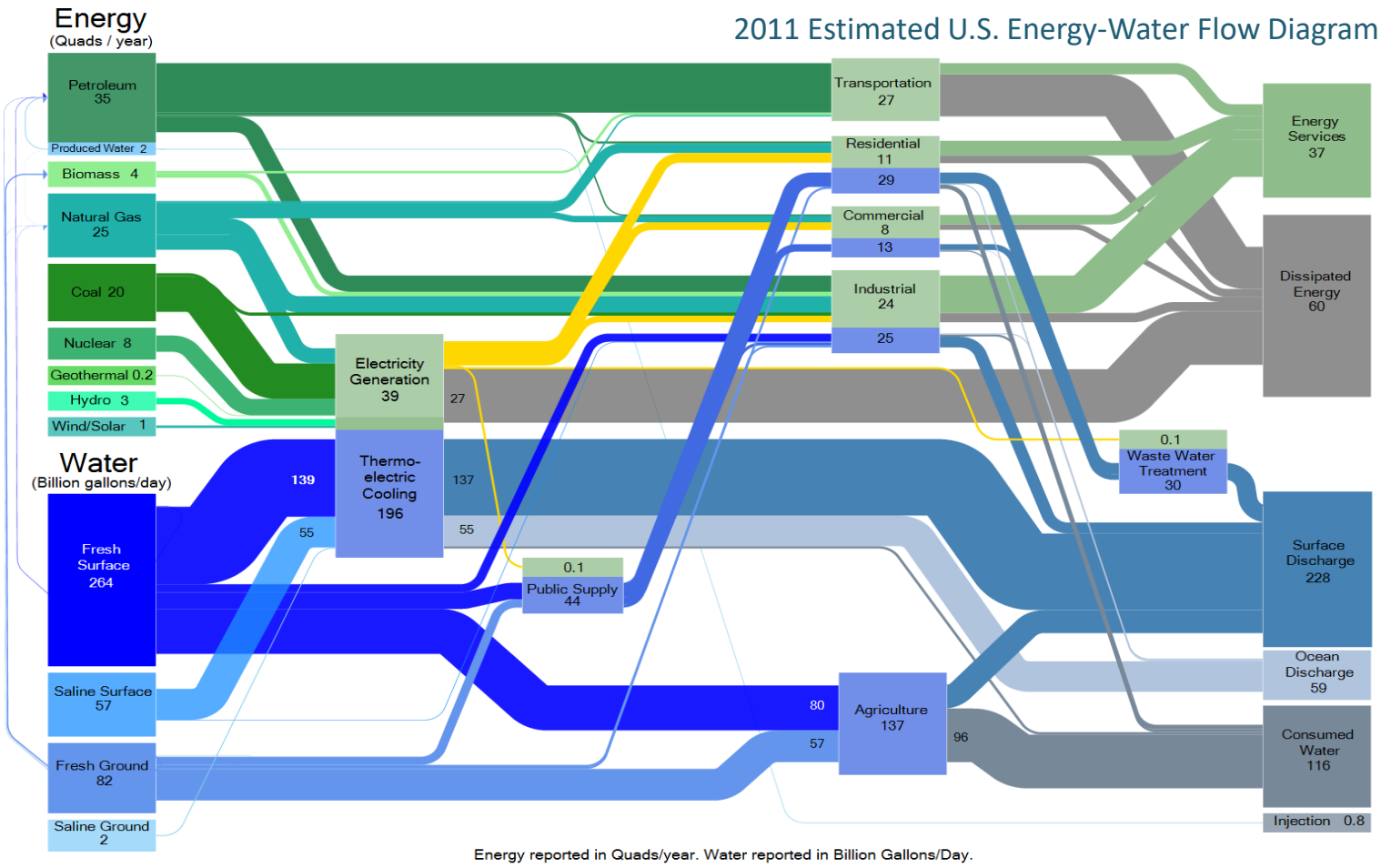
The Energy-Water Nexus at U.S. DOE and the U.S.-EU Integrated Water and Power Systems Modeling Challenge

Diana Bauer, Ph.D
Director, Office of Energy Systems Integration Analysis
Office of Policy
U.S. Department of Energy
May 29, 2018

Energy and Water Flows are Interconnected

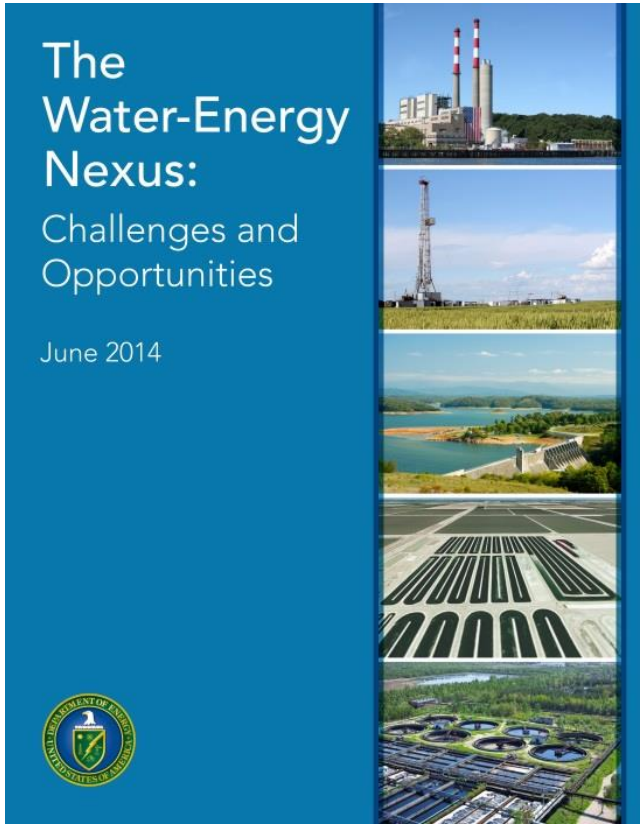


2011 Estimated U.S. Energy-Water Flow Diagram

Energy reported in Quads/year. Water reported in Billion Gallons/Day.

Strategic Pillars for the Energy-Water Nexus

- Optimize the freshwater efficiency of energy production, electricity generation, and end use systems
- Optimize the energy efficiency of water management, treatment, distribution, and end use systems
- Enhance the reliability and resilience of energy and water systems
- Increase safe and productive use of nontraditional water sources
- Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts
- Exploit productive synergies among water and energy systems



Download the full report at energy.gov

Responding to Challenges in the Energy-Water System

Energy Technology Pathways

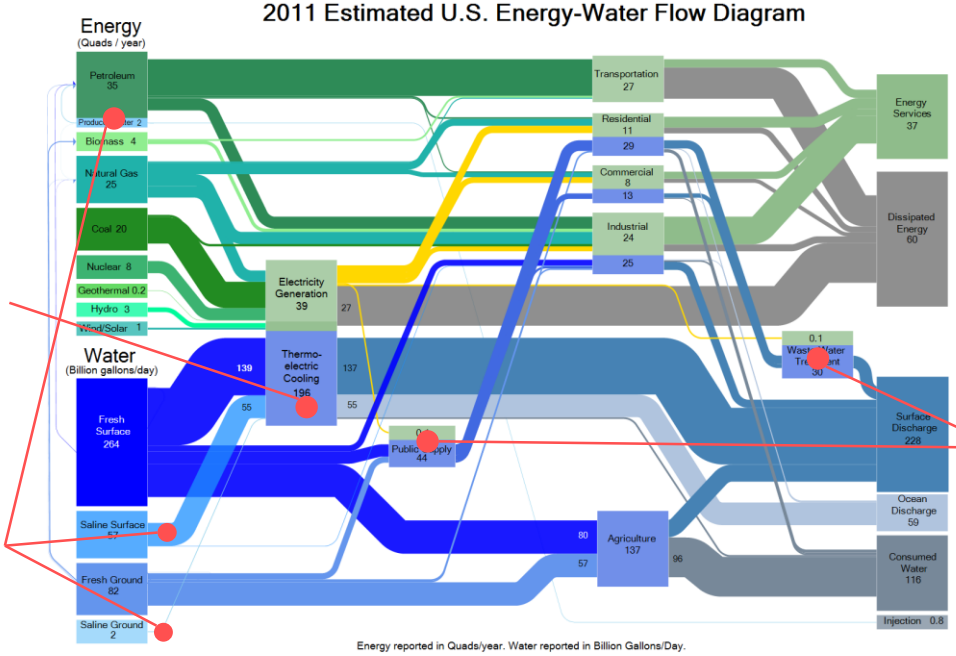
Forces on System

Climate Change (Mitigation and Adaptation)

