2016 DOE Hydrogen and Fuel Cells Program
Annual Merit Review

Life-Cycle Analysis of Water Consumption for Hydrogen Production

Amgad Elgowainy (PI), Jeongwoo Han (presenter), Uisung Lee, Jeff Li, Jennifer Dunn, and Michael Wang

Argonne National Laboratory

Argonne NATIONAL LABORATORY

SA039

June 8, 2016

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Start: April 2013
- End: Determined by DOE
- % complete (FY16): 70%

Barriers to Address

- Stove-piped/siloed analytical capability for evaluating sustainability
- Inconsistent data, assumptions and guidelines
- Insufficient suite of models and tools

Budget

- Funding for FY15: $250K
- Funding for FY16: $175K

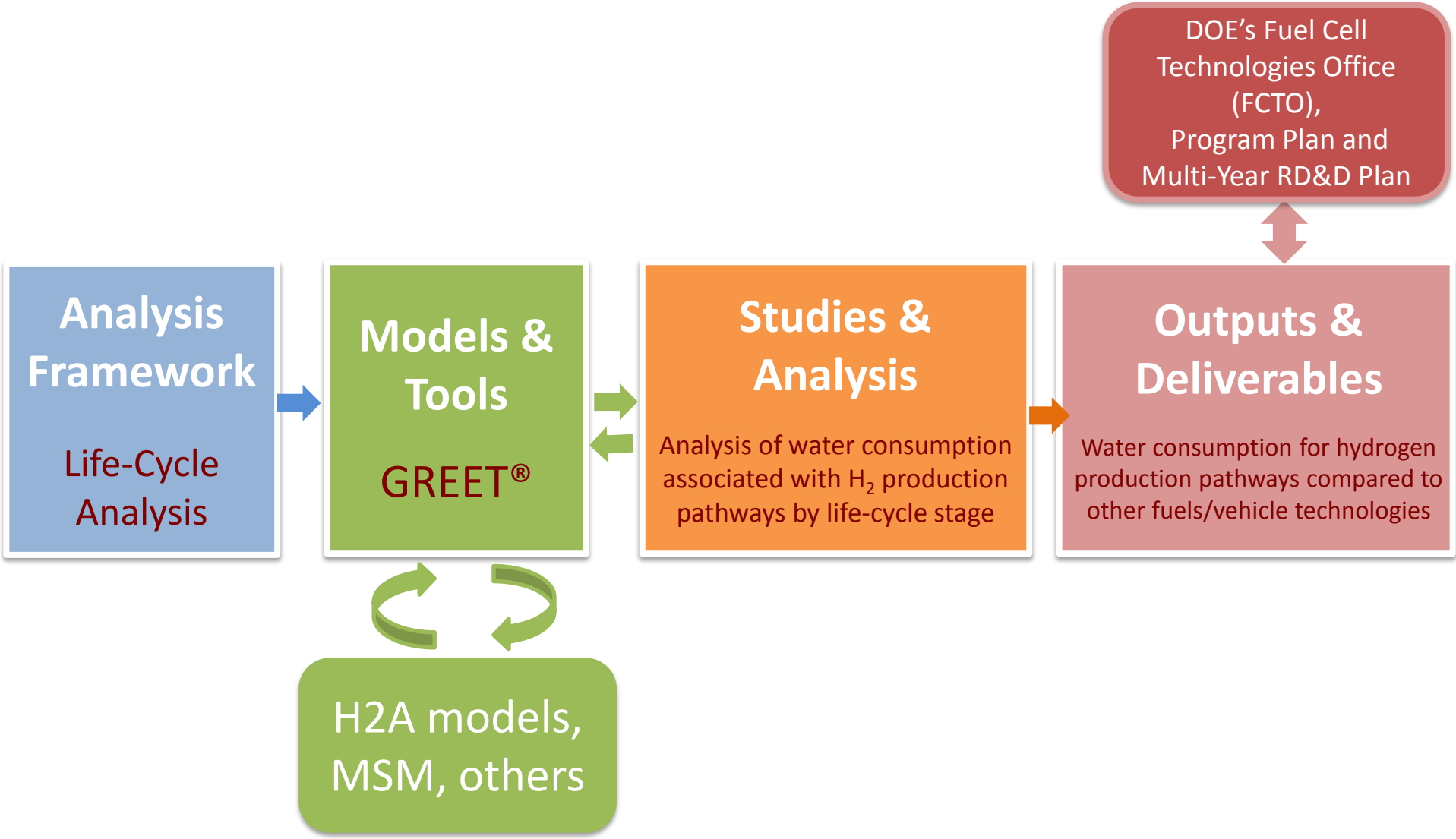
Partners/Collaborators

- Jacobs® Consultancy
- Other industry stakeholders

Relevance/Impact

- Life-cycle analysis (LCA) estimates water consumption along supply chain of different transportation fuels
  - Life-cycle water consumption includes both direct and indirect freshwater consumption embedded in energy products
  - LCA provides a consistent accounting of water consumption associated with the production of transportation fuels (including hydrogen)
- Hydrogen is a zero-carbon fuel with potential for significant reduction of GHG and air pollutant emissions
  - Water consumption, together with energy use and air emissions impacts, needs to be evaluated for hydrogen pathways in relationship to other fuel pathways
- Hydrogen is also essential for processing, refining and upgrading of other fuels, e.g.,
  - Upgrading and refining heavy crude to produce fuels
  - Hydroprocessing of biofuels (e.g., plant oils, pyrolysis oil, waste oils)

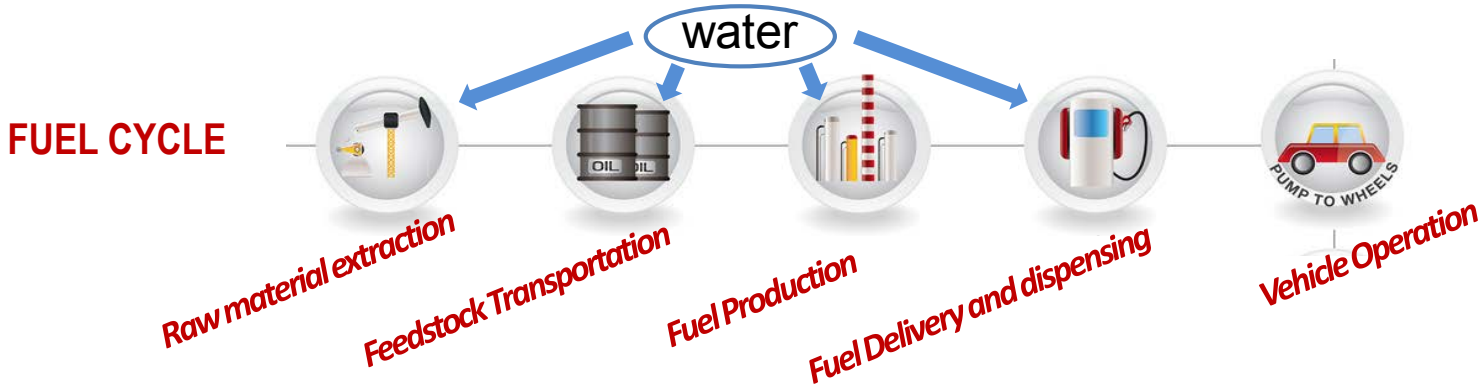
LCA of water consumption for hydrogen production pathways – Relevance



Expanded GREET to include water consumption – Approach

- Water LCA of a fuel: accounts for fresh water consumption along the pathway of producing the fuel from its feedstock

  - ✓ Water withdrawal: fresh water uptake from surface or groundwater
  - ✓ Water consumption: net water consumed through the production process (evaporated or incorporated into the product)
    - Discharged water needs to be evaluated with expanded system boundary to account for its fate



- FCTO, VTO, and BETO supported incorporation of water consumption in GREET
- FCTO supports evaluation of life-cycle water consumption for hydrogen and baseline fuels production pathways
- GREET is expanded to evaluate water consumption factors for various vehicle/fuel systems

