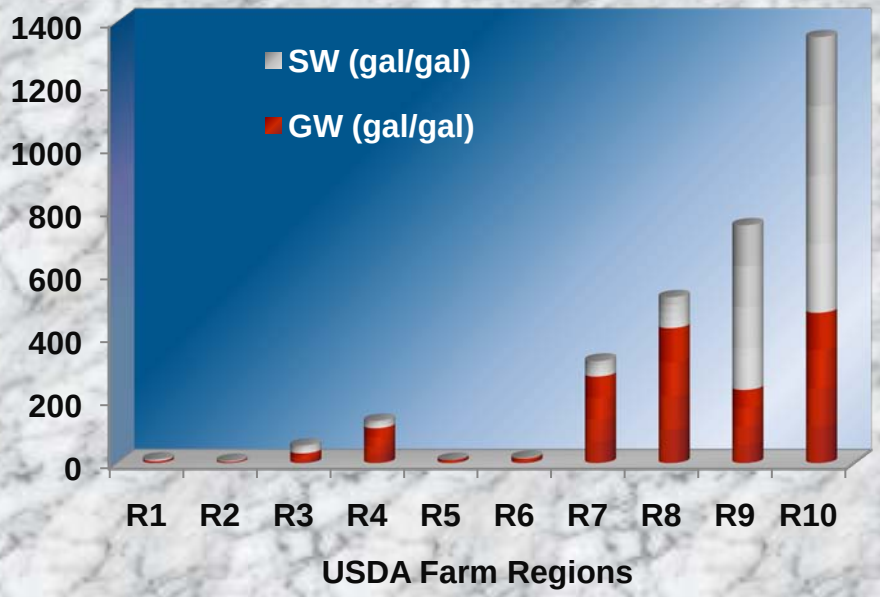
Climate, Soil, and Other Environmental Conditions Drive Irrigation Demand

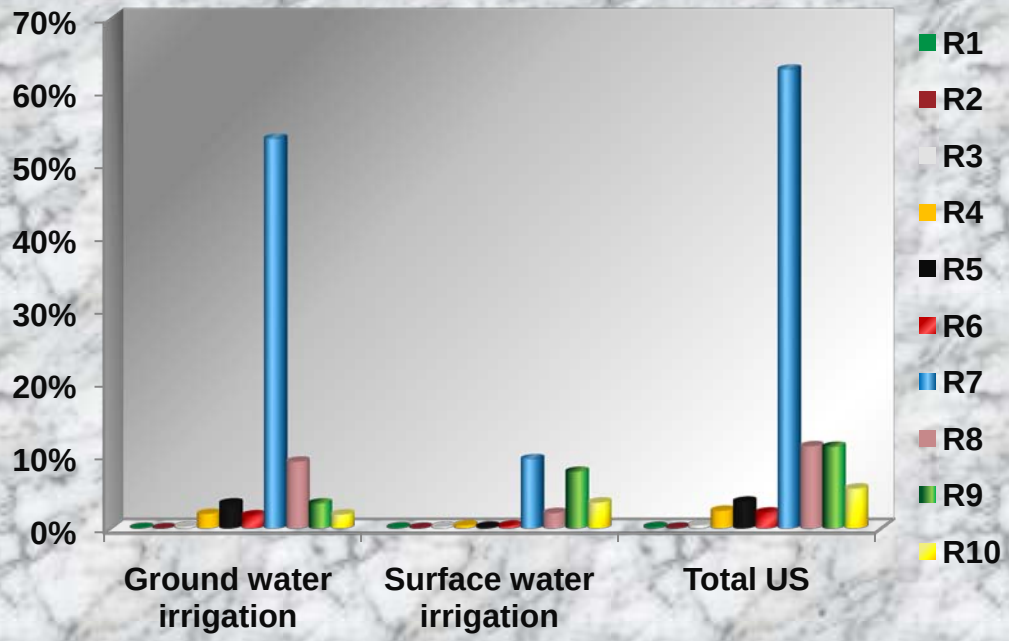


Historical average precipitation (1895–2006)