Technology Solutions

Water-Efficient Cooling

Energy-Optimized Treatment, Management, and Beneficial Use of Nontraditional Waters



Sustainable Low-Energy Water Utilities

Policy and Institutional Changes

Land Use & Land Cover Change

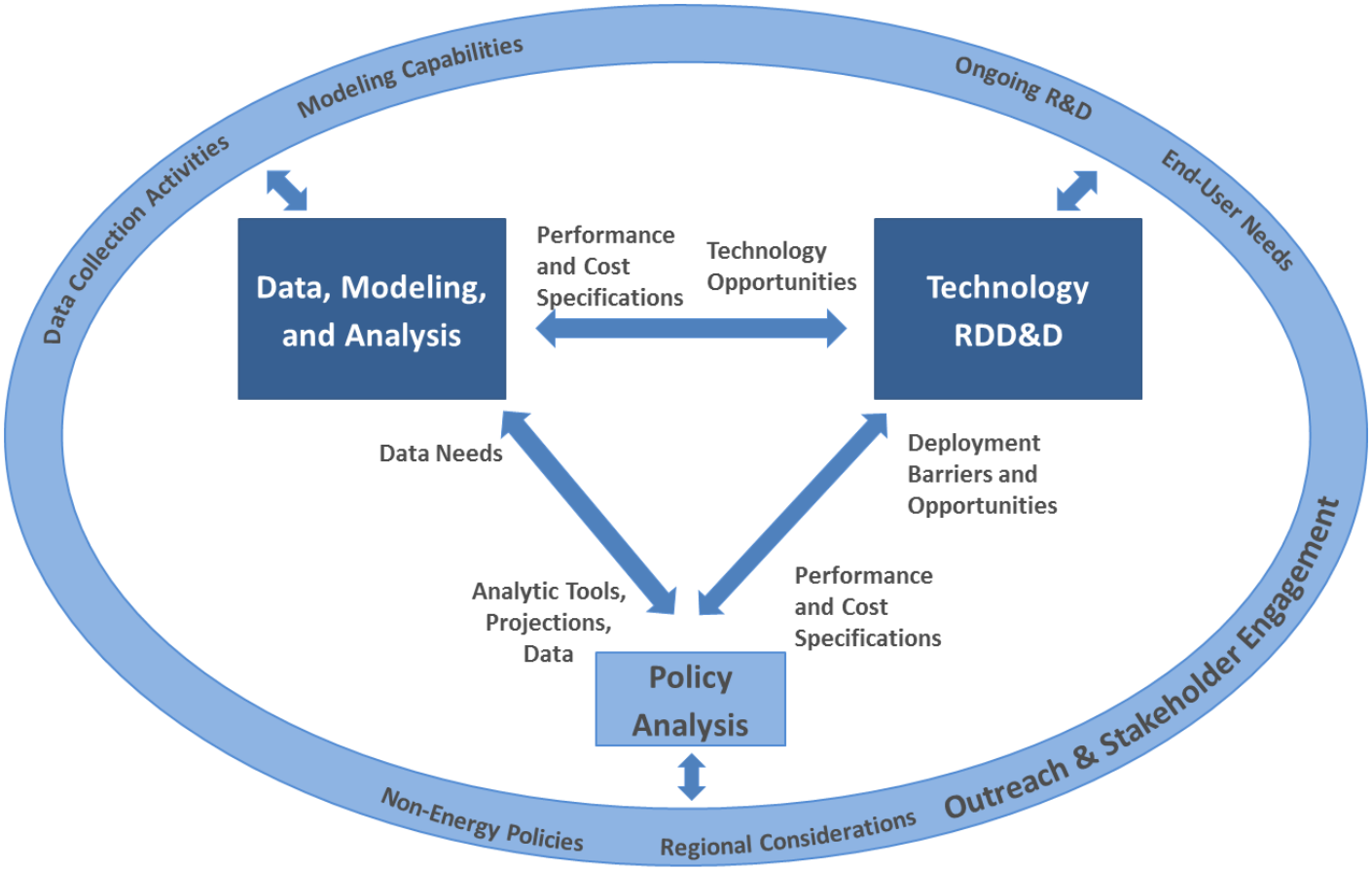
Stakeholder and Consumer Preferences

Population/ Migration

Urbanization & Infrastructure Dynamics

Regional Economic Development

DOE Energy-Water Nexus Focus Areas



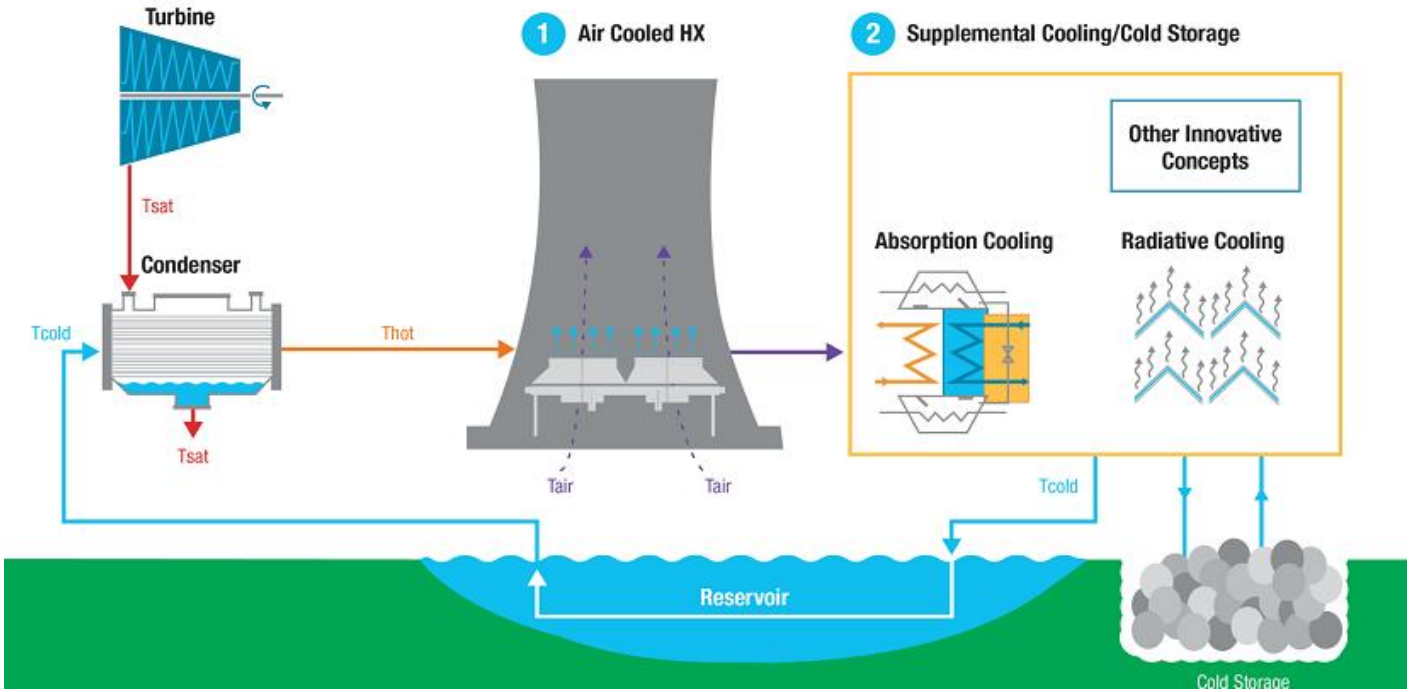
Technology and Basic Science Research Focus Areas

