2018 DOE Hydrogen and Fuel Cells Program

Annual Merit Review

Regional Water Stress Analysis with Hydrogen Production at Scale

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SA039

Overview

Timeline

- Start: April 2013
- End: Determined by DOE
- % complete (FY18): 70%

Barriers to Address

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

Budget

- Funding for FY17: $175K
- Funding for FY18: $175K

Partners/Collaborators

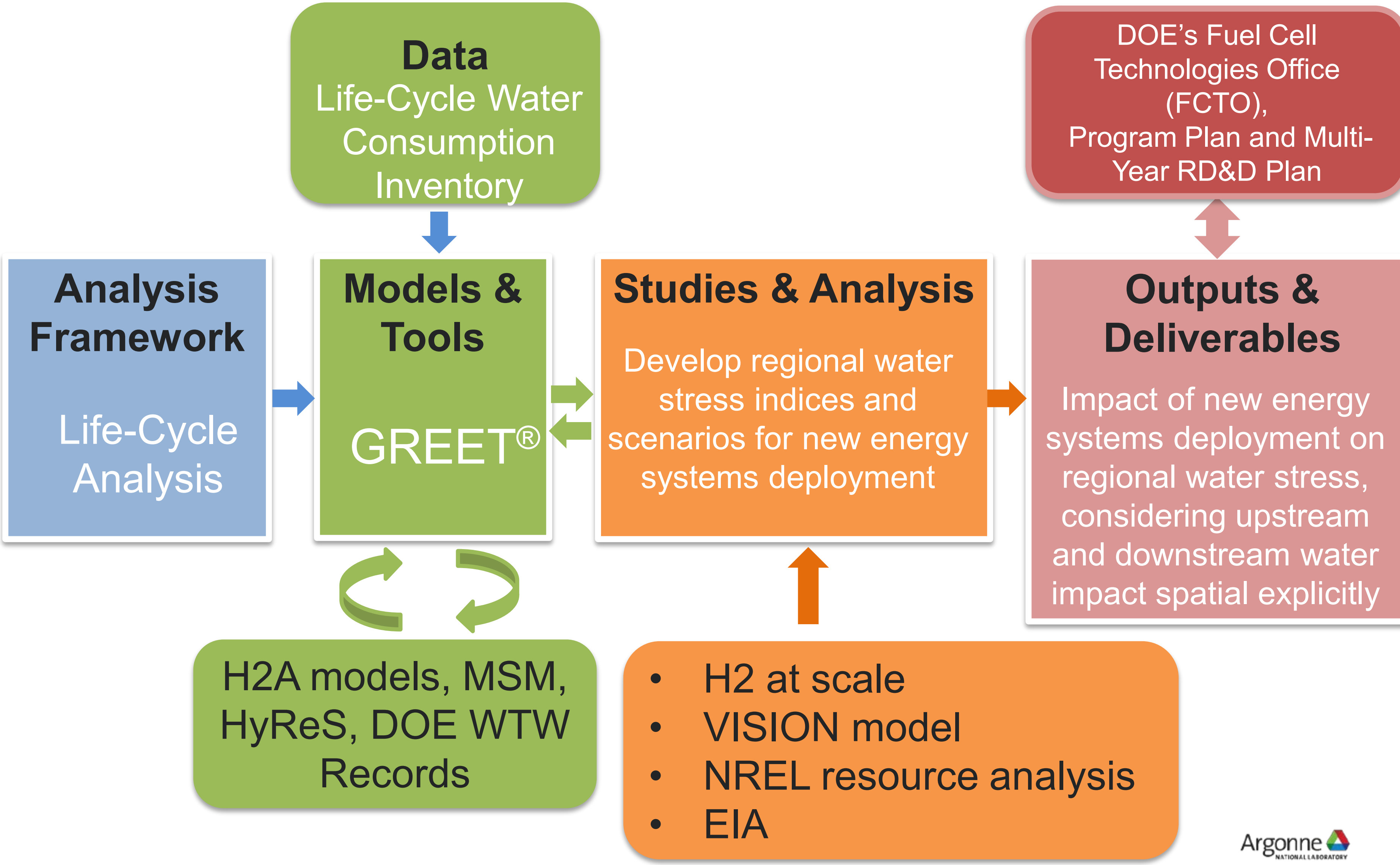
- Environmental Protection Agency
- National Energy Technology Laboratory
- Duke University
- U.S. Bureau of Reclamation
- U.S. Army Corps of Engineers
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory

Relevance/Impact

Objective: Evaluate impacts of deploying energy systems on the regional water consumption in the United States, by considering local water supply and demand

- **Freshwater is essential for energy systems**
  - Energy systems rely heavily on freshwater; evaluating freshwater consumption for energy systems is essential to sustainability assessment of large-scale hydrogen fuel cell vehicles deployment.
- **Water supply and demand vary by region**
  - The impact of water consumption on water stress varies regionally depending on available freshwater resources in each region.
- **Analyzing regional water consumption impact for electricity generation is important**
  - Electricity is a key resource for generating or packaging hydrogen; understanding water consumption impact of electricity generation is important to analyze its impact on water stress in different regions.

Regional water consumption impact analysis for energy systems – Relevance



Regional water consumption impact analysis using AWARE-US CFs – Approach

- AWARE-US characterization factors (CFs) express remaining freshwater resources in each region relative to US average freshwater availability. CF ranges from 0.1 to 100; higher values means higher water stress and lower values means more water abundant.

$$\text{AWARE-US CF}_i = \frac{\text{US average available water remaining}}{\text{Available water remaining in region } i}$$

Available water remaining = freshwater supply – demand
= (Natural runoff) - (Human water consumption + Environmental water requirement)

- AWARE-US CF is a midpoint indicator that can quantify impact of water consumption as “water scarcity footprint (adjusted water consumption)”, based on local water stress condition; physical unit is US equivalent gal.

[Water scarcity footprint] = [Water consumption] × [AWARE-US CF]

(gal US eq.) (gal)