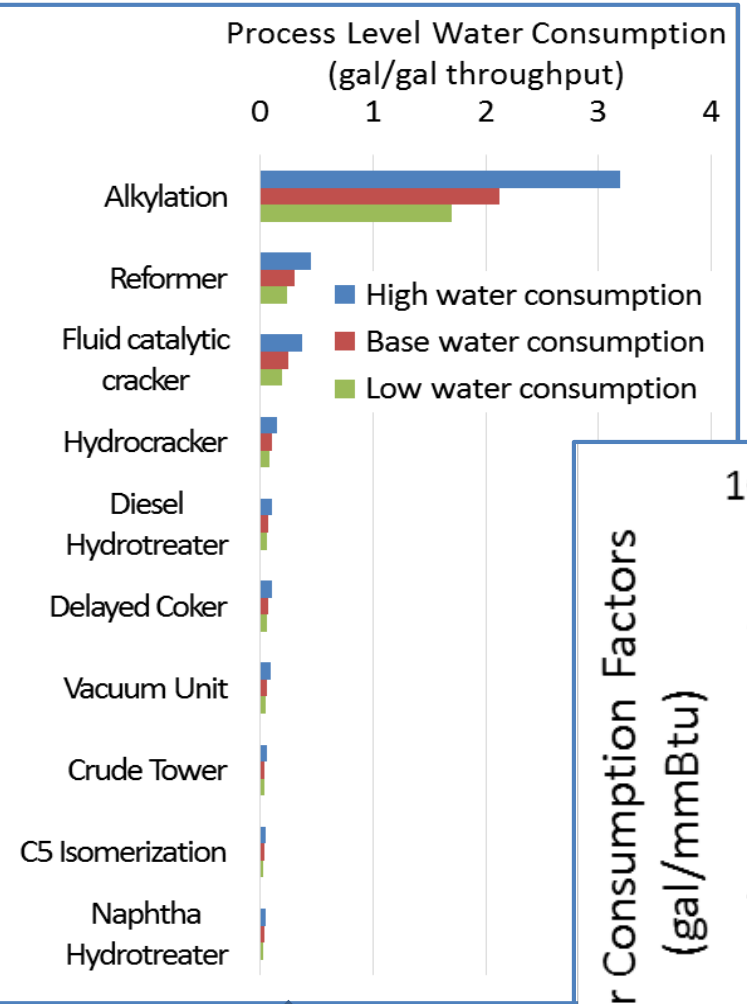
Life-cycle stages and data sources for GREET expansion – Approach

- Identify major contributors in upstream supply chain to water consumption
  - Feedstock production and fuel production
- Evaluate water consumption for fuel production stage
  - Water treatment options
  - Process water
  - Cooling water (wet vs. dry, once through vs. recycling)
  - Upstream and indirect water use
- Data Sources
  - Open literature
    - Peer-reviewed reports and papers: EPRI (2013), Choi et al. (2009), Spath et al. (2005)
    - Public database: EPA's Clean Watersheds Needs Survey (2012)
  - Industrial sources
  - Modeling of physical processes
    - Refinery water analysis model by Jacobs® Consultancy
    - H2A models
  - Water footprint database and assessment tools developed at Argonne
  - National Agricultural Statistics Service (NASS), part of USDA and USGS

Continued incorporation of water consumption in GREET in FY16 – Approach

- Review and update water consumption for baseline fuels and hydrogen production technologies
  - ✓ Petroleum fuels production
  - ✓ Natural gas SMR and electrolysis for hydrogen production
    - ❖ Evaluate fate of discharged water
  - ✓ Biomass gasification
- Examine impact of various cooling technologies and cooling water source in thermoelectricity generation
  - ✓ Single loop vs. recirculating
  - ✓ Tower vs. pond
  - ✓ Freshwater vs. saline, brackish water or wastewater
- Address outstanding water consumption issues for hydrogen production
  - ✓ Allocation of water consumption by multipurpose hydropower
  - ✓ Regional variations in water consumption factors of power generation

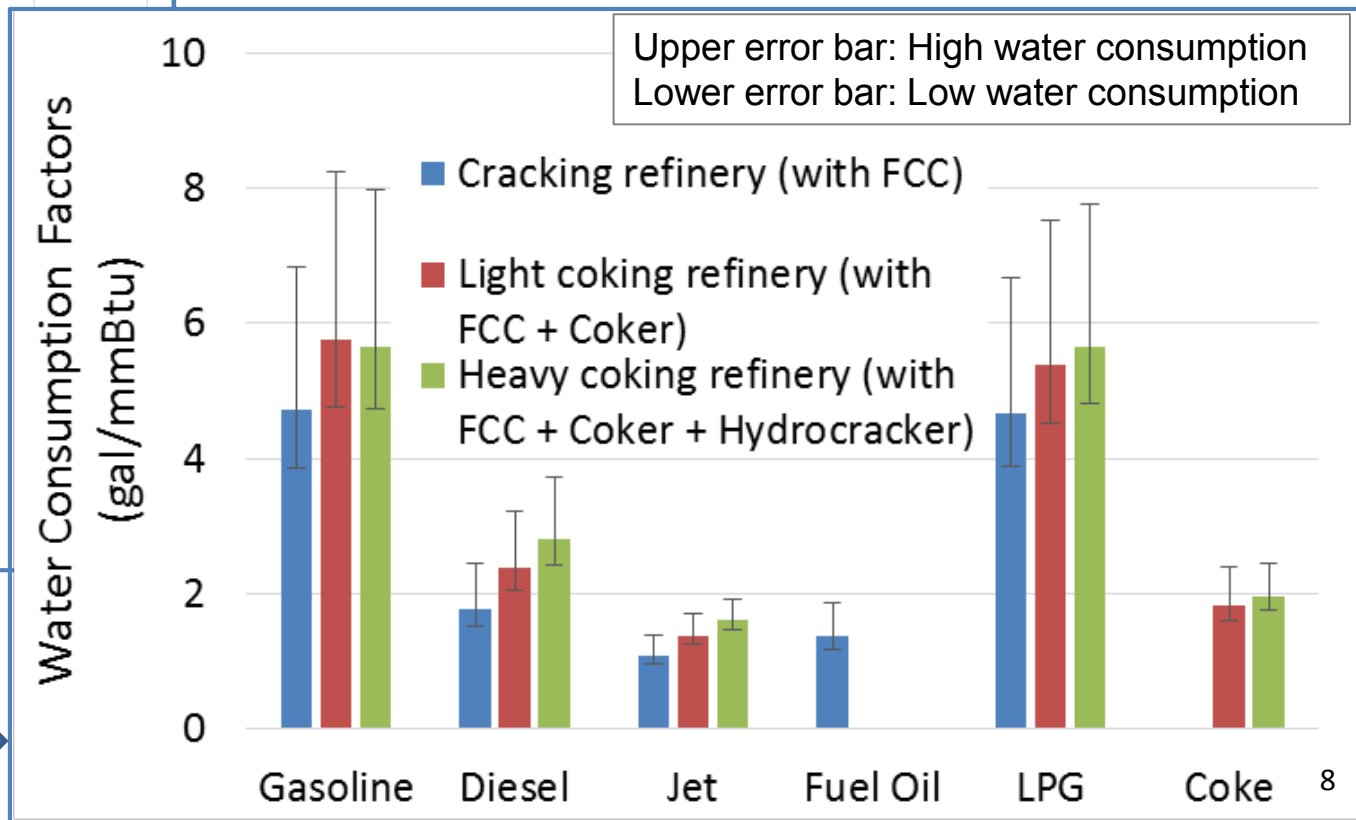
Updated water consumption factors (WCF) for petroleum products using detailed refinery water analysis model – Accomplishment



- Gasoline and LPG consume more water than the other products because their production involves water-intensive processes
- More complex refineries are more water-intensive in general
- Water consumption correlates well with energy consumption