ARPA-E: Dry Cooling for Electricity Generation

ARPA-E's Advanced Research in Dry Cooling (ARID) Research Solicitation is funding 14 projects in 2015 for a total of $30 million:

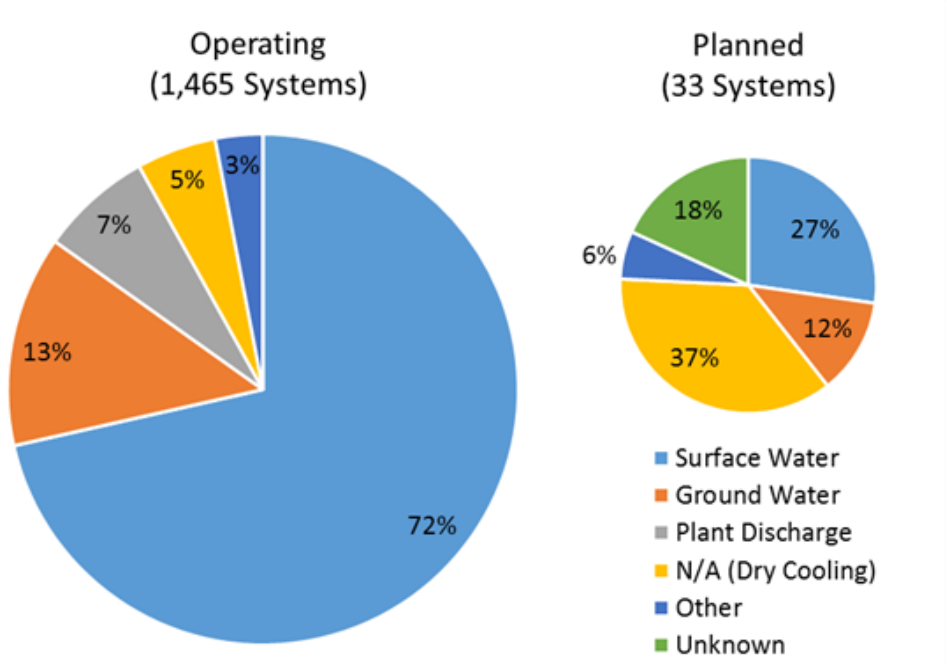
- Air-cooling heat exchangers (3 projects)
- Sorption & other supplemental cooling (4 projects)
- Radiative cooling and cool storage (3 projects)
- Flue gas H_2O recovery & cool storage (2 projects)
- Combined ACC & cool storage (2 projects)

Sample Indirect Dry-Cooling System that Satisfies ARID Program Objectives



Cooling Water Sources Are Diversifying

U.S. Power Sector is Increasing Utilization of Dry Cooling and Nontraditional Water (2016)



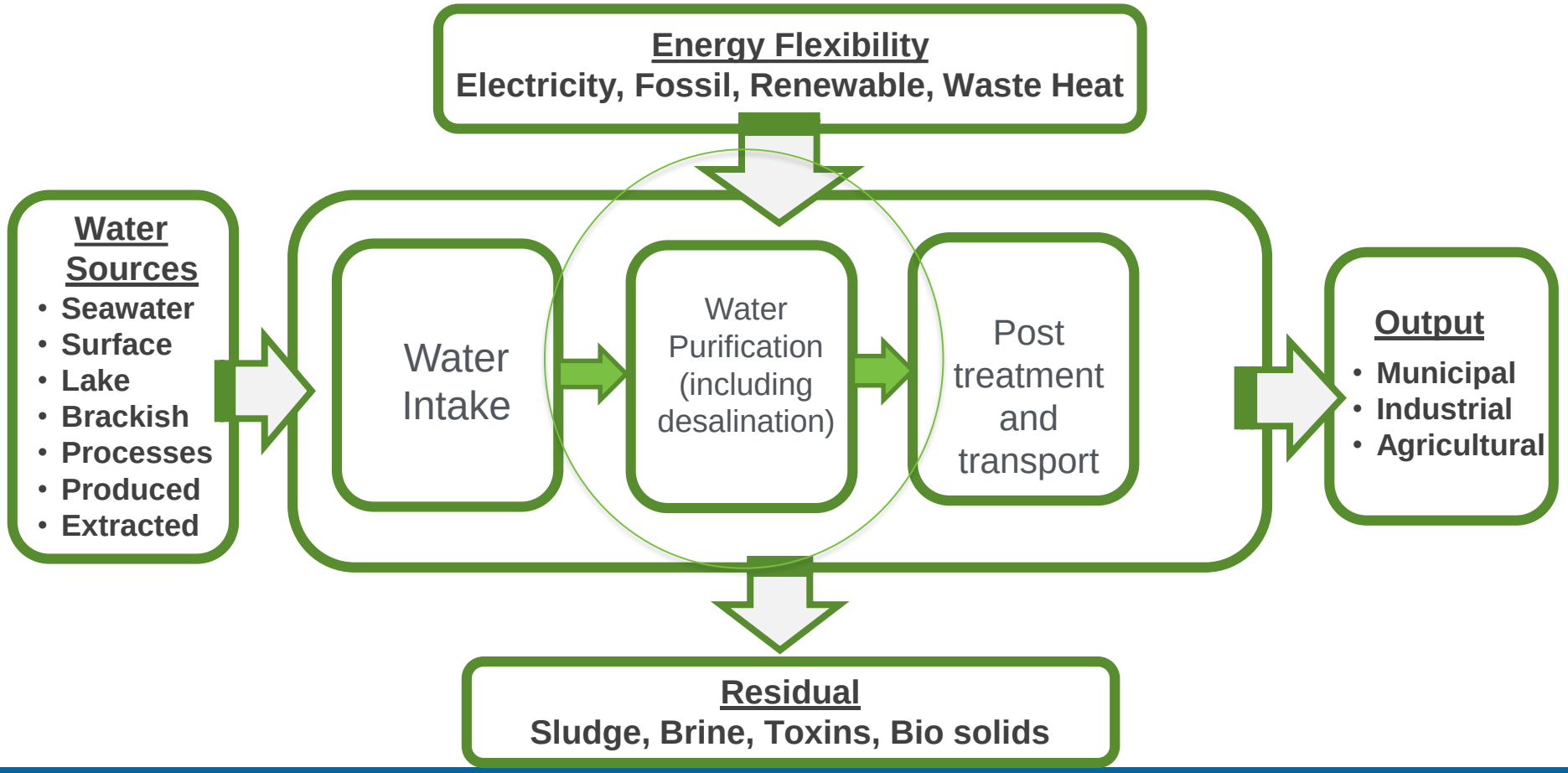
However…

- Current dry cooling technologies are more expensive and come with efficiency penalties
- Using nontraditional water usually means more electricity for pumping and treatment

Data Source: EIA (2017)

Energy-Optimized Water Treatment

- Address manufacturing barriers to producing low-energy, cost-competitive clean water
- Technology priorities arise from facility-level systems-relevant challenges
- Leverage existing federal resources (e.g. DOI/Bureau of Reclamation testbeds)
- Request for Information to be issued soon



Water for and from Oil and Gas

Table 4-1 – Top 10 States for 2010 Water Withdrawn for Oil and Natural Gas Production (MGD)
The top 10 states total 94% of water withdrawn for oil and natural gas