AWARE: Available WAter REmaining

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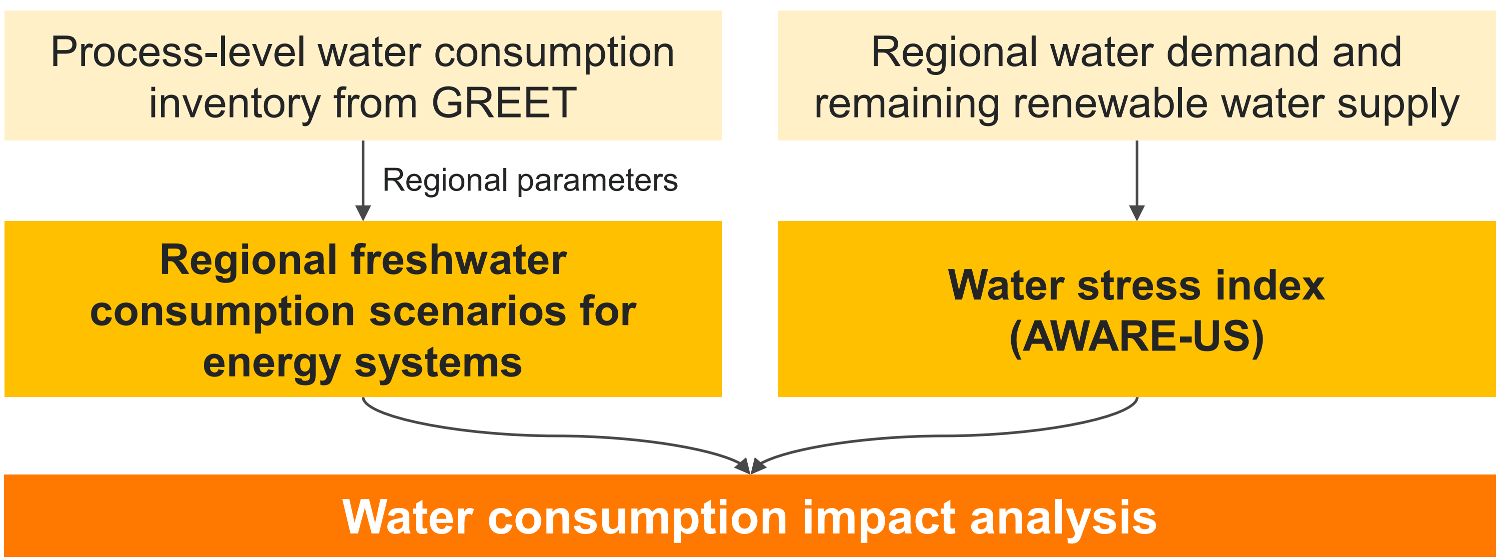
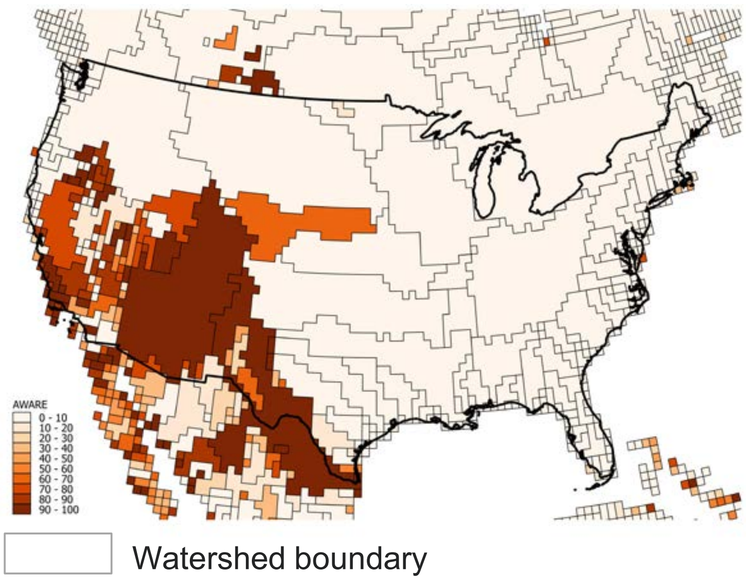
GREET is used to evaluate life-cycle water consumption and its regional impacts – Approach

- FCTO supported water LCA of hydrogen and baseline fuels production pathways.
- GREET accounts for freshwater consumption by various vehicle/fuel systems along the supply chain of fuel production from its feedstock source.
- Water LCA for energy systems:
  - Water consumption of energy production depends on regional parameters.
  - Remaining water availability (supply – demand) varies regionally; water consumption in water-rich and water-stressed regions have different impacts.



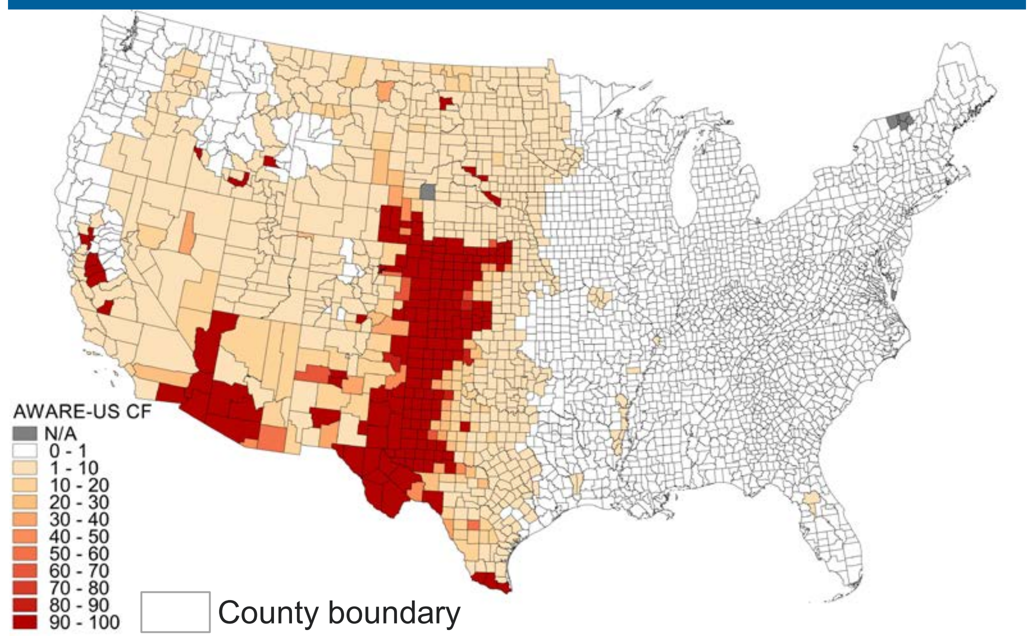
Updated a county-level baseline stress-based water index for the impact analysis – FY17 Accomplishment

Current AWARE-Global index



- Calculated based on a global-hydrological model
- Low resolution (watershed level)
- Normalized by world average