- On average, 13– 6% of corn acreage is irrigated in the United States
- In irrigated farms, the amount of water applied varies significantly
- Irrigation management has been improved recently years and new technology can further reduce water use



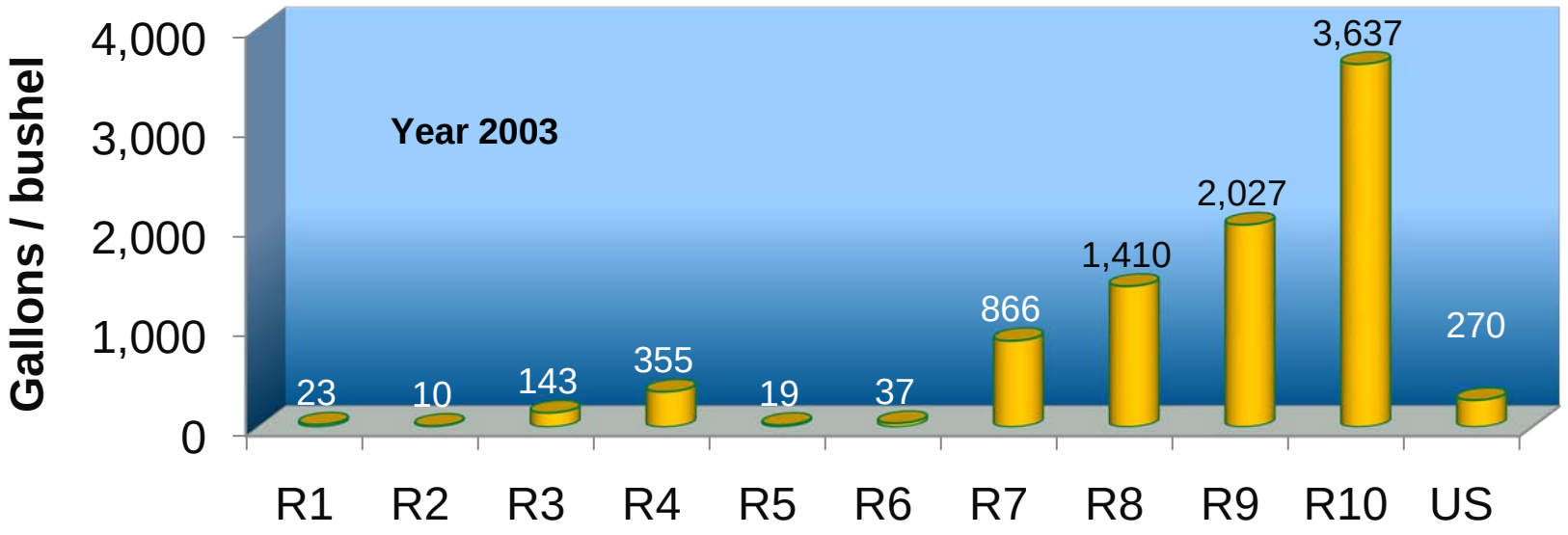




Groundwater Is the Main Source of Irrigation Water

- Nearly 70% of water irrigated to corn field is groundwater; 30% is surface water
- The three major corn producing regions (5, 6, 7) consumed
  - 59% of groundwater irrigation
  - 10% of surface water irrigation
- A majority of the remaining 31% corn irrigating water is used in regions 8, 9, and 10