Live Link Database Variables	= LLB_OilW + LLB_GasW	
Data Type	2010 MGD of water withdrawn for oil & natural gas production	2010 Percent of water withdrawn for oil & natural gas production
State Totals	**475**	**100%**
TOP 10 STATES		
AK	133.7	28.1%
CA	123.5	26.0%
TX	67.8	14.3%
LA	28.6	6.0%
OK	24.4	5.1%
CO	19.8	4.2%
PA	13.2	2.8%
AR	12.7	2.7%
NM	10.8	2.3%
KS	10.7	2.3%
BOTTOM 5 STATES[1]		
MO	0.0349	0.007%
AZ	0.0244	0.005%
FL	0.0200	0.004%
VA	0.0001	0.00003%
NY	0.00004	0.00001%

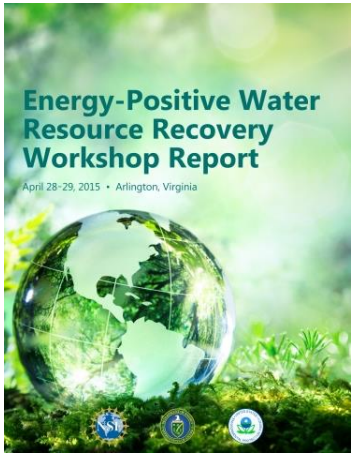
Table 4-3 – Top 10 States for 2010 Produced Water for Oil and Natural Gas Extraction (MGD)
The top 10 states total 93% produced water for oil & natural gas extraction

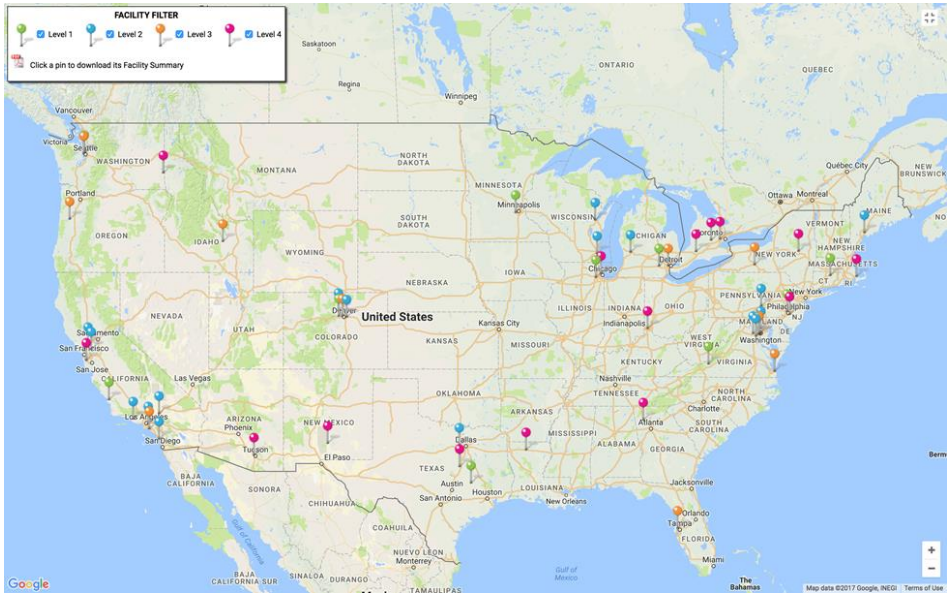
Live Link Database Variables	LLF{OilW_to_(OcDisch+SurfDisch+Wcons+Winj)+GasW_to_(OcDisch+SurfDisch+Wcons+Winj)}	
Data Type	2010 MGD of produced water for oil & gas extraction	2010 Percent of produced water for oil & gas extraction
State Totals	**1,236**	**100%**
TOP 10 STATES		
TX	470.5	38.1%
CA	191.3	15.5%
OK	141.2	11.4%
LA	103.1	8.3%
KS	90.3	7.3%
NM	43.9	3.6%
WY	36.0	2.9%
CO	31.0	2.5%
ND	27.5	2.2%
AR	16.5	1.3%
BOTTOM 5 STATES[4]		
SD	0.3	0.02%
TN	0.2	0.01%
KY	0.1	0.01%
MO	0.04	0.003%
AZ	0.01	0.0009%

Development of Energy-Water Nexus State-level Hybrid Sankey Diagrams for 2010 (2018)

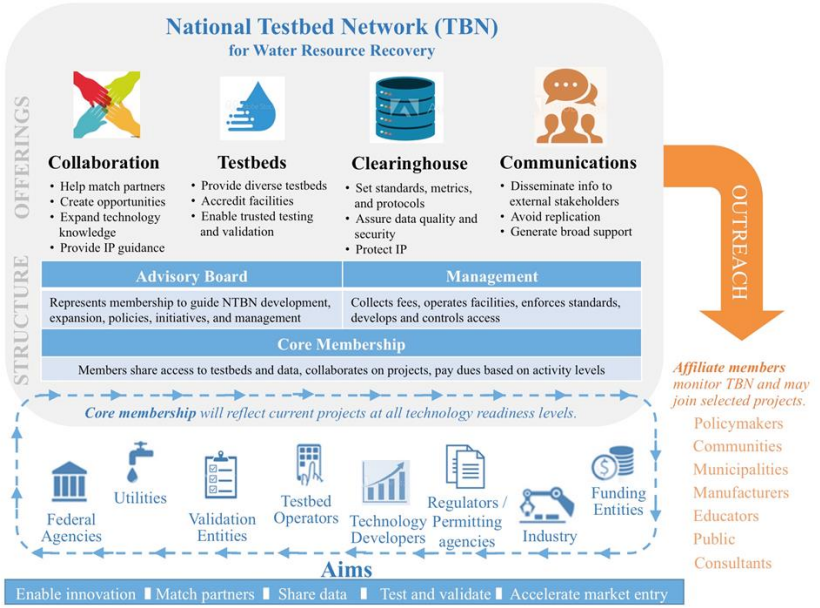
Energy Efficiency and Energy Recovery in Wastewater Utilities

- NSF/EPA/DOE/WE&RF Collaboration: Energy Positive Water Resource Recovery
  - Acceleration of advanced technology deployment in a complex policy environment
  - Design concept for testbed network





Wastewater testbed facilities (LIFT)



DOE Basic Energy Sciences (BES)
Basic Research Needs Workshop for Energy and Water

Workshop Chair:	Matt Tirrell (ANL/U Chicago)
Co-chairs:	Susan Hubbard (LBNL)
	David Sholl (Georgia Tech)
Workshop Date:	January 4-6, 2017
SC Technical Lead:	Gail McLean (BES)

PURPOSE: To assess the basic science gaps in fundamental understanding of issues related to the energy-water nexus, with an emphasis on new insights and innovations in chemistry, materials science, biochemistry, and geological sciences to help enable scientific and technological advances for the energy water nexus. The workshop panels focused on: (1) enhancing efficiency of water use in energy-intensive processes; (2) minimizing water use for energy production; (3) increasing availability of fresh water in energy-intensive water purification and distribution processes; and (4) cross-cutting research.