Updated AWARE-US index by ANL

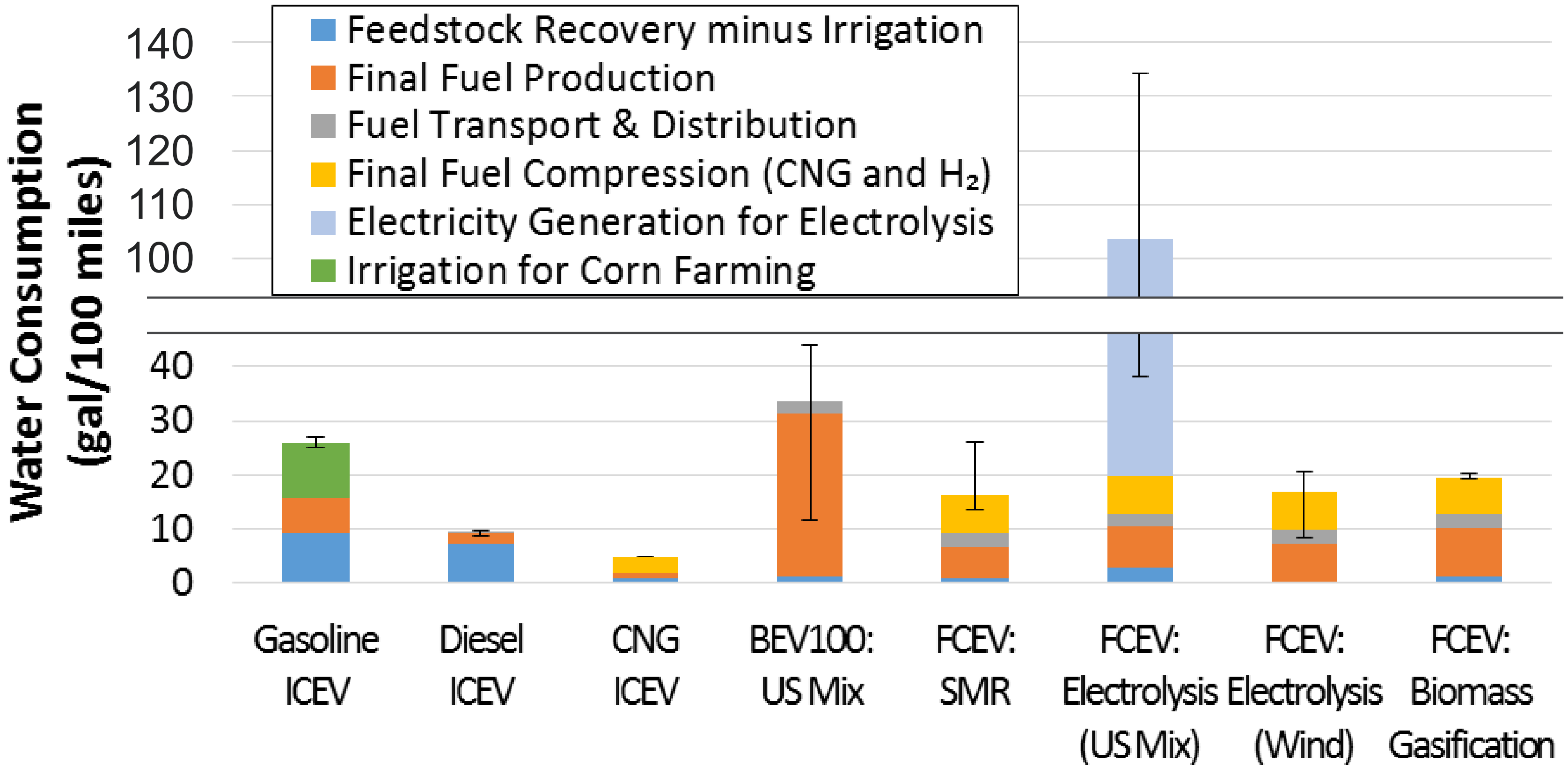


- Based on measured data for the U.S.
- Better spatial resolution (county level)
- Normalized by U.S. average remaining water

✓ **AWARE-US enables high fidelity impact analysis of regional water use by new energy systems deployment in the United States.**

Life-cycle water consumption of various transportation fuels is dominated by electricity use – FY16 Accomplishment

Source: https://www.hydrogen.energy.gov/pdfs/review16/sa039_elgowainy_2016_o.pdf



Fuel Economy: (MPPGE) 26 31 27 94 55 55 55 55

✓ **Analyzing water consumption impact due to electricity generation is essential for fuel use by the transportation sector**

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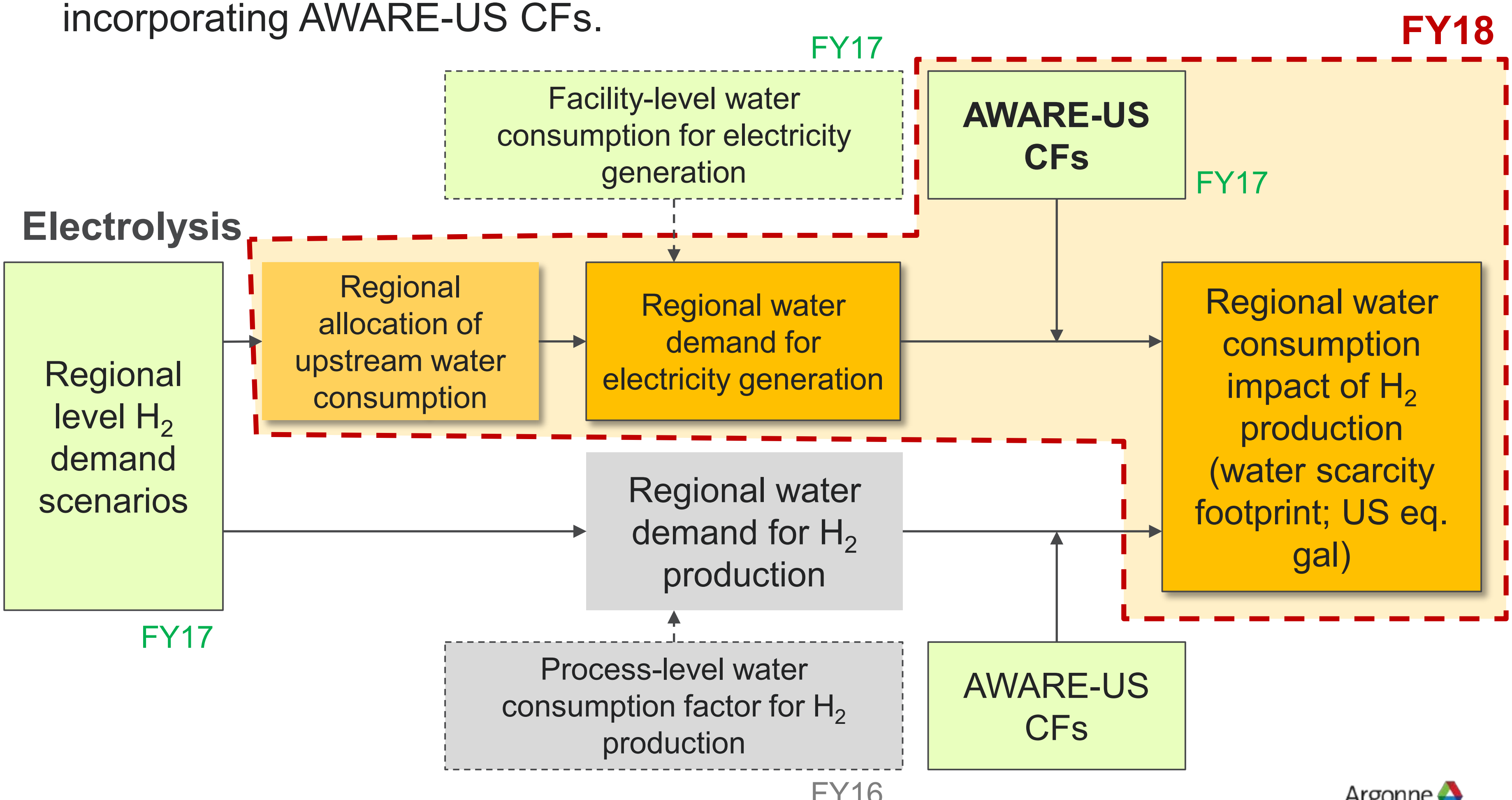
Regional water consumption impact analysis for the electric power sector – Approach

- Previous water studies for the electric power sector focused on analyzing water consumption factors (gal/kWh) (facility-level and NERC-level).
- Expanded the analysis to regional water consumption impact analysis by incorporating AWARE-US CFs.

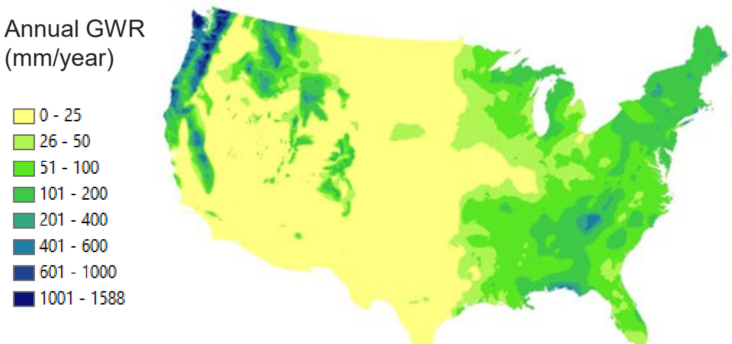


NERC: North American Electric Reliability Corporation

Updated groundwater recharge for AWARE-US – Accomplishment

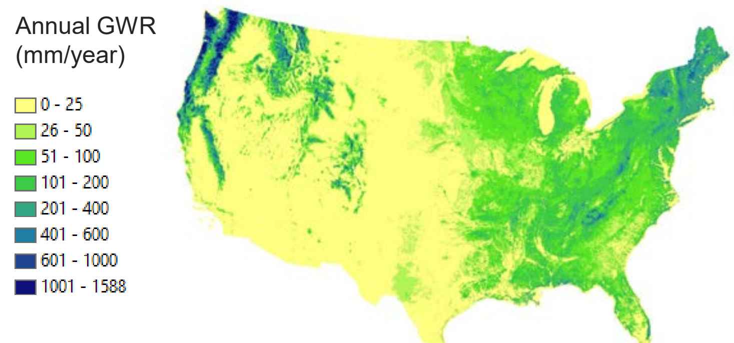
- Replaced previous groundwater recharge (GWR) with the latest data derived from USGS with better spatial resolution and higher data quality.