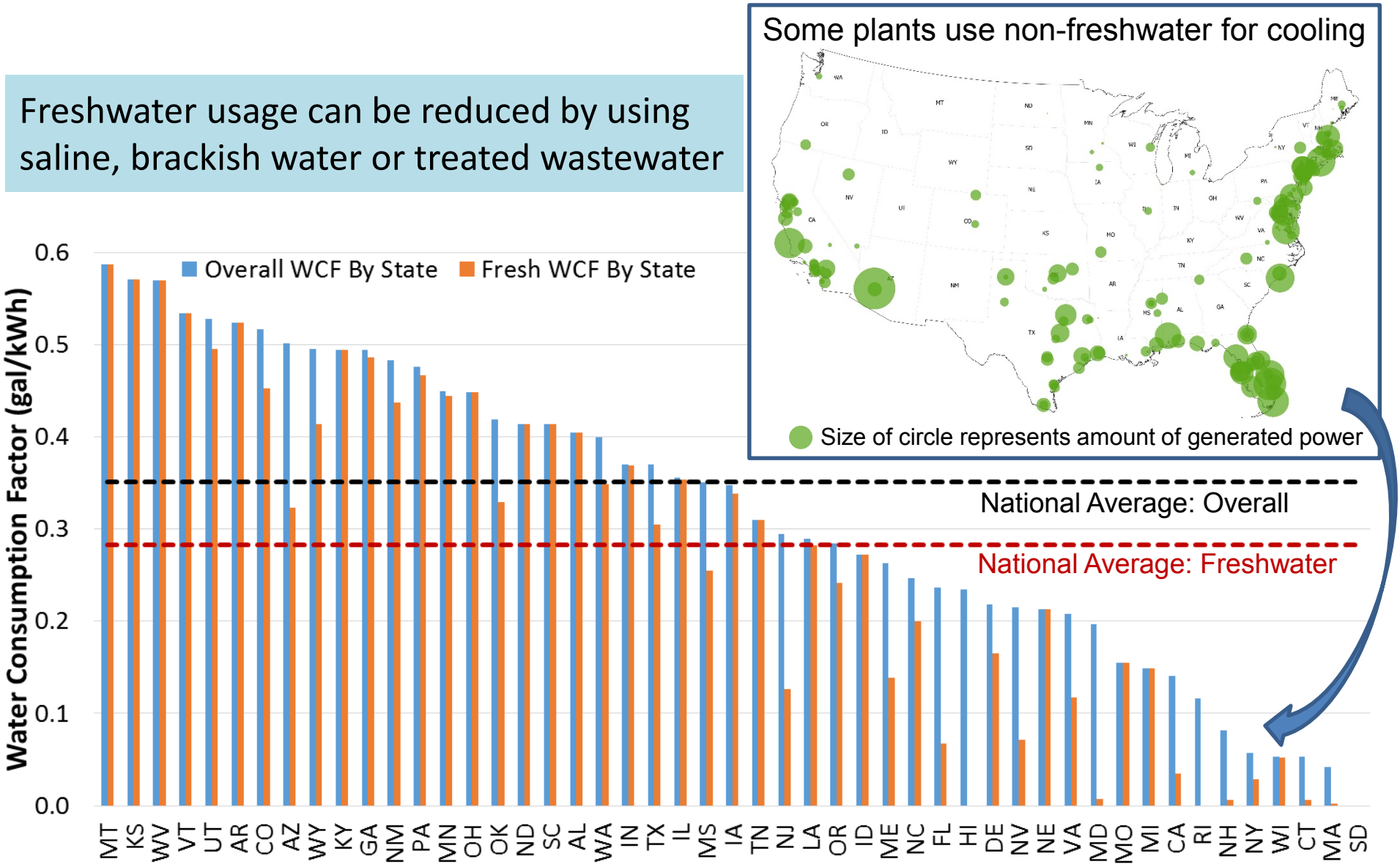
By refining process

By refinery product



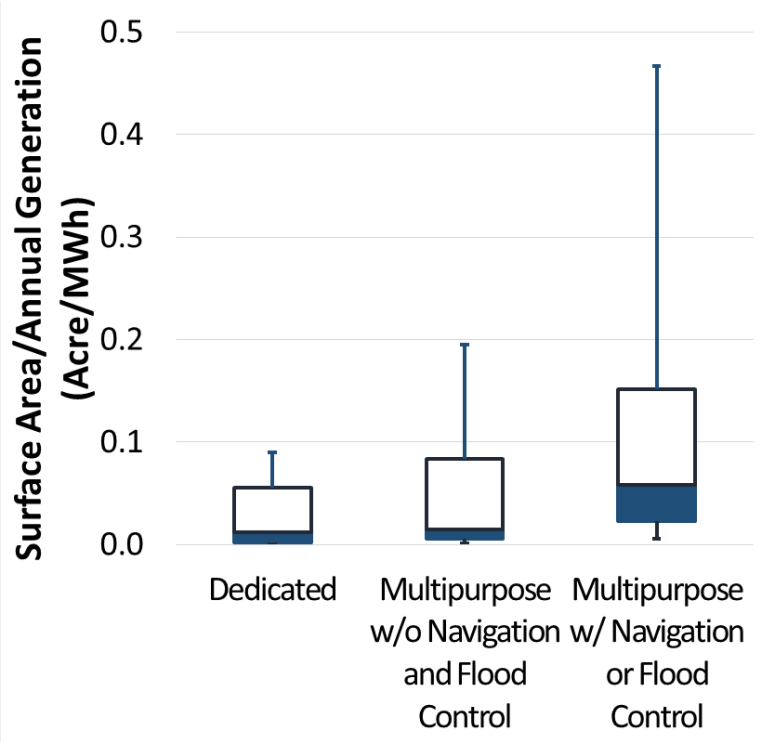
Developed cooling WCF of thermoelectric generation by region – Accomplishment

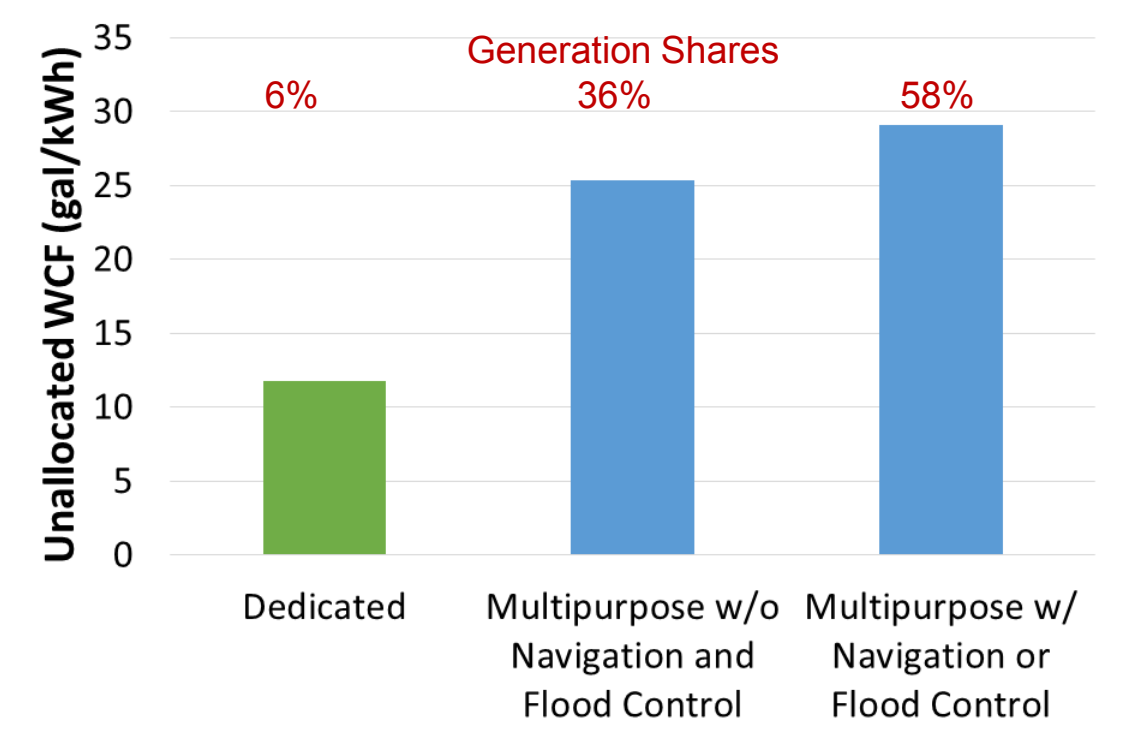
Freshwater usage can be reduced by using saline, brackish water or treated wastewater



Source: US EIA (EIA-923 and EIA-860)