Breakout Sessions and Panel Leads:

Basic science challenges to improve water use for industrial applications & electricity generation,
Eric Peterson (INL) and Michael Tsapatsis (Univ. Minnesota)

Basic science challenges to reduce water use in energy & fuel production,
Daniel Giammar (Washington Univ. St. Louis) and Benjamin Gilbert (LBNL)

Basic science challenges to increase fit-for-purpose water availability,
Kate Maher (Stanford Univ.) and William Tumas (NREL)

Crosscutting basic science in the energy-water systems,
Lynn Loo (Princeton Univ.) and Martin Schoonen (BNL)

Plenary Session Speakers:

The Energy-Water Nexus at DOE, ***Diana Bauer, DOE***
Complex Aqueous Interfaces, ***Geraldine Richmond, Univ Oregon***
Advanced Water Treatment Materials, ***Jaehong Kim, Yale***
Engineered & Natural Water Treatment, ***David Sedlak, UCB***
Porosity and Subsurface Rocks, ***Susan Brantley, Penn State***
Non-traditional Water Sources, ***Seth Darling, ANL***
Subsurface Resource Extraction & Storage, ***Charles Werth, UT-Austin***
Smart Distributed Water Treatment, ***Yoram Cohen, UCLA***

U.S. DEPARTMENT OF ENERGY | Office of Science

Workshop report is available at:
https://science.energy.gov/bes/community-resources/reports/

Basic Research Needs for Energy and Water
Priority Research Directions

- Predict static and dynamic properties of multicomponent fluids

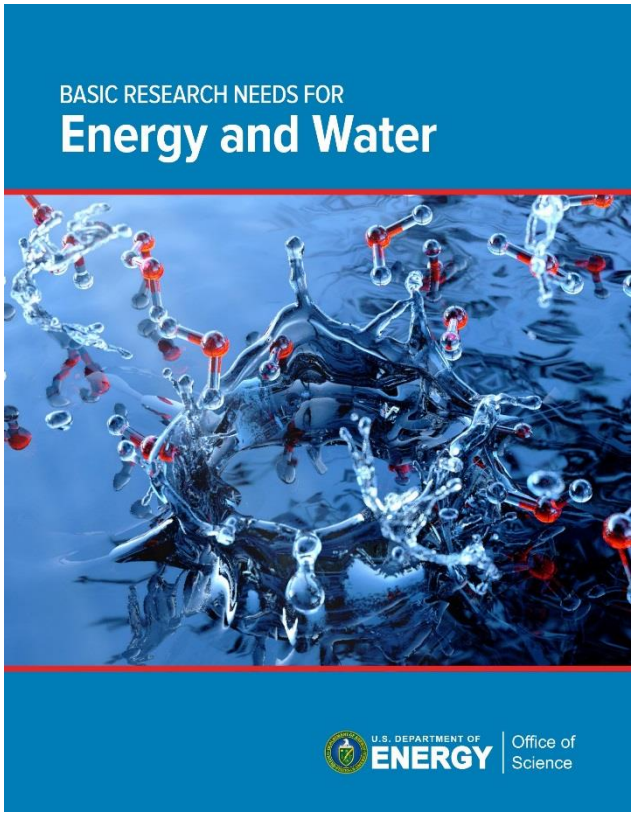
  Key question: How can we predict and control molecular-to-macroscopic properties and behavior of complex, multicomponent fluids?

- Achieve mechanistic control of interfaces and transport in complex and extreme environments

  Key question: What are the underlying mechanisms of affinity and reactivity at interfaces in aqueous systems?

- Exploit specific material-fluid interactions to design and discover innovative fluids and materials

  Key question: How can we codesign the dynamic interactions between materials and reactive fluids for unprecedented tunability?



- Advance science to harness the subsurface for a transformational impact on water

  Key question: How do we develop the ability to predict and control multiscale, multiphase, multiphysics subsurface properties?

Workshop report is available at:
https://science.energy.gov/bes/community-resources/reports/

Data, Modeling, and Analysis

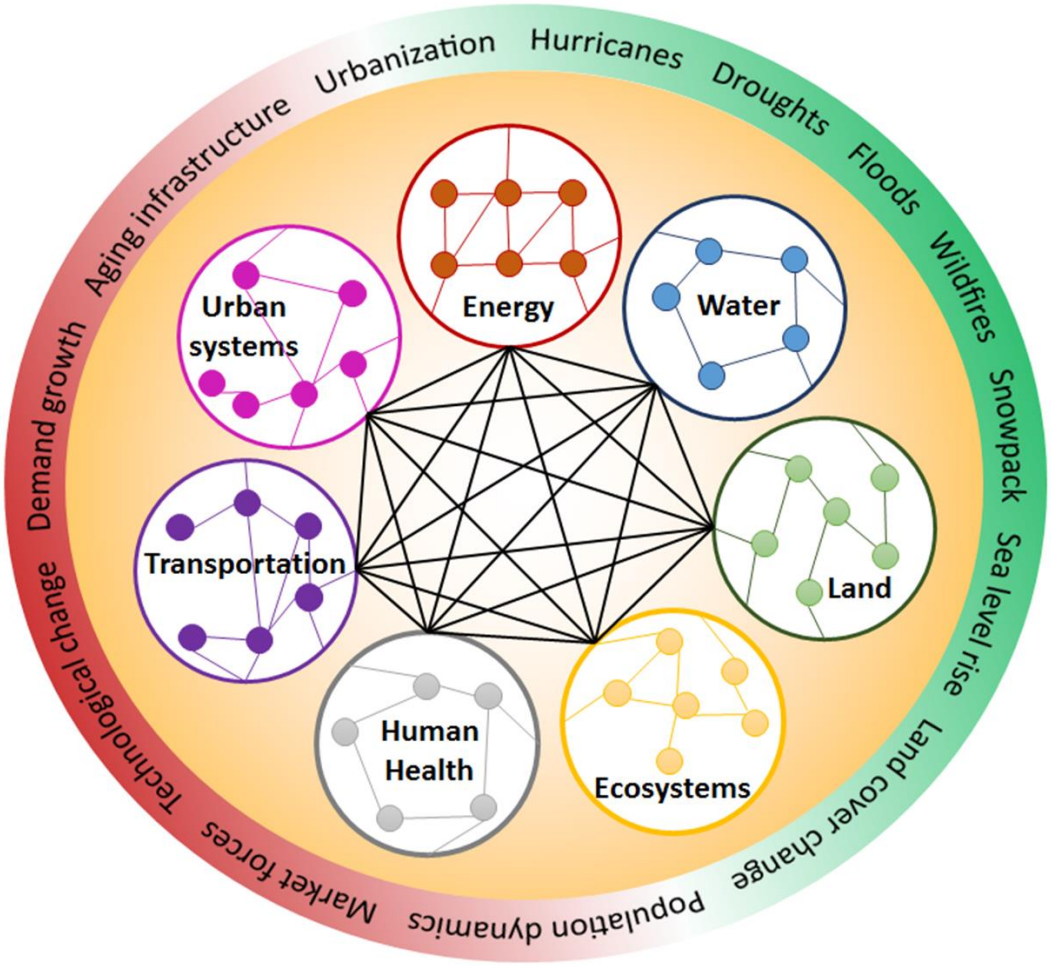
Office of Policy

U.S. DEPARTMENT OF ENERGY

Office of Science

BER's work in Energy and Water through the lens of Multi-Sector Dynamics

Exploring the interactions, influences, and complex dynamics among natural, built, and economic systems and sectors



Motivated by several major scientific questions/challenges

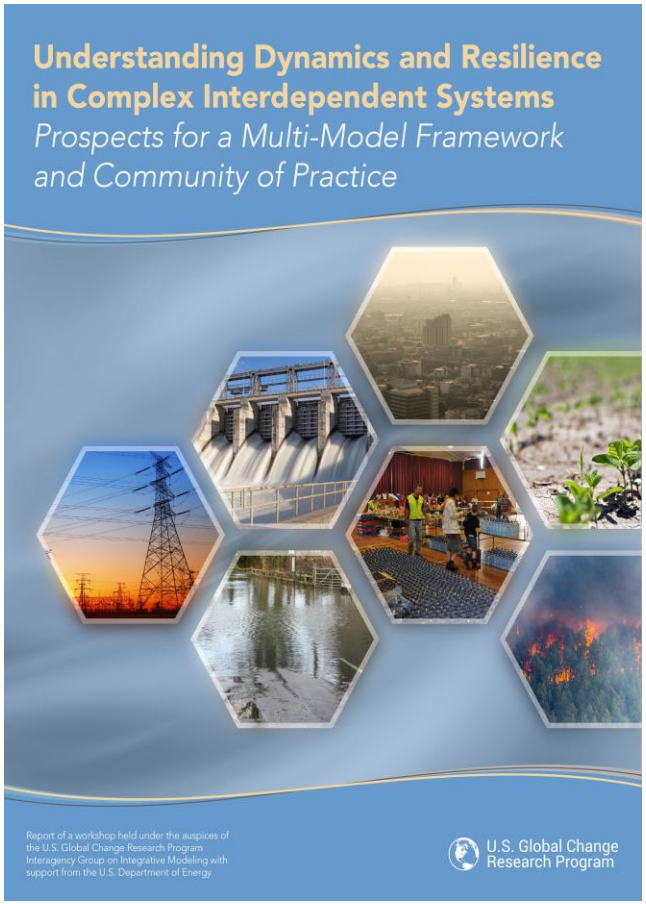
1. How do natural environments and built environments interact and how are they interdependent across systems and temporal and spatial scales?