Previous GWR Data

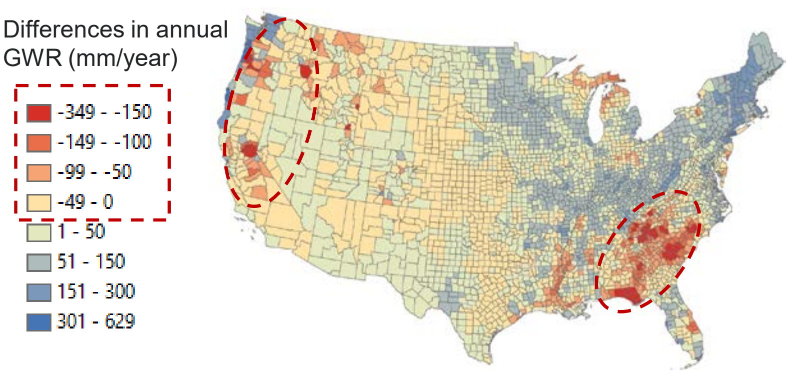


1950-1980 average GWR (Wolock et al. 2003)

Updated GWR Data



2000-2013 average GWR (Reitz et al. 2017)



- Updated data shows significantly lower renewable GWR in Southeastern and the Pacific costal regions.

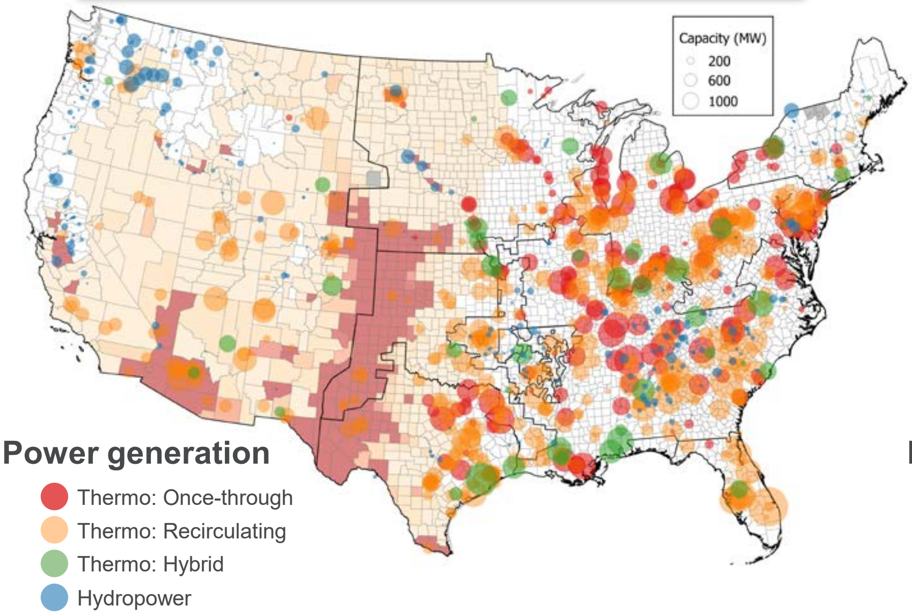
Using improved GWR data allows to:

- ✓ **better differentiate HWC sourced from renewable versus non-renewable groundwater**
- ✓ **improve reliability of AWARE-US, especially in regions relying on groundwater resources**

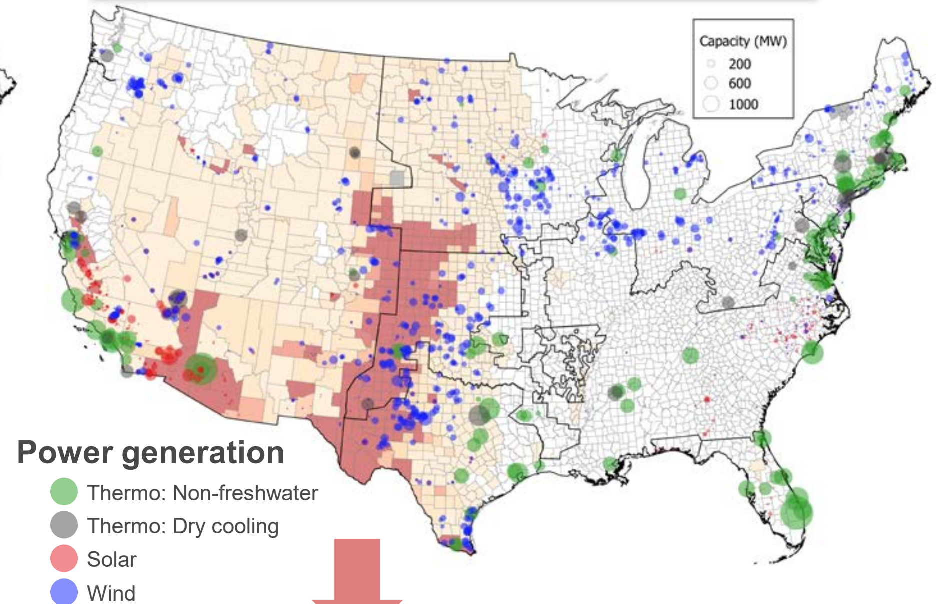
USGS: United States Geological Survey

Electric power generation has adapted to available water resources – Accomplishment