Corn Irrigation Water Consumption Factor

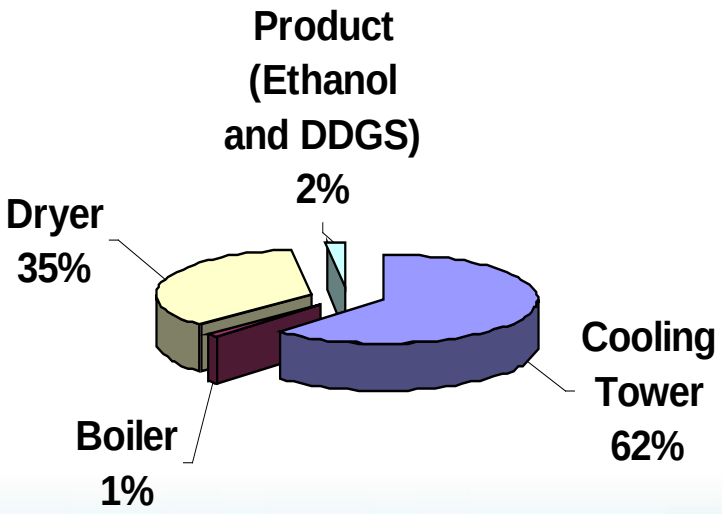


2003 Corn production share	2.3%	3.4%	0.9%	1.9%	52.0%	15.8%	19.7%	2.2%	1.5%	0.4%	100 %

On production-weighted average,

- *Two-thirds of U.S. corn is from regions where 19–37 gal of irrigation water are consumed per bushel produced*

Water Consumption in Ethanol Dry Mills



Shares of Water Consumption in Ethanol Dry Mills (Keeney, 2007)

- Cooling Tower
  - Evaporative loss
  - Drift
  - Blow down
- Boiler
  - Deaerator & leaks
  - Blow down
- Dryer
  - Water vapor loss
- Products
  - Ethanol
  - DDGS

→ Cycle up

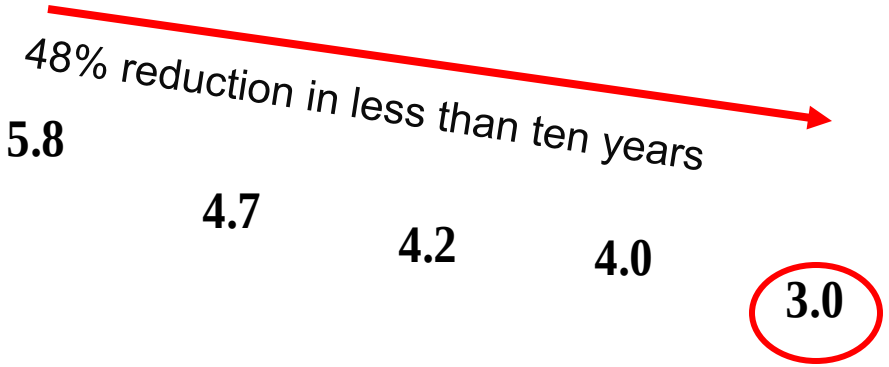
→ Condensate collection and recycle

→ Wet DGS

- Reduction of water use is achievable
  - Efficient design in newly built plants
  - Water recycle and reuse in existing plants
  - New technology

Water Consumption in Ethanol Production Is a Local Issue

- *There is a downward trend in water consumption in dry mills*
- *On production-weighted average: three gallons of water consumed per gallon of ethanol produced*
- *Although water use factor is small, its impact is concentrated at one location*