2. What combination of factors, varying by region and sub-region, contribute most significantly to observed development in transregional, regional, and sub-regional landscape evolutions, including settlement and infrastructure expansions and type?

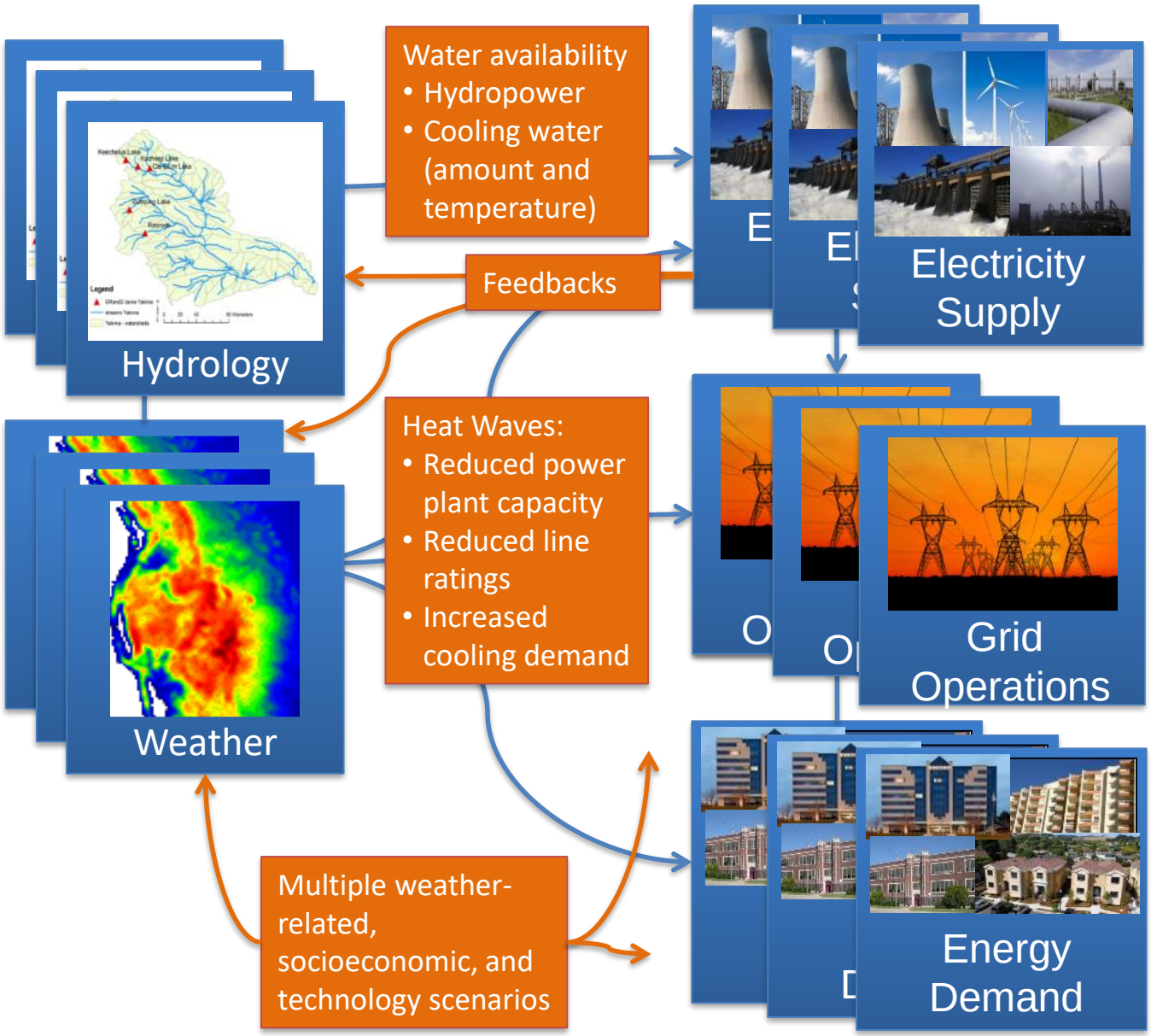
3. How might future co-evolutions within landscapes, including demands for natural resources, environmental services, and products and sectoral services diverge from historical patterns based on compounding stressors and influences?

4. What characteristics of combined built and natural landscapes lead to instabilities and/or resilience?

Underpinned by growing science community interest and perspectives



Importantly, energy systems respond to changes in weather and hydrology, with corresponding feedbacks



Research Gaps

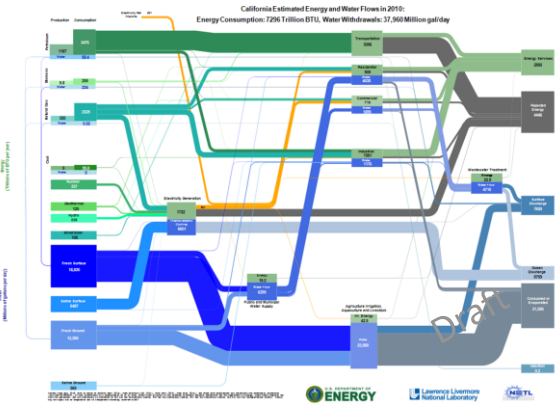
- What are the tradeoffs and synergies between energy diversity and resilience enhancements?
- What spatial and temporal scales, degree of coupling, data needs, etc., are required for accurate simulations?
- What other factors must be accounted for (e.g., urbanization, air quality, feedbacks related to water use,…)

Regional Analysis

Office of Policy

New State-Level Energy and Water Sankey Diagrams (LLNL)

Figure 3-5 - Hybrid Energy-Water Sankey Diagram for California



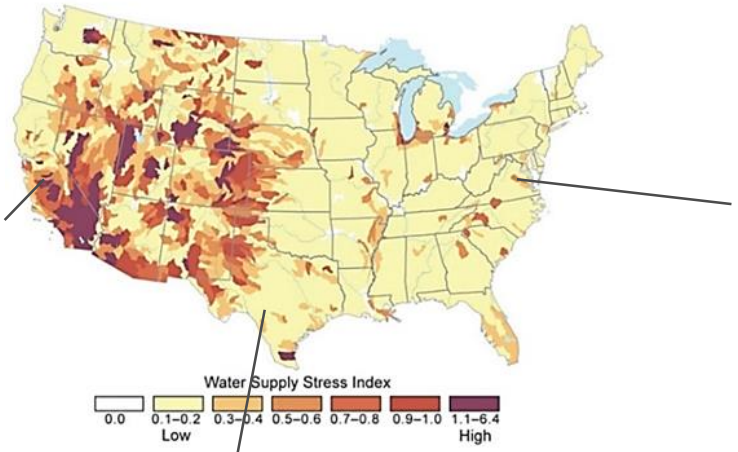


Figure 3-46 - Hybrid Energy-Water Sankey Diagram for Virginia

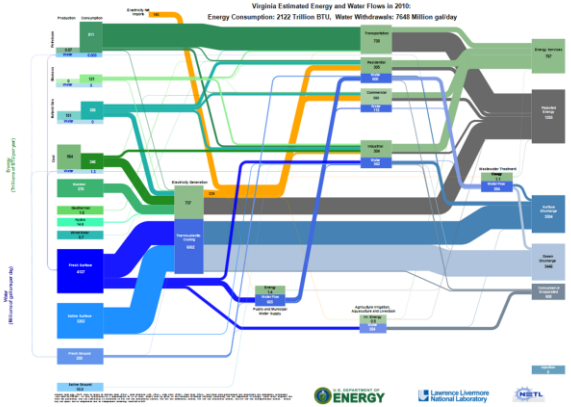
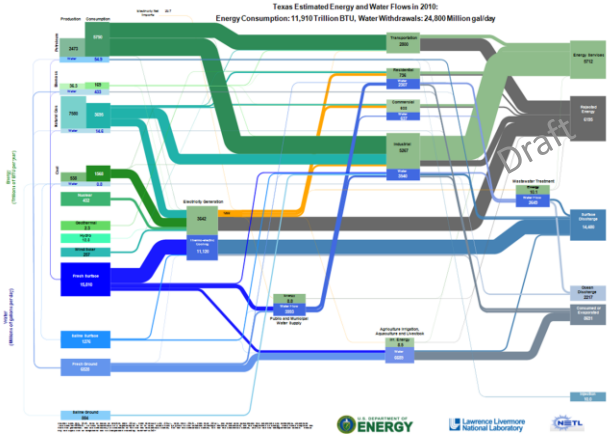