Freshwater use



Non freshwater use

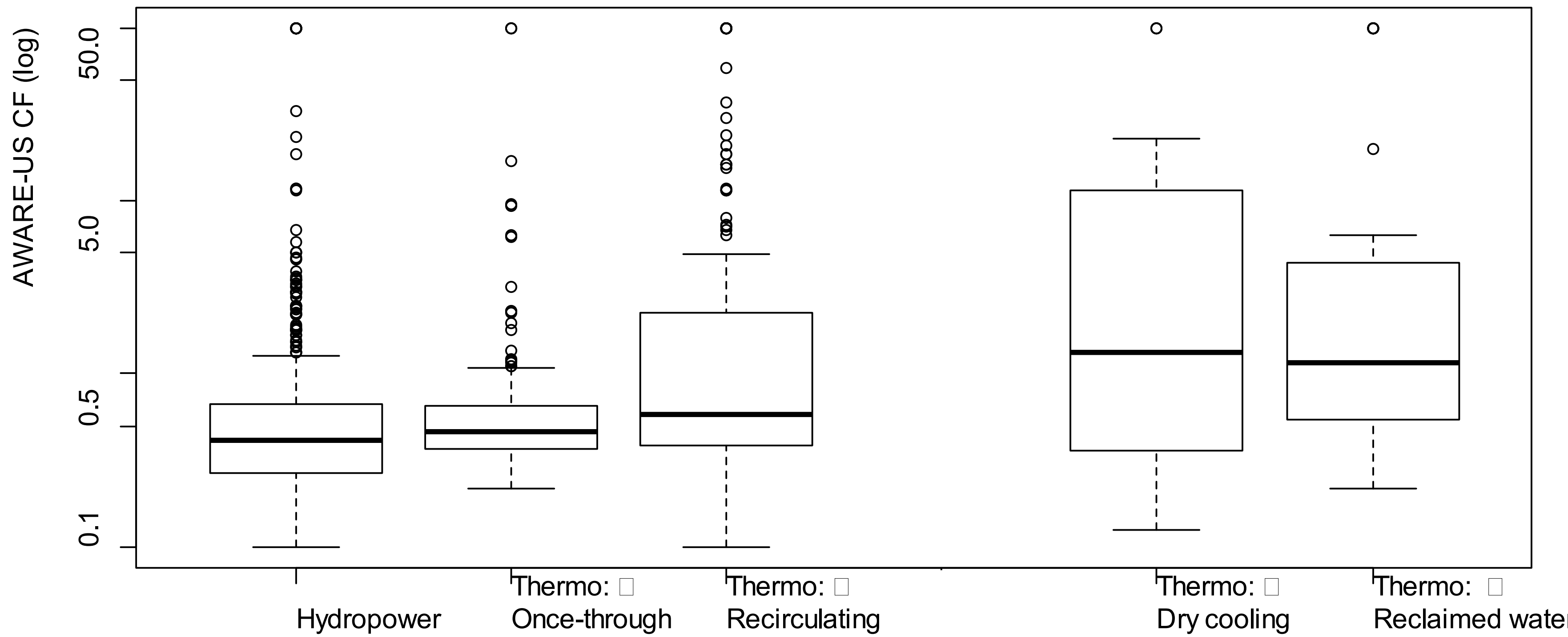


- The regional trend of electric power generation shows the adaptation of the power sector in terms of resource use, including freshwater availability

✓ **Regions in water stressed areas tend to use technologies not involving freshwater consumption for power generation (solar/ wind/ dry cooling / reclaimed water use)**

The types of electricity generation relies on resources (water/solar/wind) – Accomplishment

Freshwater use | **Non freshwater use**

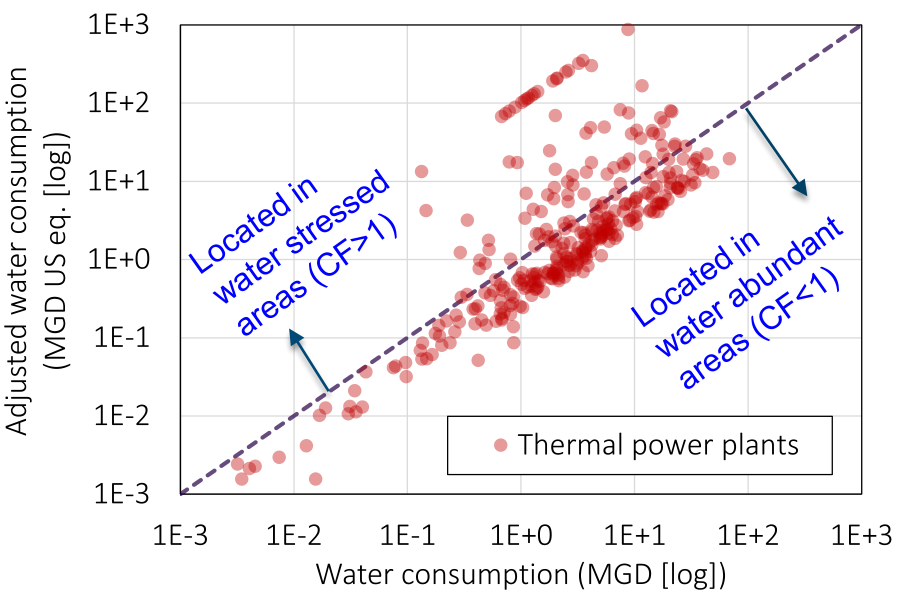


- ✓ **Existing hydro- and thermo-electricity generation facilities are mostly located in water abundant regions (AWARE US CF<1), whereas non-freshwater based power plants are predominately located in water stressed regions (AWARE-US CF>1)**

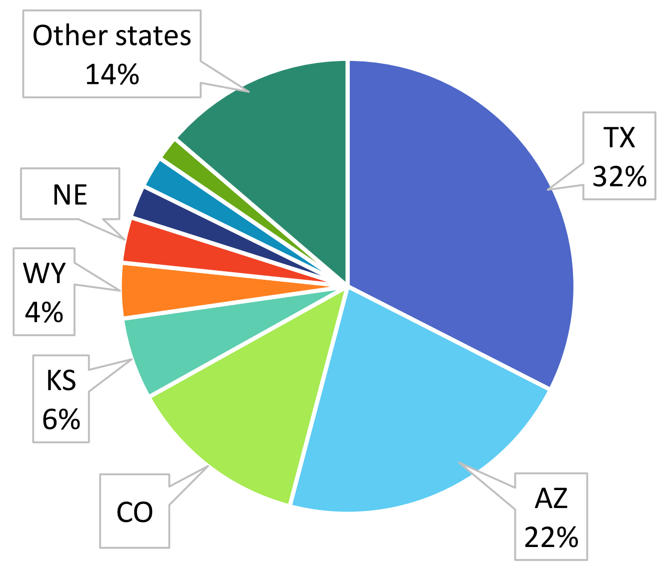
Water consumption impact of thermal power generation – Accomplishment

- 23% of thermal power plants (by power generation) are located in water-stressed counties, where remaining water availability is lower than the U.S. average (AWARE-US CF>1).
  - 91% of these power plants adopted recirculation cooling to reduce cooling water withdrawal; however, re-circulation consumes water via evaporation
  - Texas, Arizona, Colorado and Kansas contributed most of the water scarcity footprint (73%), but only 17% of total thermal power generation
- Using dry cooling or non-freshwater are possible options to reduce freshwater consumption

Water consumption vs. Water scarcity footprint



Water scarcity footprint of thermo-electricity by state



✓ **A majority of existing thermal power plants that use freshwater are located in water abundant regions**