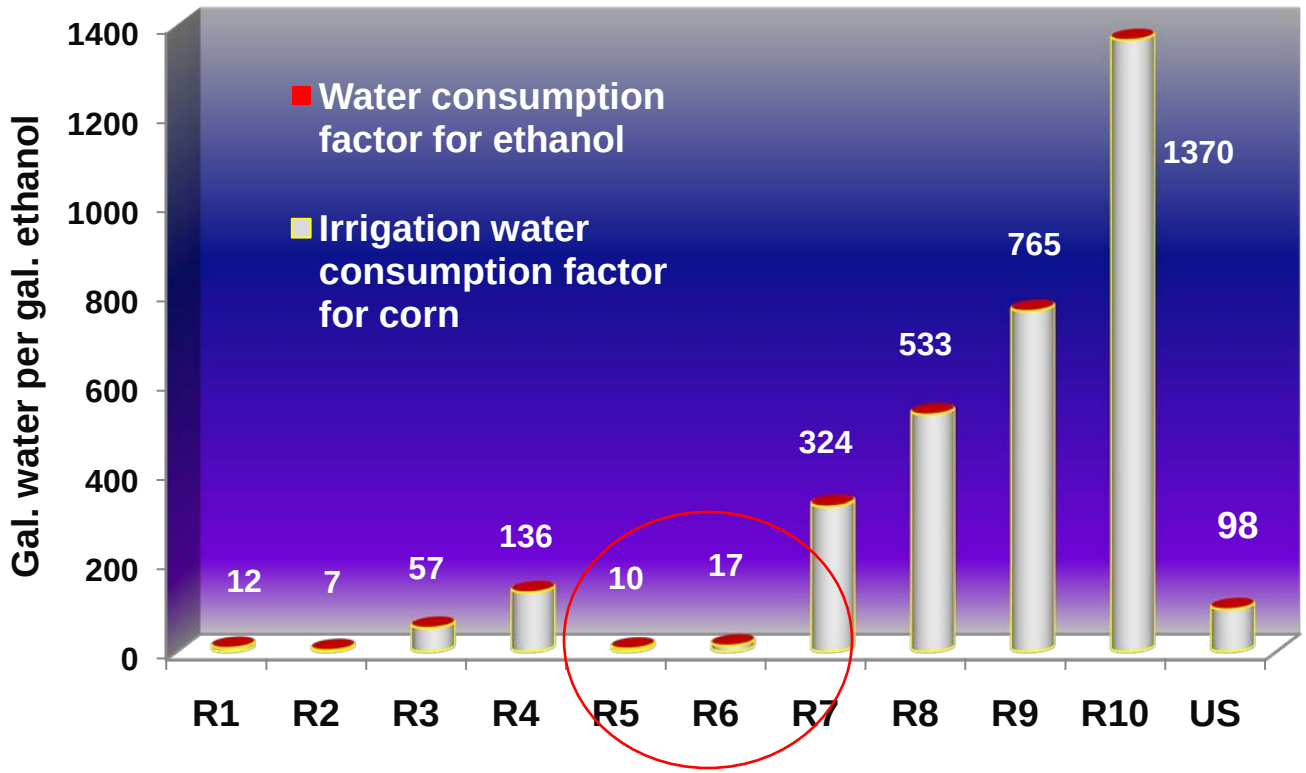


Dry mills, average (NREL)	USDA survey	MN dry mills	MN dry mills	RFA survey
1998	2003	2005	2006	2007

Water consumption in ethanol dry mills

gal/gal

Water Consumption Factor for Corn Ethanol in the United States - From Corn Farming to Ethanol Production



If ethanol is produced from corn grown in each region

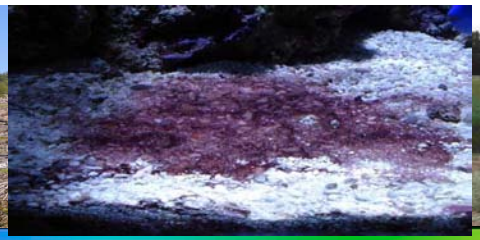
- *On three-region weighted average, it takes 82 gal of water to produce 1 gal of ethanol in the regions responsible for 88% of U.S. corn*