Significant variability/uncertainty exist with hydropower WCF – Accomplishment

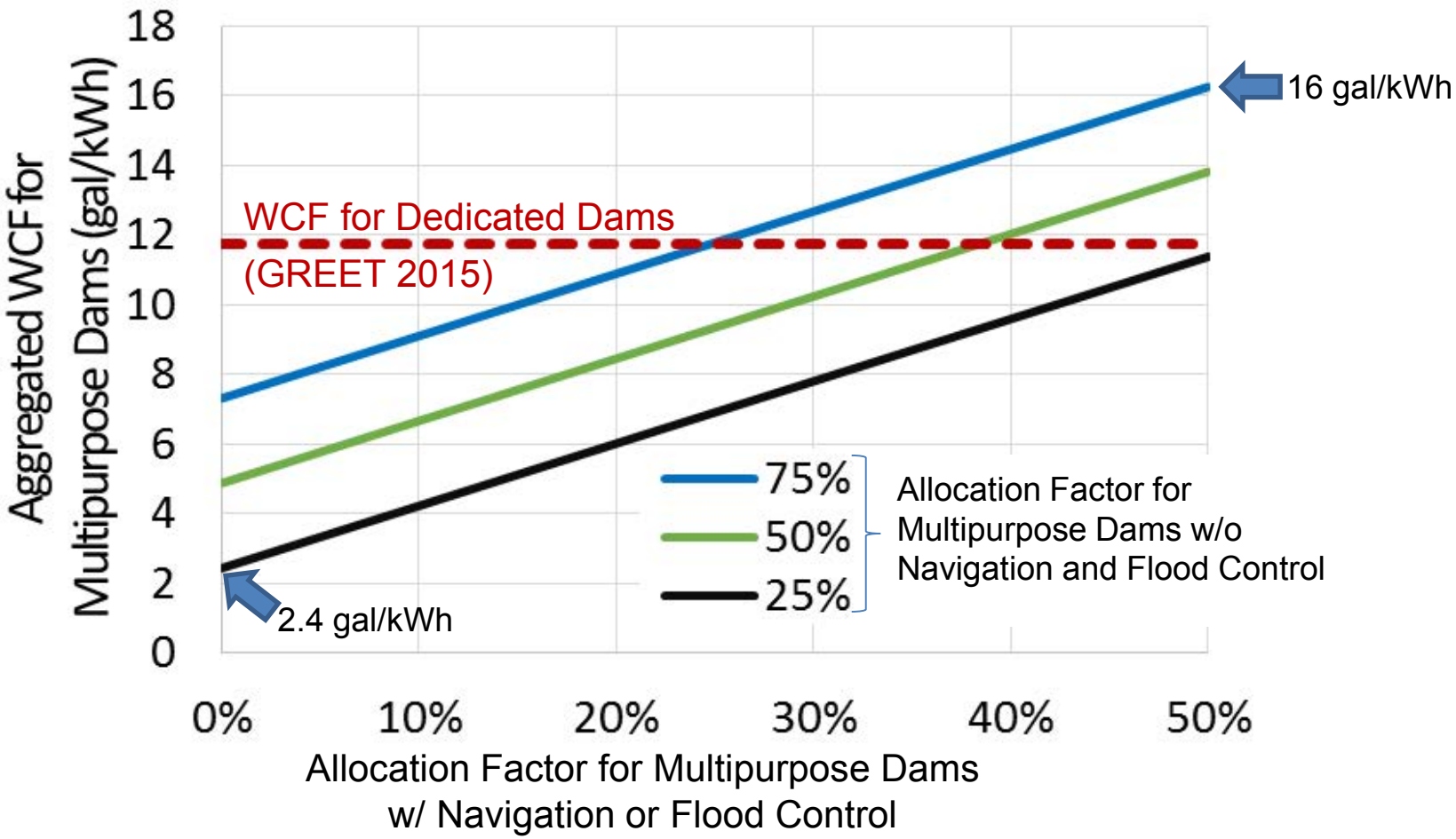




Source: eGRID (US EPA) and National Inventory of Dams (US Army Corps of Engineers)

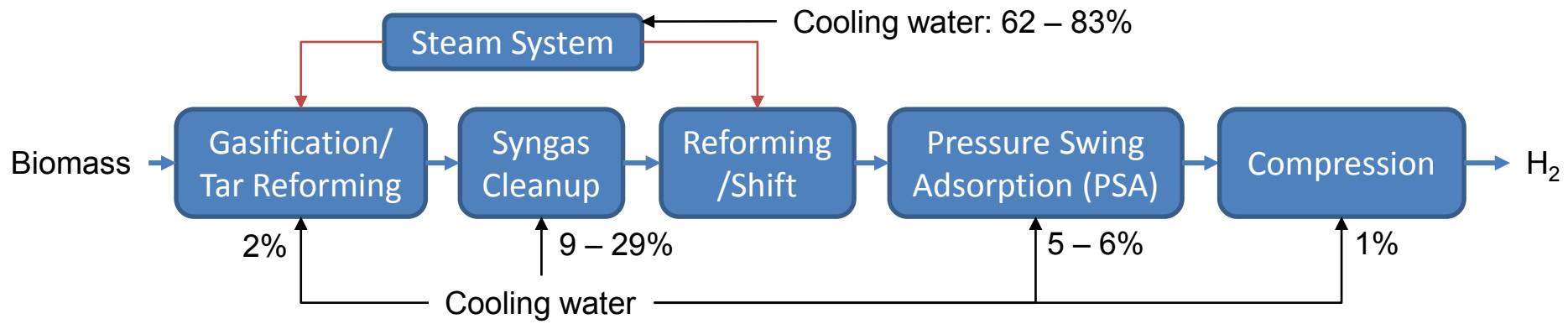
- Multipurpose dams dominate hydropower generation and consume (or evaporate) a large amount of water due to their larger surface area
- Allocation of water consumptions for these multipurpose dams is a key issue
- Two different allocations could be used for these multipurpose dams (by purpose)
  - With navigation or flood control: Large surface area, mainly for navigation and flood control
  - Without navigation and flood control

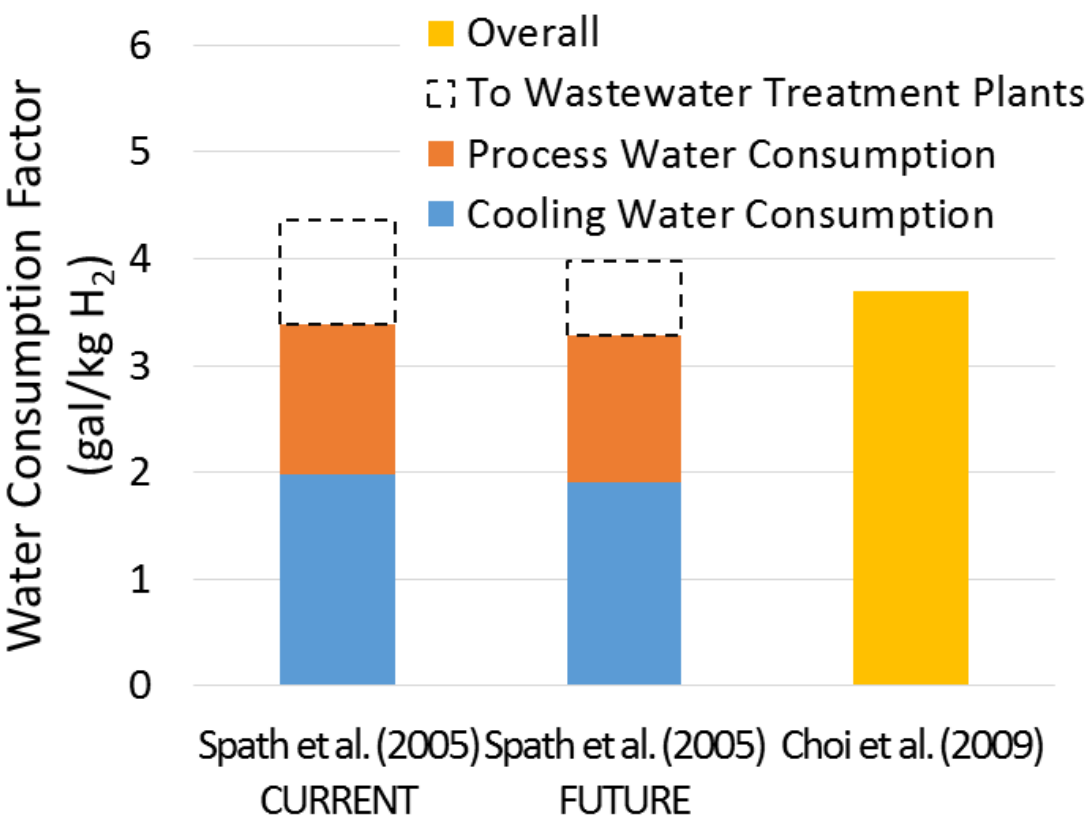
WCF for multipurpose dams varies by allocation factor approach – Accomplishment