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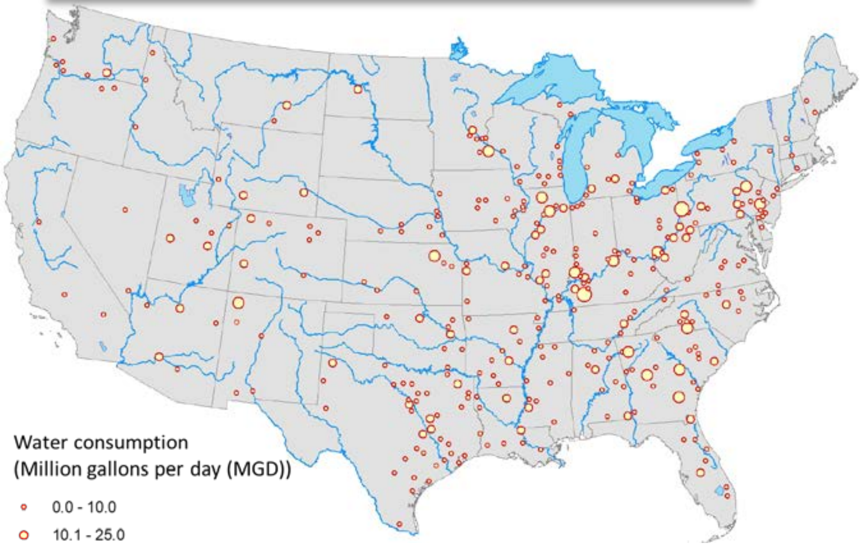
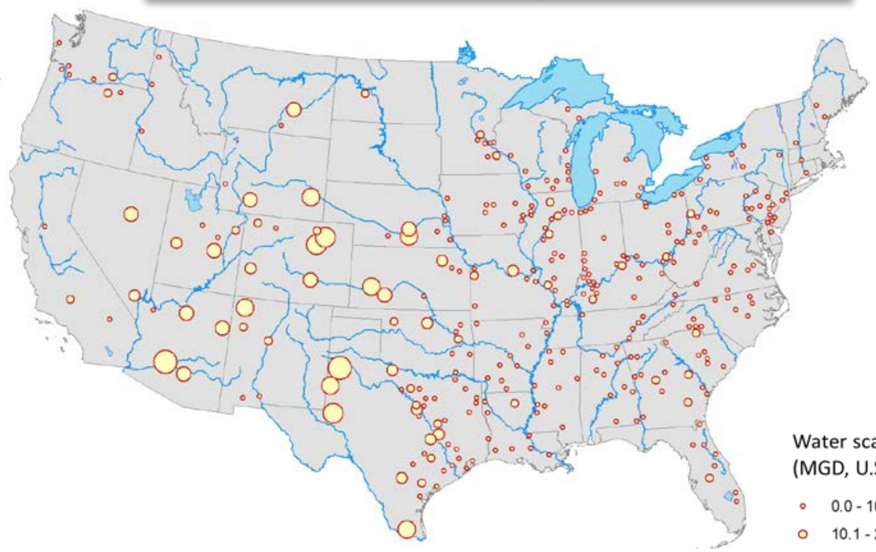
Distribution of thermal power water scarcity footprint at the county level – Accomplishment

- While water consumption of thermal power generation is higher in the eastern U.S., water use impact (water scarcity footprint) is significantly higher in the southwestern U.S., primarily due to limited freshwater supply

Water consumption



Water scarcity footprint



✓ **Water scarcity footprint provides more robust information needed to quantitatively evaluate water consumption impact of thermal power generation across regions, explicitly considering local water stress conditions**

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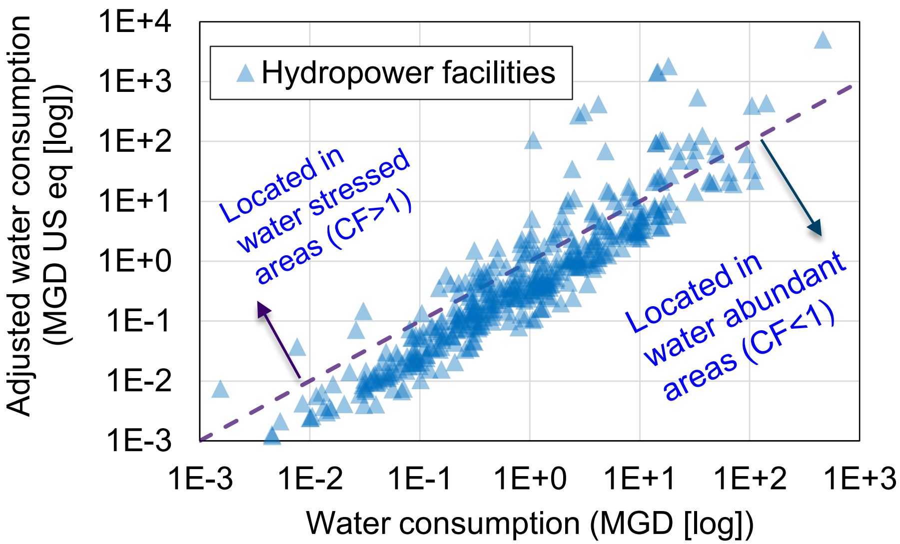
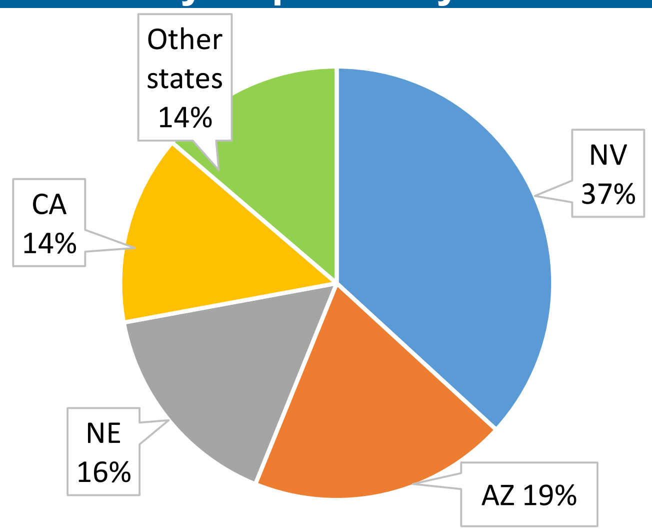
Water consumption impact of hydropower generation – Accomplishment

- 18% of hydropower plants (by power generation) are located in water-stressed regions where water supply is less than the U.S. average (AWARE-US CF>1):
  - Nevada, Arizona, Nebraska and California contributed the majority (~%86) of water scarcity footprint of hydropower generation
  - Dams are built mainly to serve purposes like irrigation or flood/drought management
- For multi-purpose reservoirs, water consumption would continue regardless of hydropower generation; reducing water use impact requires coordinated efforts among all stakeholders

Water consumption vs. Water scarcity footprint



Water scarcity footprint of hydropower by state



✓ **Most hydropower reservoirs consume water through evaporation are located in regions with relatively abundant water resources**

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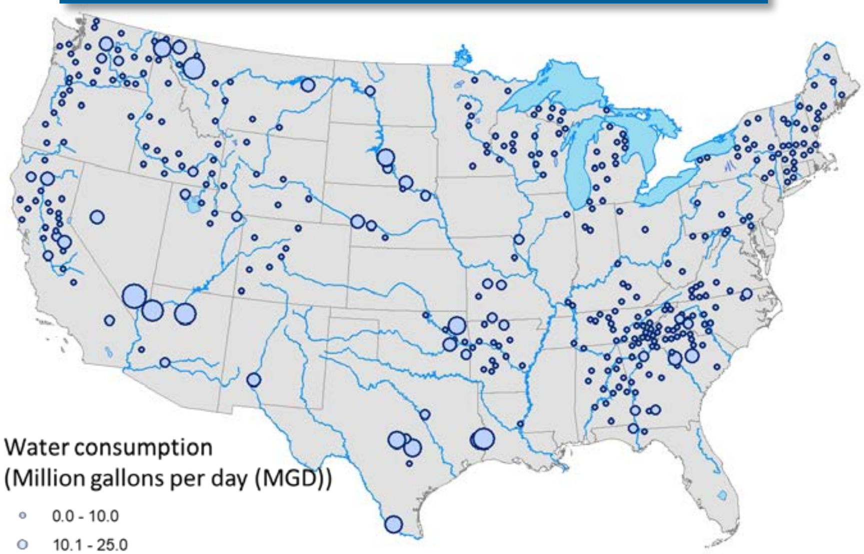
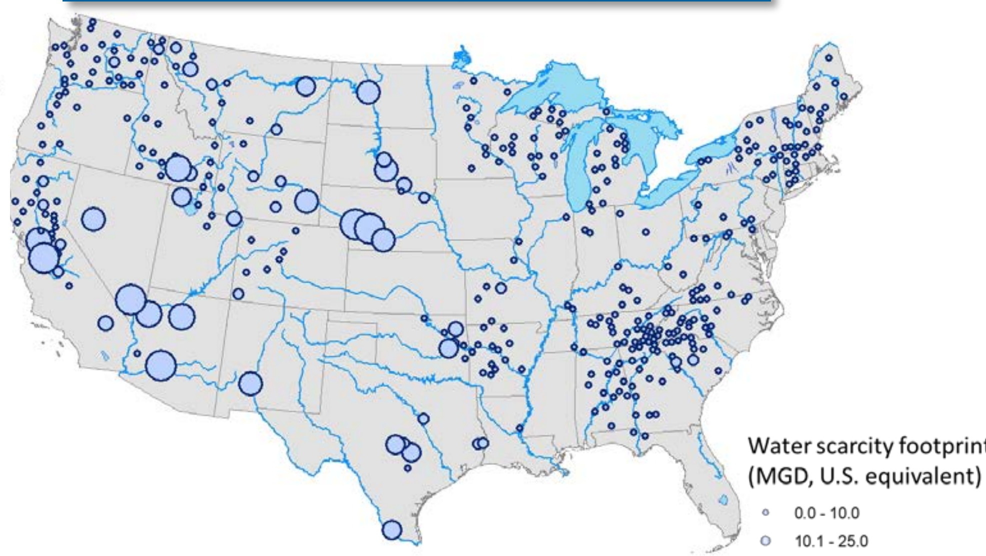
Distribution of hydropower water scarcity footprint at the county level – Accomplishment