Figure 3-43 - Hybrid Energy-Water Sankey Diagram for Texas

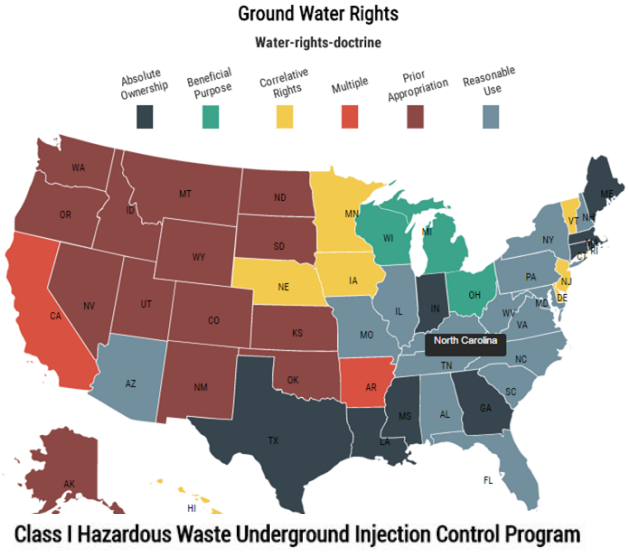


https://flowcharts.llnl.gov/report

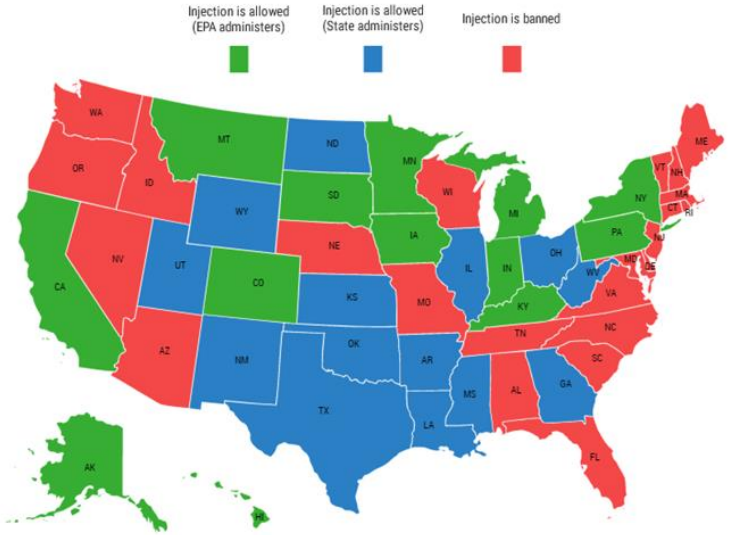
Beta Database of Water Policies Impacting Energy

- More than 1,700 entries with searchable fields such as jurisdiction, dates enacted, energy subsector affected, relevant statute, contact information of implementing authority, and a concise summary of the policy
  - State and national PDES and NPDES permitting programs
  - Underground injection control permitting
  - Policies affecting surface water rights and groundwater rights
  - Water quality standards
  - Hydraulic fracturing water regulations
  - River and/or dam operations