- Pasqualetti and Kelley (2008) allocated 55% of water consumption by Glen Canyon Dam in Lake Powell (multipurpose w/o navigation and flood control) to hydropower using the revenue from four principal uses (hydropower, recreation, irrigation and domestic supply)

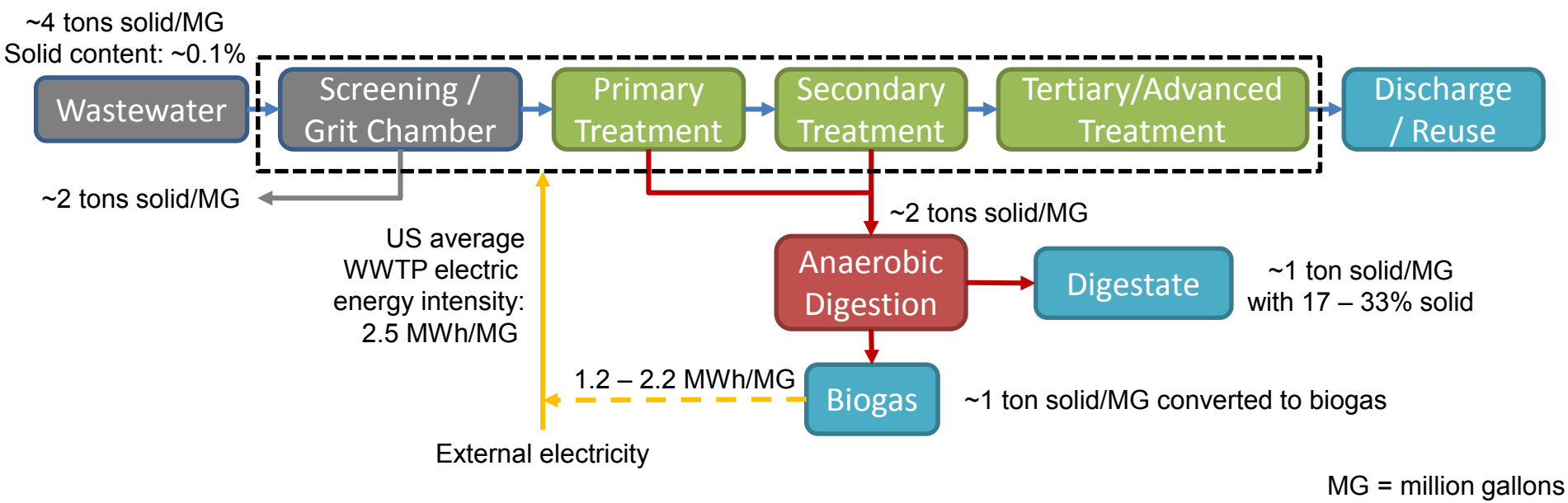
Updated WCF for hydrogen production via biomass gasification – Accomplishment





- WCF of H_2 from biomass gasification: 3.3 – 3.7 gal/kg H_2
- 0.7 – 1.0 gallon of water per kg H_2 is sent to wastewater treatment plants before discharge
- Steam turbine condenser is the largest cooling water consumer, followed by gas clean-up

Examined Wastewater Treatment Plants (WWTP) to evaluate impact of discharged water in WCF calculations – Accomplishment



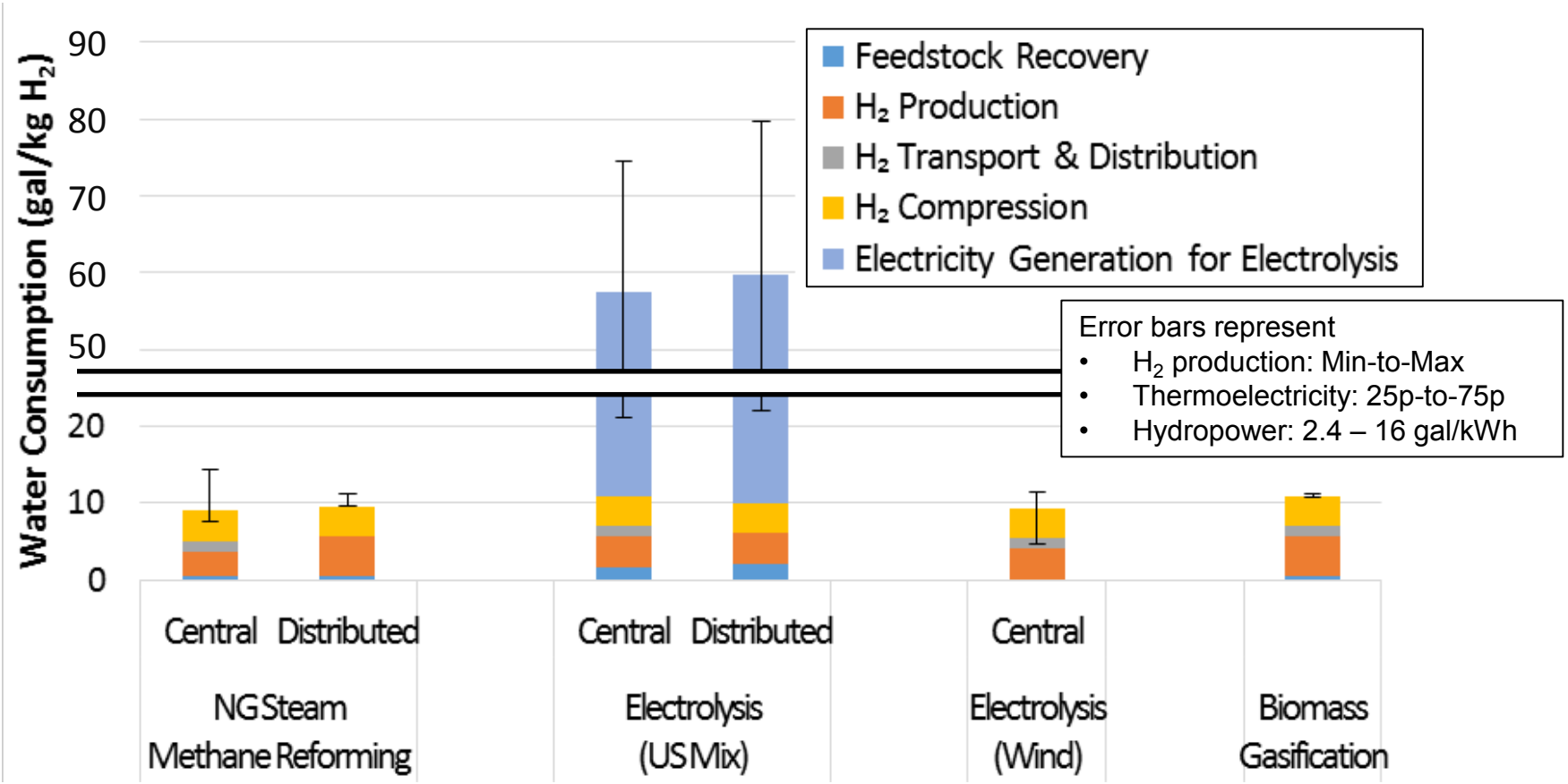
- ❑ Water consumption associated with wastewater treatment process electricity
  - ✓ Without CHP: 0.0028 MG/MG (or 0.28%)
  - ✓ With CHP: 0.0003 – 0.0015 MG/MG (or 0.03 – 0.15%)
- ❑ Water consumption by solid disposal: 0.001 – 0.02 MG/MG (or 0.1 – 0.2%)
- ❑ Water consumption via evaporation: negligible
- ❑ WCF of wastewater treatment **is negligible**
  - ❑ Without CHP: **0.38 – 0.48%**
  - ❑ With CHP: **0.13 – 0.35%**