Based on 2006 corn production

Cellulosics- Water Requirement Depends on Feedstock Types

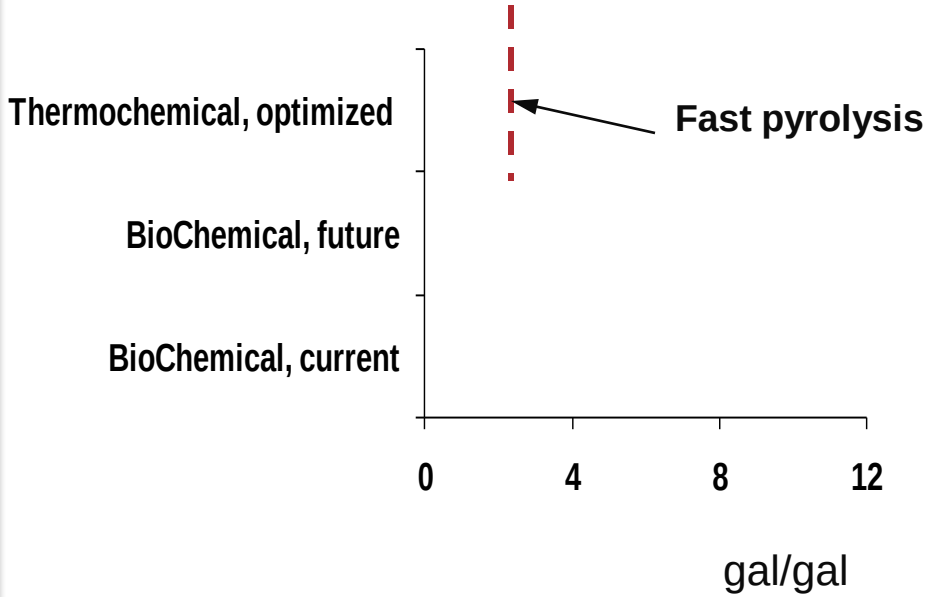
- Switchgrass
  - Requires less water to grow because of its long roots that are able to absorb water efficiently.
  - Studies suggested that a yield of 4–8 dry tons per acre can be achieved without irrigation in its native habitat.
  - Irrigation water will be required for growing switchgrass in certain areas not native to SWG.
- Other grasses
- Forest wood residue
  - No irrigation to existing forest
- Short-rotation woody crops
  - High
- Algae
  - High
- Agricultural residue
  - Crop types
    - *Corn stover*
    - *Corn cob*
    - *Rice hulls*
    - *Wheat straw*
    - *Cotton gin*






Water Consumption in Cellulosic Ethanol Production Is Sensitive to Process and Yield