- Due to high evaporation rate, water consumption for hydropower is high in Southern US
- Constrained water resources make water scarcity footprint of hydropower significantly amplified in water-stressed regions (Colorado river, San Joaquin river and upper Mississippi river basins).

Water consumption



Water scarcity footprint



✓ **AWARE-US provides spatial explicit evaluation of hydropower generation impact on water stress**
✓ **Water scarcity footprint enables cross-regional comparison without losing physical meaning (US. eq. Gal)**

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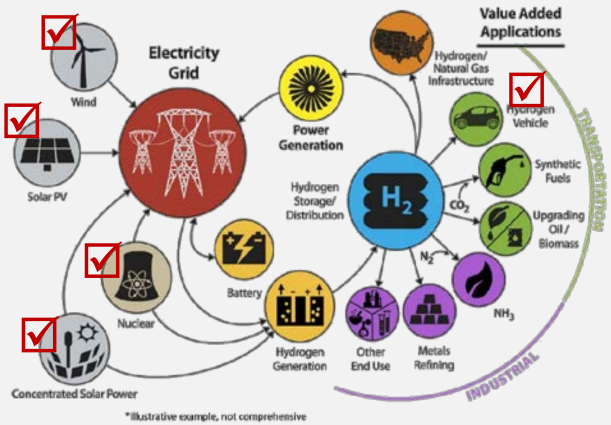
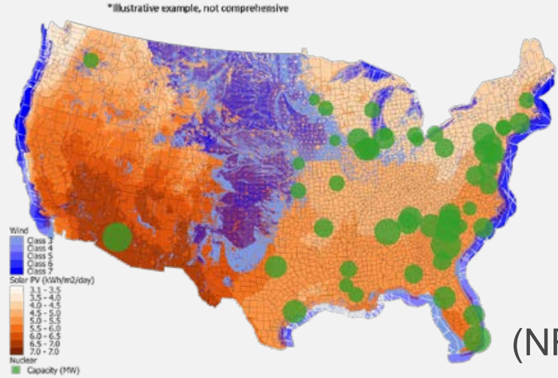
H_2 production scenarios based on H2@Scale and NREL resource analysis – Accomplishment

- Electricity (wind/solar/nuclear) is used for renewable H_2 production
- Steam methane reforming (SMR) of natural gas is used where renewable resources are not available

H_2 at scale

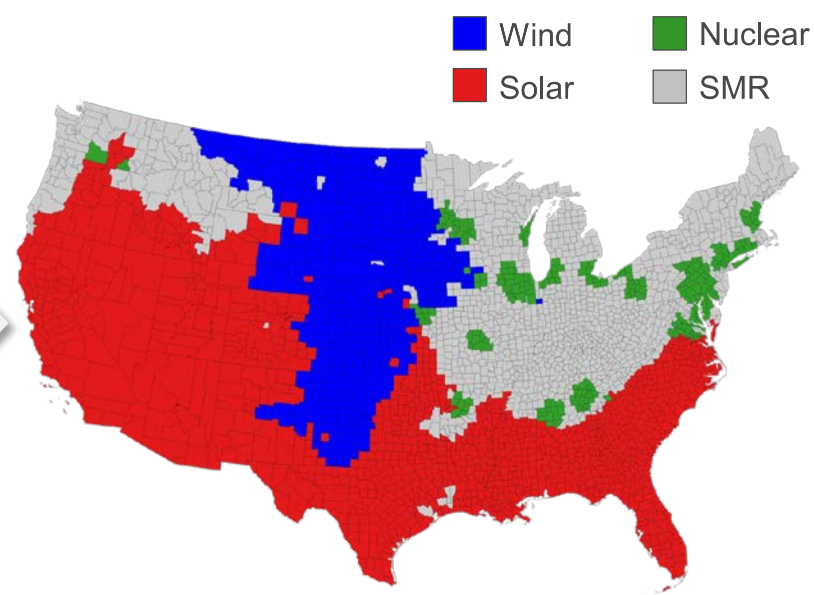


Renewable resource analysis



(NREL)

H_2 production scenarios



- H_2 production scenarios were generated based on the resource availability and demand

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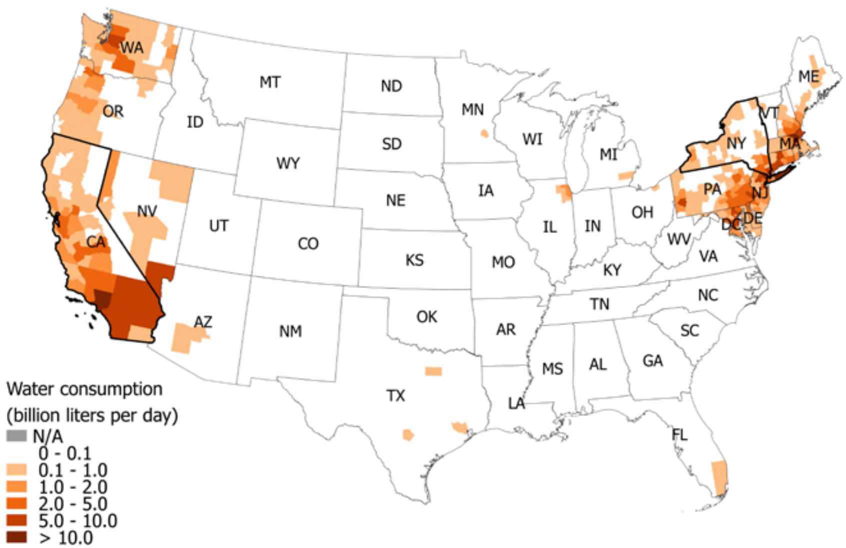
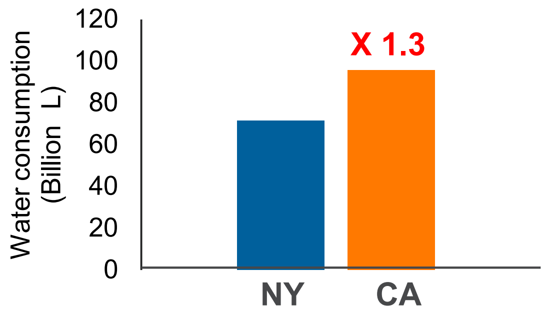
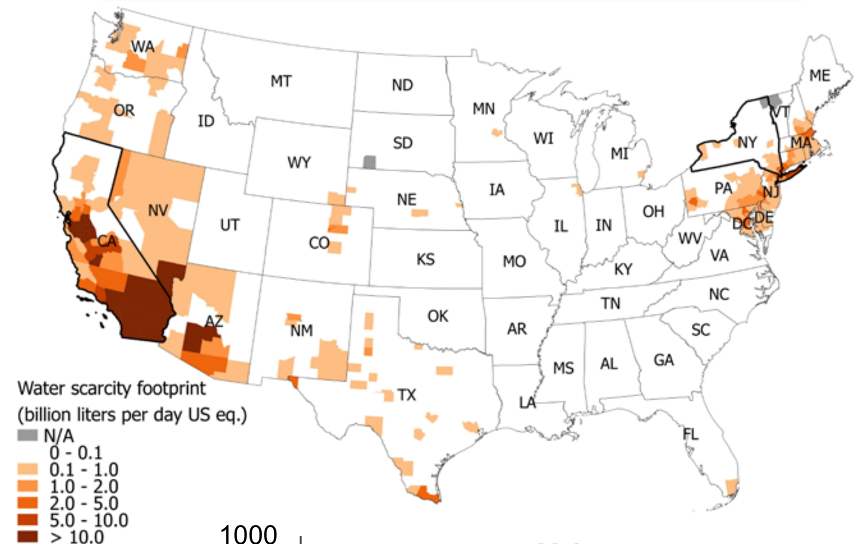
Impact of water consumption on regional water scarcity footprint for hydrogen production used for FCEVs in 2040 – Accomplishment