Revised Water Consumption of SMR and Electrolysis – Accomplishment

	Production Technology				
	SMR			Electrolysis	
Process	Central w/o CCS	Central w/CCS	Distributed	Central	Distributed
~~Water Treatment Process~~	~~0.7~~	~~0.75~~	~~3.3~~	~~3.9~~	~~3.9~~
Production Process	1.7	1.7	2.5	2.9	2.9
Cooling Loss	0.65	1.15	0	1.2	0
Total WCF [gal/kgH_2]	3.1 → **2.4**	3.6 → **2.9**	5.8 → **2.5**	8.0 → **4.1**	6.8 → **2.9**

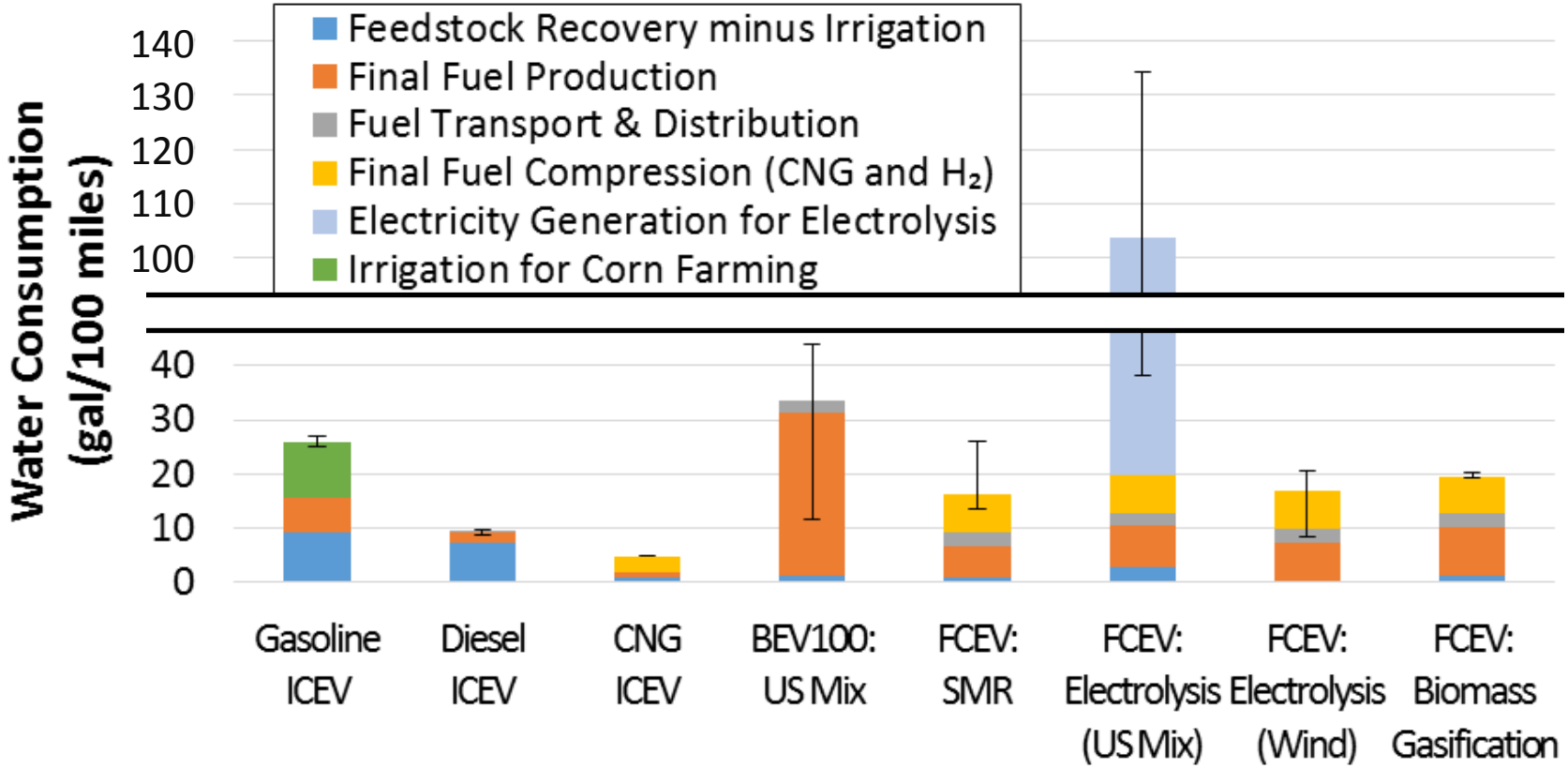
Water consumption factors for SMR and electrolysis were revised after discounting discharged water from being "consumed"

Life-cycle water consumption of hydrogen production varies by feedstock source and conversion process – Accomplishment



- ✓ WCF for electricity strongly impacts water consumption for H_2 production via electrolysis and compression at refueling stations
- ✓ H_2 production and compression are the largest water consumers in the fuel's life cycle

Life-cycle water consumption among various transportation fuels is dominated by electricity use
– Accomplishment



	Gasoline ICEV	Diesel ICEV	CNG ICEV	BEV100: US Mix	FCEV: SMR	FCEV: Electrolysis (US Mix)	FCEV: Electrolysis (Wind)	FCEV: Biomass Gasification
Fuel Economy: (MPPGE)	26	31	27	94	55	55	55	55

- FCEVs fueled by H_2 from SMR and biomass gasification consume 37% and 24% less water compared to baseline gasoline (E10) ICEVs, respectively.

Summary – Accomplishment

- Updated water consumption for petroleum products
- Evaluated impact of various cooling technologies and cooling water source in thermoelectricity generation
- Examined impact of methodology for allocating water consumption to hydropower generation from multipurpose reservoirs
- Examined WWTP to evaluate impact of discharged water in water consumption factor calculations
- Revised water consumption factors for hydrogen production via biomass gasification, SMR and electrolysis
- Expanded the GREET model to include updated and new water consumption factors
- Compared water consumption on per mi basis for various fuel/vehicle combinations

Collaborations and Acknowledgments

- Jacobs® Consultancy developed a detailed refinery water analysis model to estimate WCF of petroleum products
- Jason Turgeon, US EPA Region 1 Energy and Climate Unit, and LouAnn Unger, EPA Region 5 Water Division, provided critical information on WWTPs operation and regulations
- Meltem Urgun-Demirtas, Principal Environmental Engineer in ANL, shared information on energy and water consumption in WWTPs
- Received water consumption data for large scale SMR plants from industrial gas companies
- Reached out to individual organizations and U.S. DRIVE Partnership technical teams for guidance and input

Future Work

- Continue development and implementation of water consumption factors of other hydrogen and alternative fuel pathways in GREET
- Examine hydrogen pathways with low or no water consumption (e.g., tri-generation CHHP systems)
- Reconcile different water consumption evaluation methods with respect to system boundary and allocation.
- Assess variability of water consumption by region and availability
- Develop probability distribution functions for WCF of various processes
- Develop water consumption factors for chemicals and vehicle materials (GREET2)
- Examine energy penalty/cost of alternative water production processes (e.g., desalination)
- Update GREET model and submit report with new water factors for peer review

Project Summary

- **Relevance:** Develop water consumption as a new sustainability metric for evaluating the production of energy products. Life-cycle analysis (LCA) is needed to estimate water consumption to provide a consistent accounting of water consumption of transportation fuels (including hydrogen).
- **Approach:** Expand the GREET model to assess life-cycle water consumption along the pathways of producing transportation fuels from various feedstock sources.
- **Collaborations**: Sought data and guidance from the industry experts who provided guidance and valuable input on various production and water treatment technologies.
- **Technical accomplishments and progress:**
  - Updated water consumption for petroleum products
  - Evaluated impact of various cooling technologies and cooling water source in thermoelectricity generation
  - Examined impact of methodology for allocating water consumption to hydropower generation from multipurpose dams
  - Examined WWTP to evaluate impact of discharged water in water consumption calculations
  - Revised water consumption factors for hydrogen production via biomass gasification, SMR and electrolysis
- **Future Research**:
  - Examine hydrogen pathways with low or no water consumption (e.g., tri-generation CHHP systems)
  - Develop water consumption factors for vehicle materials (GREET2)
  - Assess variability of water consumption by region and availability
  - Develop probability distribution functions for WCF of various processes