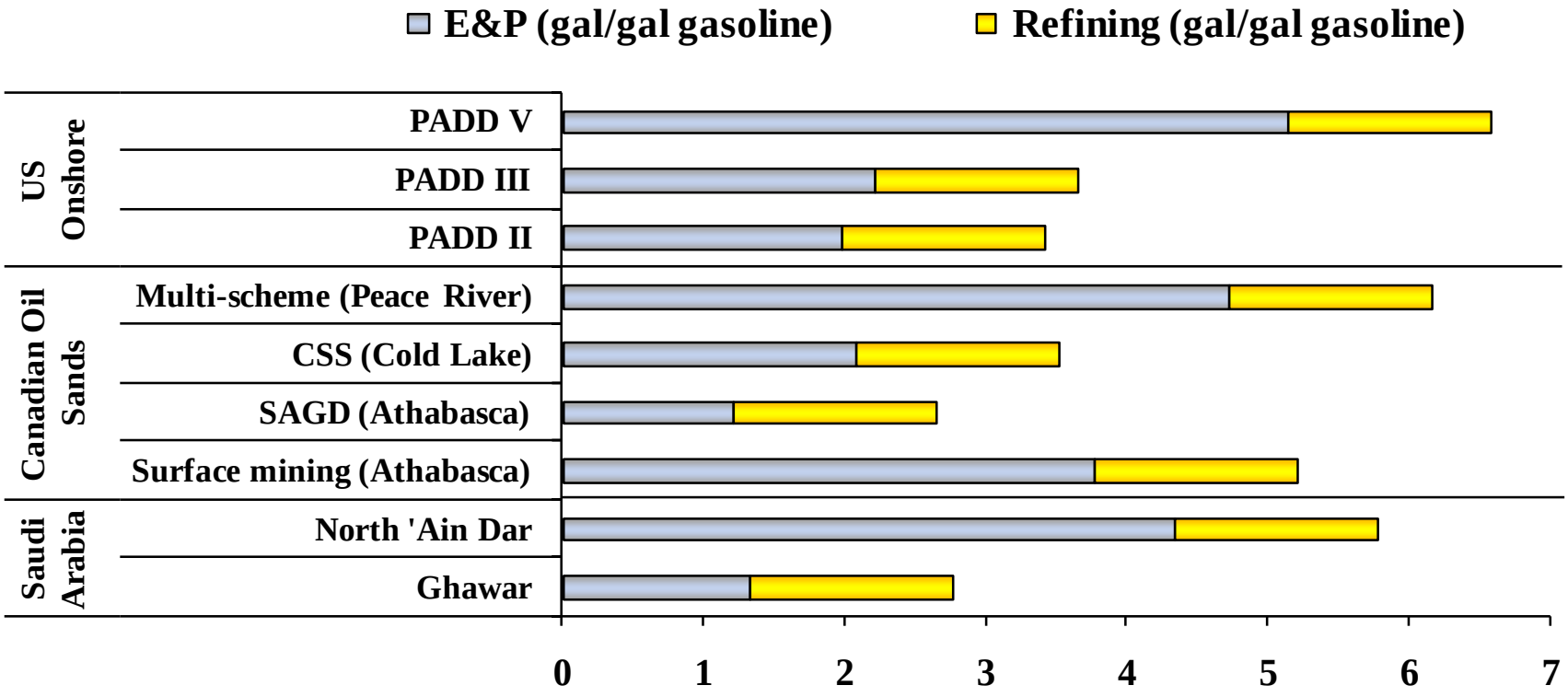
- Conversion processes
  - Biochemical: fermentation
  - Thermochemical: gasification, pyrolysis followed by catalytic synthesis
  - Hybrid: gasification/syngas fermentation
- Fuel yield
  - Unit water use decreases when yield increases
- Future reduction is expected
  - Process optimization
  - Technology advancement



Current estimates:

2–10 gal/gal cellulosic ethanol

Water Consumption during Production of Gasoline from Conventional Source (United States and Saudi Arabia) and Oil Sands



- *Water consumption for the production of gasoline from conventional source and oil sands varies from 3 to 7 gal/gal*
- *Saline water is increasingly used in oil fields in Saudi Arabia and the United States*

How Much Water Is Consumed to Drive a Passenger Car for a Mile?

	Corn Ethanol			Cellulosic Ethanol			Petroleum Gasoline
Regions	USDA 5	USDA 6	USDA 7	Native habitat			PADD II, III, V
Production process	Dry milling			Thermochemical	Biochemical		Varies
Share of fuel production	*52%*	*14%*	*30%*				*81%*
Share of feedstock production	*52%*	*16%*	*20%*				*90%*
gal water/gal gas. eq.	*15*	*26*	*492*	*3*	*9**	*15*	*3–7*
gal water/mile traveled	***0.6***	***1.1***	***21.0***	***0.1***	***0.4***	***0.6***	***0.1–0.3***

* Advanced biochemical process

Major Issues In Water Analysis For Biofuels

Water quality requirement

- Alternative irrigation water sources for biofuel feedstock production

Accounting for differences in irrigation water use among some studies

- Same term “water use” may account for either water withdrawal or consumption

Co-product water credit

- Most studies attribute all water use during production to one single product. Approach to allocate water credit to co-product should be developed.

Methodology

- Water LCA, virtual water footprint

Process economics consideration in water reduction

- Further reduction of water use will be determined by economics

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Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline

ANL Technical report, ANL/ESD/09-1

www.transportation.anl.gov/pdfs/AF/557.pdf

mwu@anl.gov

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