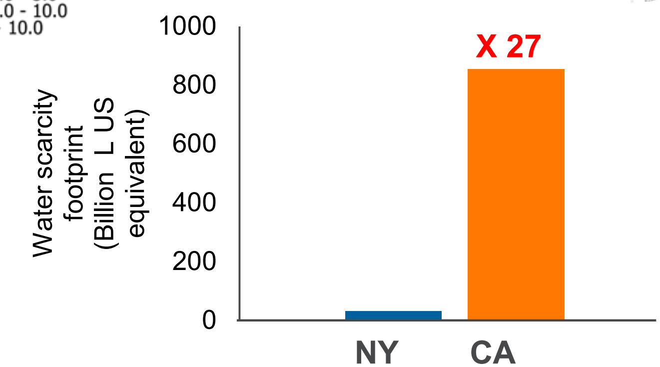
Water consumption





Water scarcity footprint





✓ **Implications of water consumption on water scarcity footprint for H2 FECV deployment differ by region**

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Summary – Accomplishment

- **Updated AWARE-US index with improved ground water recharge data**
  - Updated AWARE-US index for regional water stress impact analysis associated with major deployment of fuel/vehicle Systems
- **Evaluated water consumption and its impact of electricity generation**
  - Most (~80%) existing hydro- and thermo-electricity generation facilities are located in water abundant regions (AWARE US CF<1), whereas non-freshwater based power plants are predominately located in water stressed regions (AWARE-US CF>1)
  - TX, AZ, CO and KS contributed most of water scarcity footprint (73%), but only 17% of total thermal power generation in water stressed regions
  - NV, AZ, NE and CA contributed the majority (~%86) of water scarcity footprint of hydropower generation
  - AWARE-US provides more robust information needed to quantitatively evaluate water consumption impact of power generation across regions, explicitly considering local water stress conditions
  - Implications of water consumption on water scarcity footprint (based on AWARE-US) for H2 FCEVs differ by region

Collaborations and Acknowledgments

- Allocation of water consumption for multipurpose reservoirs
  - Bureau of Reclamation (David Raff, Kenneth Nowak, Clark Bishop, and Max Spiker), Oak Ridge National Laboratory (Rocio Uria Martinez), U.S. Army Corps of Engineers (Chandra Pathak) provided critical guidance for allocating water consumption of multipurpose reservoirs to hydropower
- Water index development
  - Duke University (Jesse Daystar) evaluated environmental water requirement
  - PNNL (Andre Coleman) provided weighting factors by sector/region used to disaggregate annual human water consumption into county level
- Water consumption impact analysis for electricity generation
  - Discussed potential collaboration with NETL and EPA

Future Work

- Update AWARE-US CFs
  – Update AWARE-US CFs to reflect seasonal variation in freshwater supply and demand
  – Evaluate implications of water right issues on water availability: not all remaining available water can be used for new water consumption

- Water impact analyses related to H2@Scale
  – Allocate upstream water consumption: develop a framework to allocate upstream water consumption (e.g. power generation, refining) to where it is actually consumed
  – Analyze “net water consumption” impact of H2 FECVs deployment on water stress by considering vehicle displacement impacts

- Document data and analysis in peer-reviewed publication

Any proposed future work is subject to change based on funding level

Project Summary

- **Relevance**: The impact of electricity production, as a major water consumer, is a key part for the regional water consumption impact analysis of transportation fuels
- **Approach**: Estimate regional water scarcity footprint using AWARE-US CFs for the U.S. electricity generation sector that consume water at regional level
- **Collaborations**: Sought data and guidance from the experts (national labs/ government agencies/ academia/ US DRIVE technical teams)
- **Technical accomplishments and progress**:
  - Updated AWARE-US CFs with the latest groundwater recharge data with higher spatial resolution and better data quality
  - Analyzed regional water consumption and its spatial distribution pattern of thermal power plants and hydropower facilities
  - Applied AWARE-US CFs to the electric power sector to quantify water use impact (water scarcity footprint) of power generation in the U.S.
  - Applied AWARE-US CFs to H2@Scale scenario to demonstrate that impact of water consumption on water scarcity footprint differ by region
- **Future Research**:
  - Address outstanding issues (allocating upstream water consumption and comparing regional water consumption impact with baseline fuels/vehicles)
  - Expand GREET with regional data and document analysis in peer-reviewed publications

Acronyms

- AMR: Annual Merit Review
- ANL: Argonne National Laboratory
- AWARE: Available WAter REmaining
- AZ: Arizona
- BEV: Battery Electric Vehicle
- CA: California
- CF: Characterization Factor
- CNG: Compressed Natural Gas
- CO: Colorado
- DOE: Department of Energy
- EIA: Energy Information Administration
- EPA: Environmental Protection Agency
- FCEV: Fuel Cell Electric Vehicle
- FCTO: Fuel Cell Technologies Office
- FY: Fiscal Year
- GREET: Greenhouse gases, Regulated Emissions, and Energy use in Transportaiton
- GWR: GroundWater Recharge
- H_2: Hydrogen
- H2A: Hydrogen Analysis
- HWC: Human Water Consumption
- HyReS: Hydrogen Regional Sustainability
- ICEV: Internal Combustion Engine Vehicle
- KS: Kansas
- LCA: Life-Cycle Analysis
- MGD: Million Gallons per Day
- MPGGE: Miles Per Gallon Gasoline Equivalent
- MSM: Macro-System Model
- NE: Nebraska
- NERC: North American Electric Reliability Corporation
- NETL: National Energy Technology Laboratory
- NV: Nevada
- PNNL: Pacific Northwest National Laboratory
- RD&D: Research, Development, and Demonstration
- TX: Texas
- US: United States
- US eq. gal: U.S. equivalent gallon
- US DRIVE: U.S. Driving Research and Innovation for Vehicle efficiency and Energy sustainability
- USGS: United States Geological Survey
- WTW: Well-to-Wheels
- WY: Wyoming