Argonne NATIONAL LABORATORY

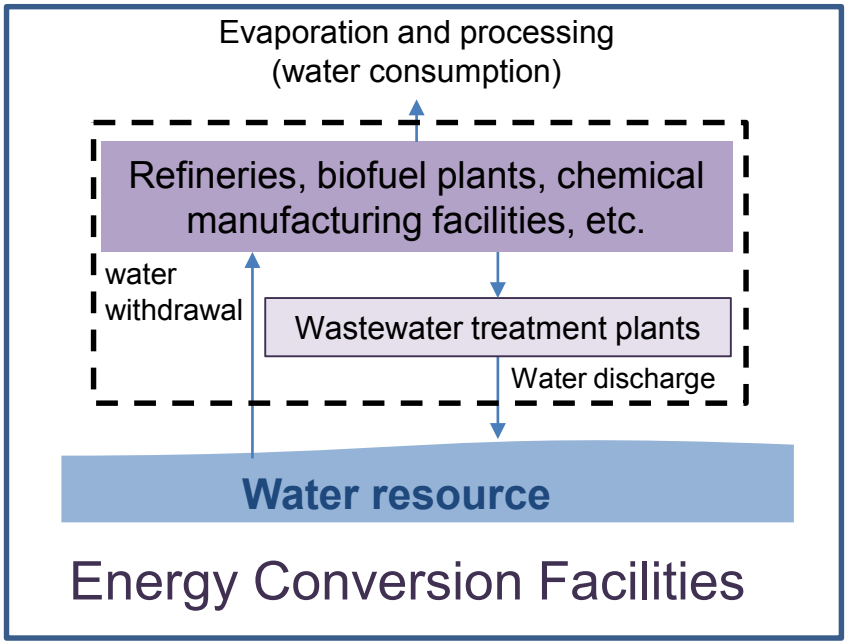
Amgad Elgowainy
aelgowainy@anl.gov

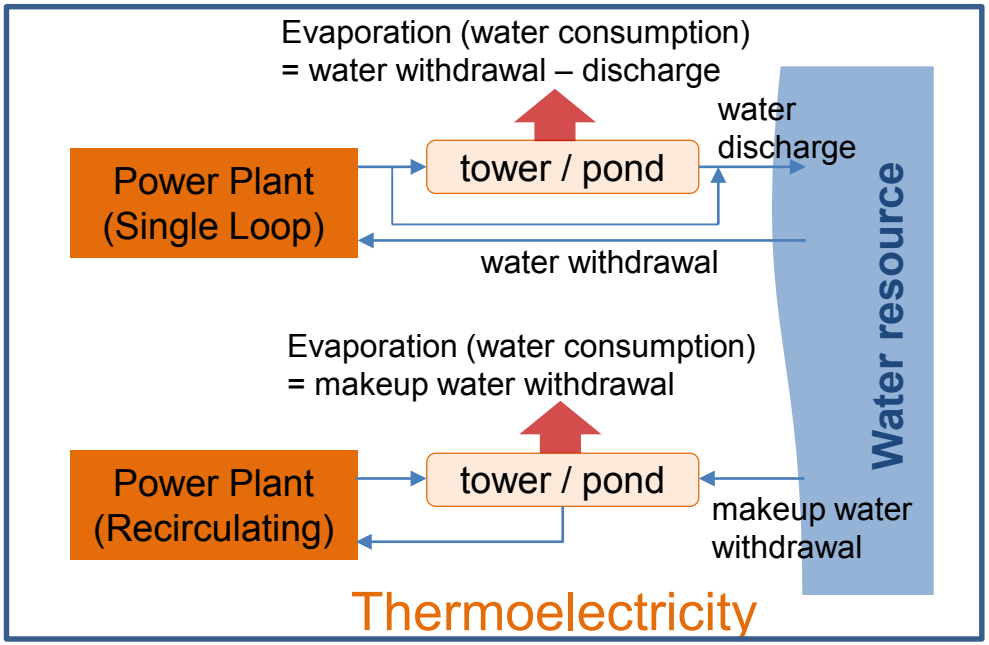
Acronyms

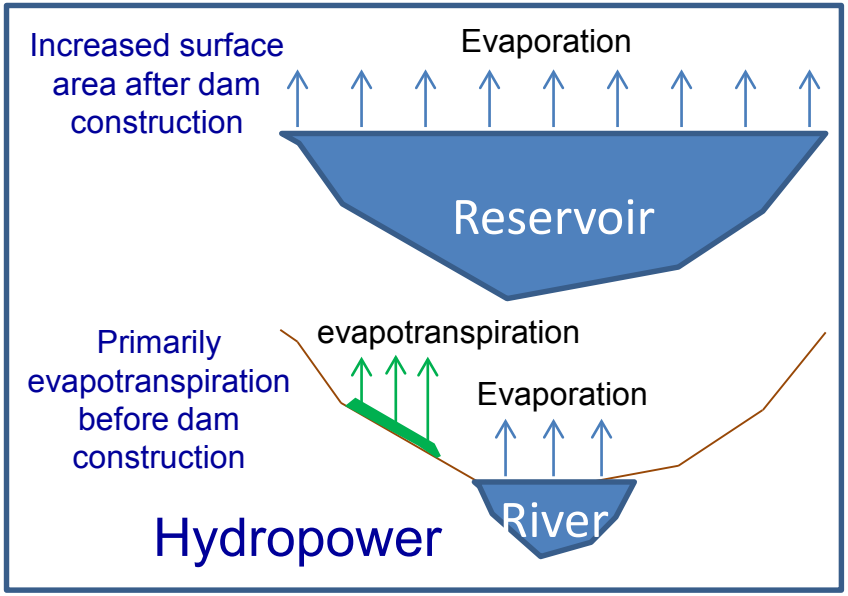
- ANL: Argonne National Laboratory
- BETO: Biomass Energy Technologies Office
- BEV: Battery Electric Vehicles
- CHP: Combined Heat and Power
- CNG: Compressed Natural Gas
- DOE: Department of Energy
- E10: 10% ethanol by volume blended in gasoline
- EIA: Energy Information Administration
- EPA: Environmental Protection Agency
- EPRI: Electric Power Research Institute
- FCC: Fluid Catalytic Cracking
- FCEV: Fuel Cell Electric Vehicle
- FCTO: Fuel Cell Technologies Office
- FY: Fiscal Year
- Gal: Gallon
- GHG : Greenhouse Gases
- GREET: Greenhouse gases, Regulated Emissions, and Energy use in Transportation
- H_2: Hydrogen
- H2A: Hydrogen Analysis
- ICEV: Internal Combustion Engine Vehicle
- LCA: Life-Cycle Analysis
- LPG: Liquefied Petroleum Gas
- MCFC: Molten-Carbonate Fuel Cells
- MG: Million Gallons
- MPGGE: Miles Per Gallon of Gasoline Equivalent
- MSM: Macro-Systems Model
- NG: Natural Gas
- PAFC: Phosphoric Acid Fuel Cells
- PSA: Pressure Swing Adsorption
- RD&D: Research, Development, and Demonstration
- SMR: Steam Methane Reforming
- U.S. DRIVE: United States Driving Research and Innovation for Vehicle efficiency and Energy sustainability
- USDA: United States Department of Agriculture
- USGS: United States Geological Survey
- US Mix: US electricity grid mix
- VTO: Vehicle Technologies Office
- WCF: Water Consumption Factor
- WWTP: Wastewater Treatment Plants