www.energywaterpolicy.org



Class I Hazardous Waste Underground Injection Control Program



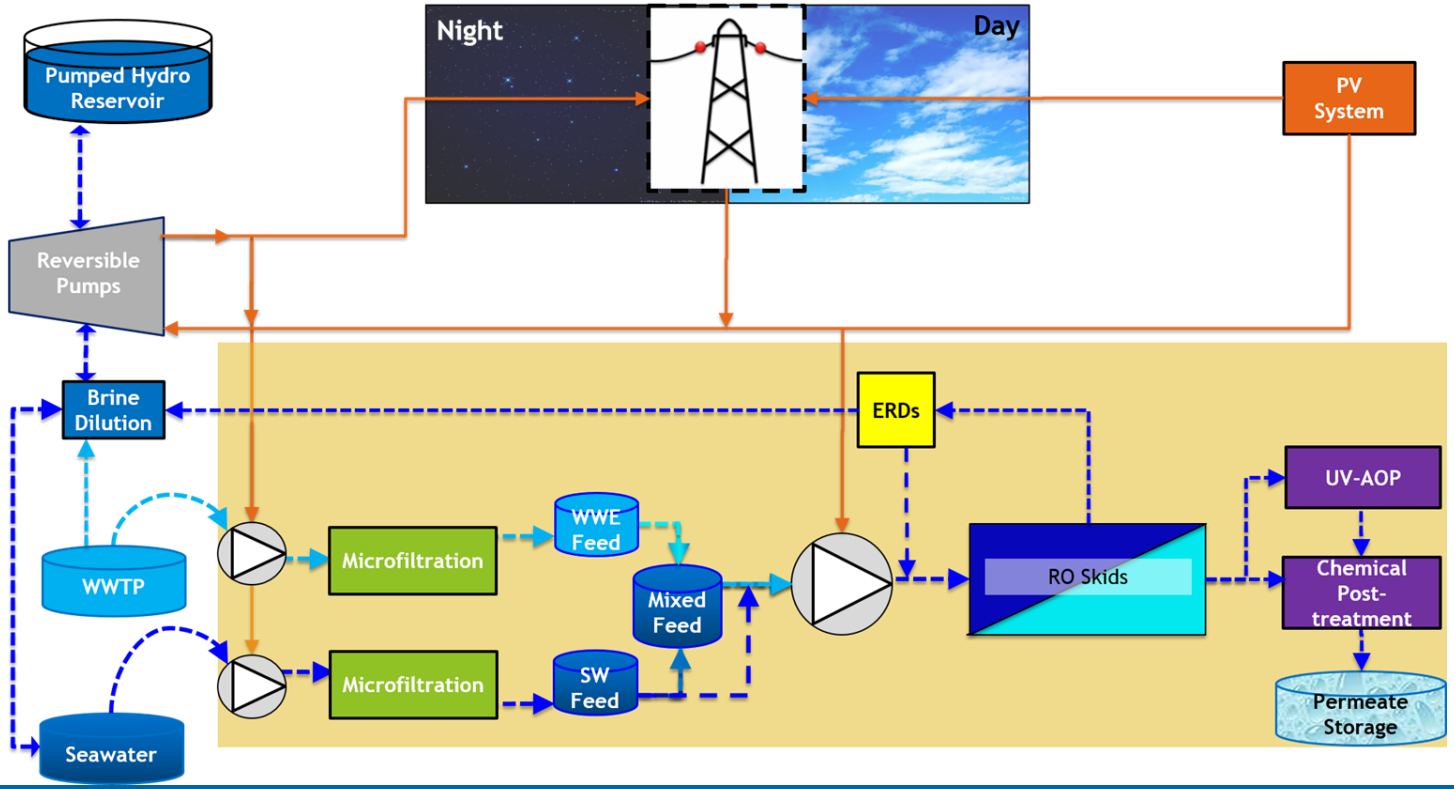
International Collaboration

Office of Policy

US-Israel Integrated Energy and Desalination Design Challenge

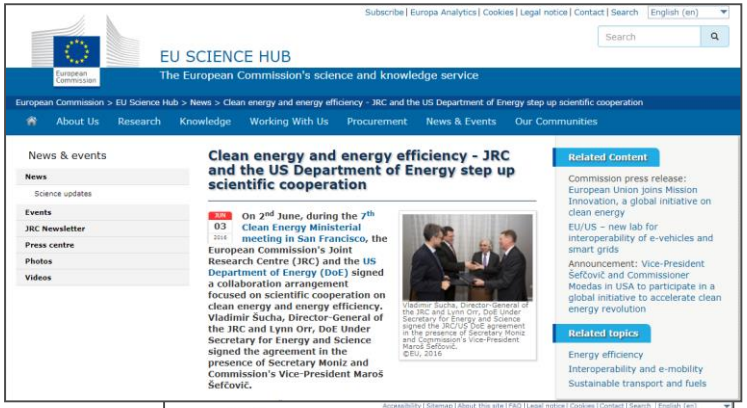
- The joint US-Israel challenge sought innovative desalination systems that could operate flexibly to provide demand response and ancillary services to support electricity system reliability.
- ORNL's winning design features a RO system that operates at a range of salinity and corresponding electricity demand
- Current work is a full technical design and market analysis

ORNL's winning design:



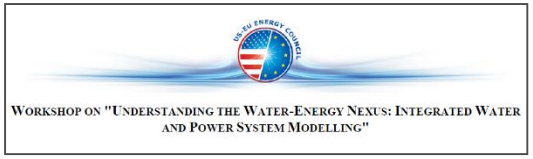
US-EU Integrated Water And Power Modeling Challenge

- Exploring emerging water and power infrastructure questions, particularly related to expansion planning and flexible operations.
- Workshop Sept 28-29, 2016 Ispra, Italy
  - Understanding the water-energy nexus: integrated water and power system modelling
- Sponsored modeling teams examining flexibility in current and future energy and water systems
  - US: Ames/ Iowa State, NREL/ Dartmouth, PNNL/ NWPCC/ BPA
  - EU: ICCS/E3M-Lab, Fraunhofer ISE power sector modeling, Politecnico di Milano DEIB water modeling
- Expected workshop Fall 2018 USA



Criteria for modelling a region	Value
Annual electricity generation	>100 TWh in 2015
Hydropower share	>5% in 2015
Variable energy resources share	>5% in 2015
Water infrastructure-related electricity consumption	>3% of annual energy consumption in 2015

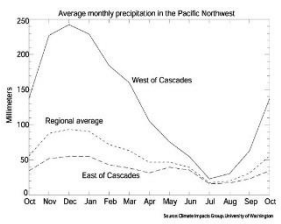
6 Scenarios	Current water infrastructure system	Flexible water infrastructure system
Current power system (2015)	Scenario 1	Scenario 2
Future BAU power system (2040)	Scenario 3	Scenario 4
Future flexible power system (2040)	Scenario 5	Scenario 6

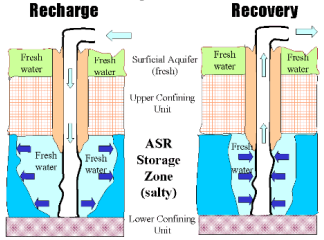


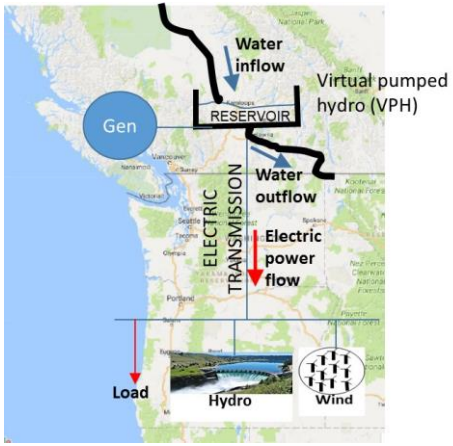
Reimagined flexible electric & water infrastructure (Ames Team)

1. Increased water storage ability:

- Virtual pumped hydro (VPH) [A] for regulation, reserves, and weekly, seasonal, & annual changes
- [B].Aquifer storage & recovery (ASR)

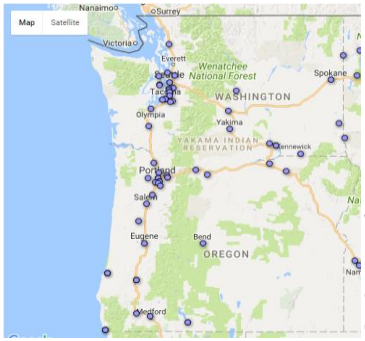






2. Demand response & on-site generation

- Agricultural pumping
- Water treatment plants
- Wastewater treatment plants

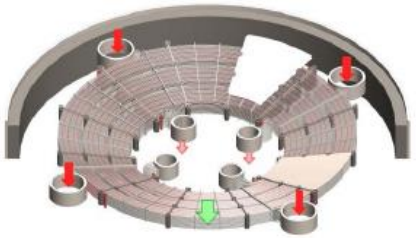


Wastewater treatment plants having on-site anaerobic digestion w/ electric power gen.

[A] Y. Gu, et al., "A novel market simulation methodology on hydro storage," IEEE Trans. on Smart Grid, V. 5, No. 2, March 2014. This is MISO work.

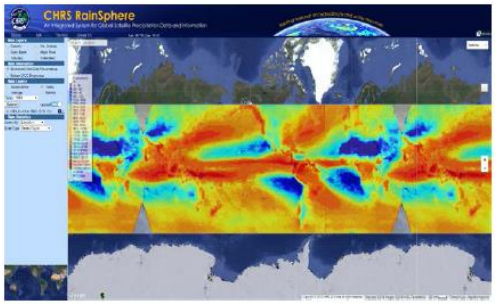
[B] "Hydropower Vision: A New Chapter for America's 1st Renewable Electricity Source," July 26, 2016, available at https://energy.gov/eere/water/articles/hydropower-vision-new-chapter-america-s-1st-renewable-electricity-source.

U.S.-China Clean Energy Research Center: Energy and Water Track



Reheat air combined cycles simulation

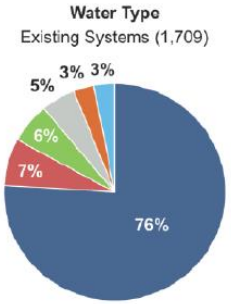
Water Use Reduction at Thermoelectric Plants

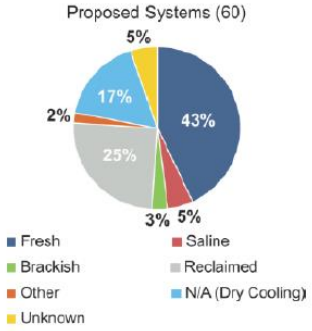


Climate-Scale Precipitation Database

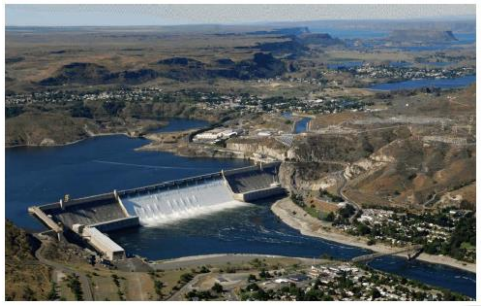
Climate Impact Modeling

Expected changes in cooling water sources between 2013 and 2022





Treatment and Management of Non-Traditional Waters



Grand Coulee Dam

Improving Sustainable Hydropower Design and Operation

California's Complex Water Conveyance System

Data Analysis to Inform Planning, Policy, and Other Decisions