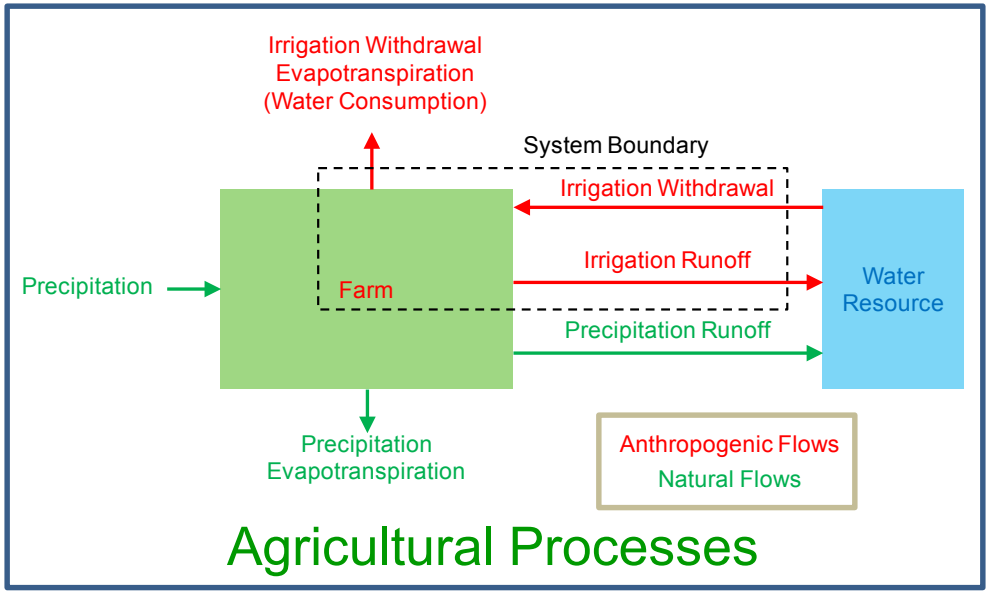
Technical Backup Slides

Water consumption accounting –Approach

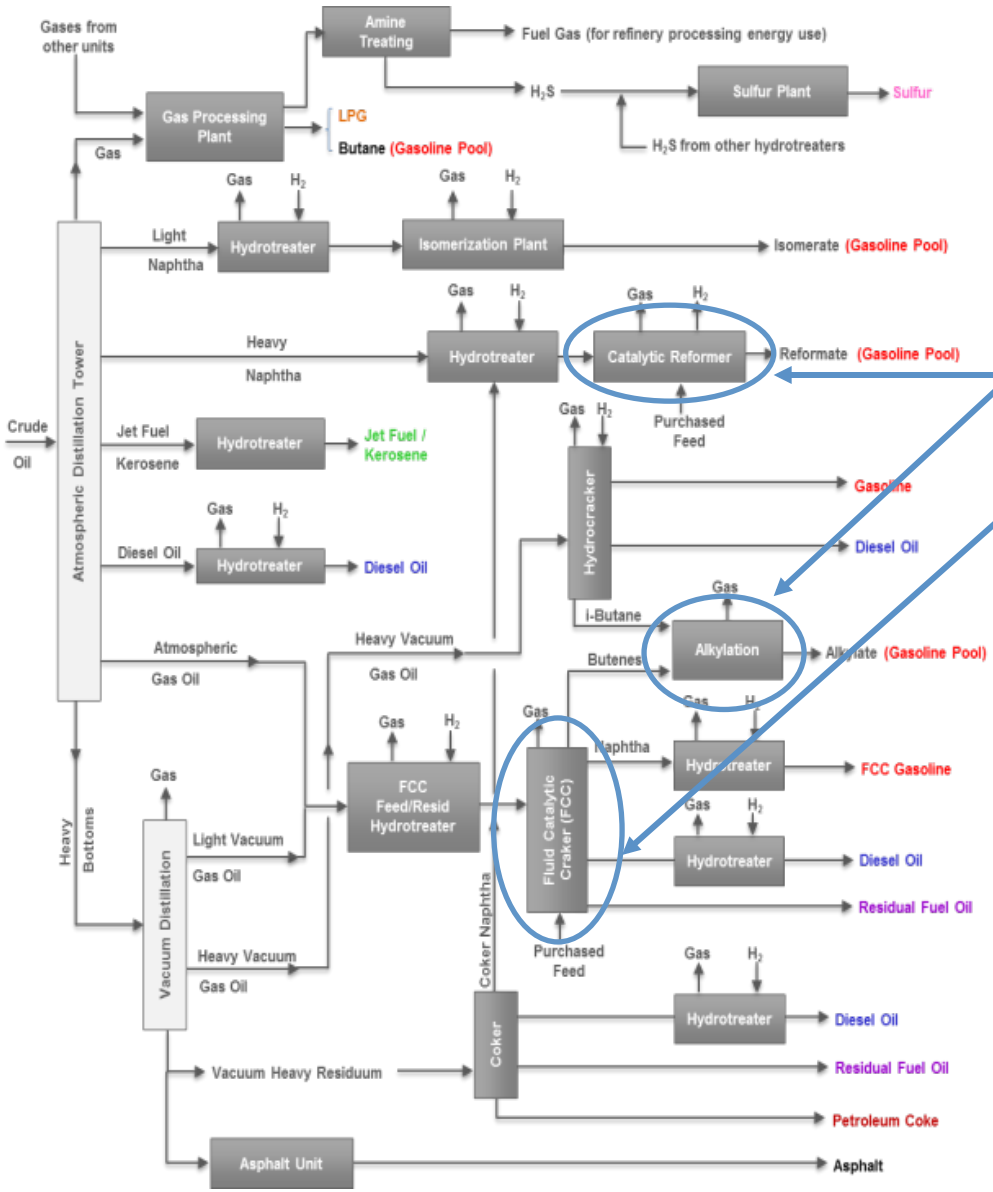


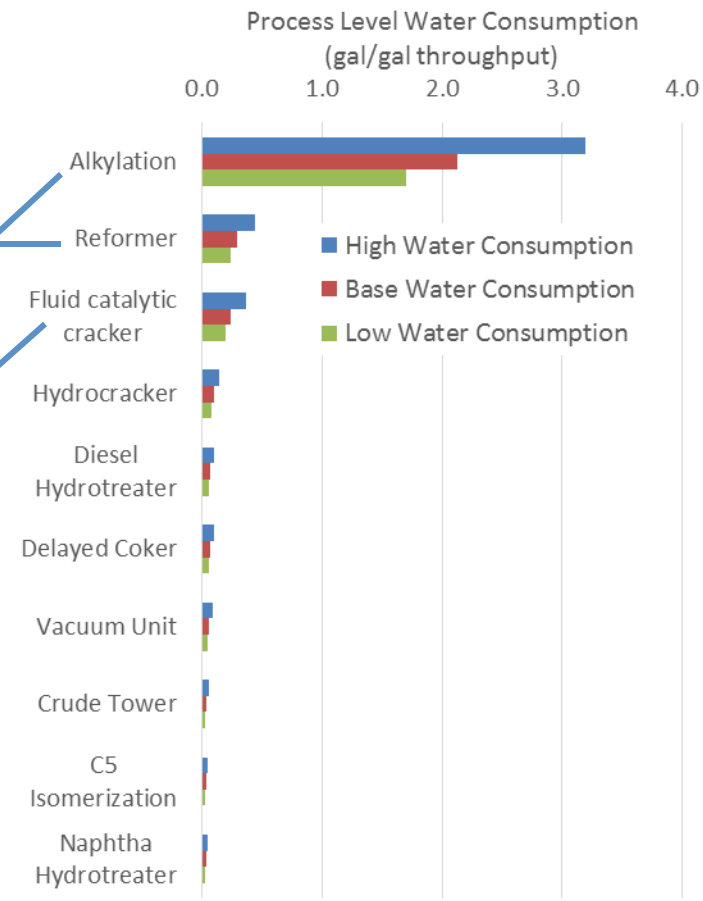






Estimated WCFs for petroleum products using detailed refinery water analysis model– Accomplishment





Collected data on electricity and water consumption in WWTPs – Accomplishment

	Flow Rate (MGD)[a]				Electrical Energy Intensity (kWh/MG)[b]
	Municipal		Industrial		
	w/o Reuse	w/ Reuse	w/o Reuse	w/ Reuse	
Primary	229	166	11	18	750
Secondary	6,437	133	758	3	2,080
Tertiary/Advanced	9,476	1,249	1,317	116	2,690
Total	**16,142**	**1,548**	**2,086**	**137**	**2,424**

[a] EPA's Clean Watersheds Needs Survey (2012); MGD = Million gallons per day
[b] EPRI's Electricity Use and Management in the Municipal Water Supply and Wastewater Industries (2013); MG = Million gallons

- ❑ Approximately 8.5 % of wastewater treated in WWTPs is reused
- ❑ With pumping energy, total electricity energy intensity is 2.5 MWh/MG
  - ✓ Electric energy intensity for pumping in WWTP is 1.3 MWh/MG
- ❑ With electricity WCF of 1.13 gal/kWh, WCF of wastewater treatment is **0.0028 gal/gal** (without biogas CHP)