S4-3

Energy-Water Interactions, Opportunities, and Challenges

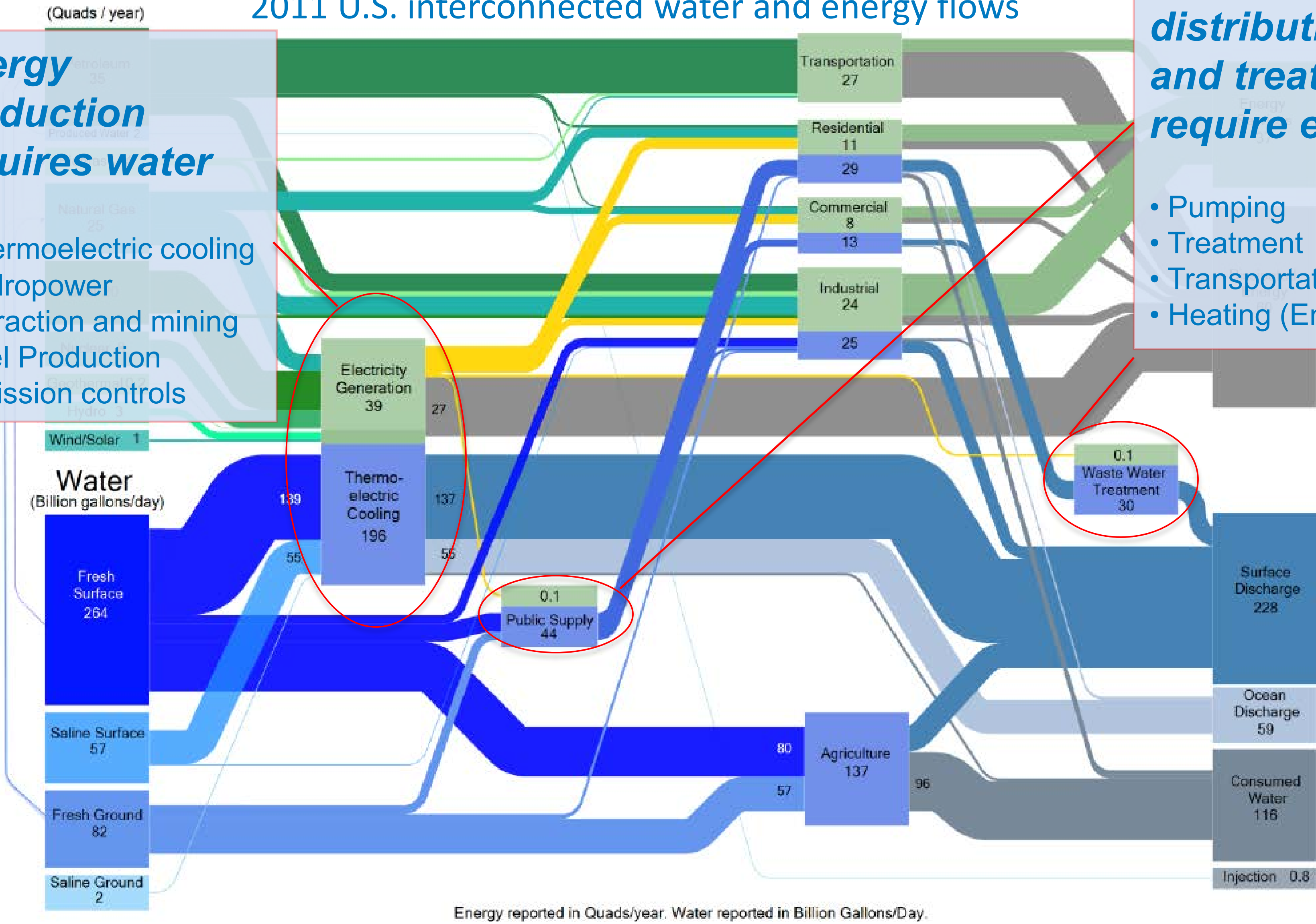
Jordan Macknick

ASIA PACIFIC ENERGY RESEARCH CENTRE
APERC Annual Conference 2018
30-31 May 2018, Tokyo Prince Hotel, Japan

Water Requirements of Energy

Energy and Water are interconnected

2011 U.S. interconnected water and energy flows



Energy production requires water

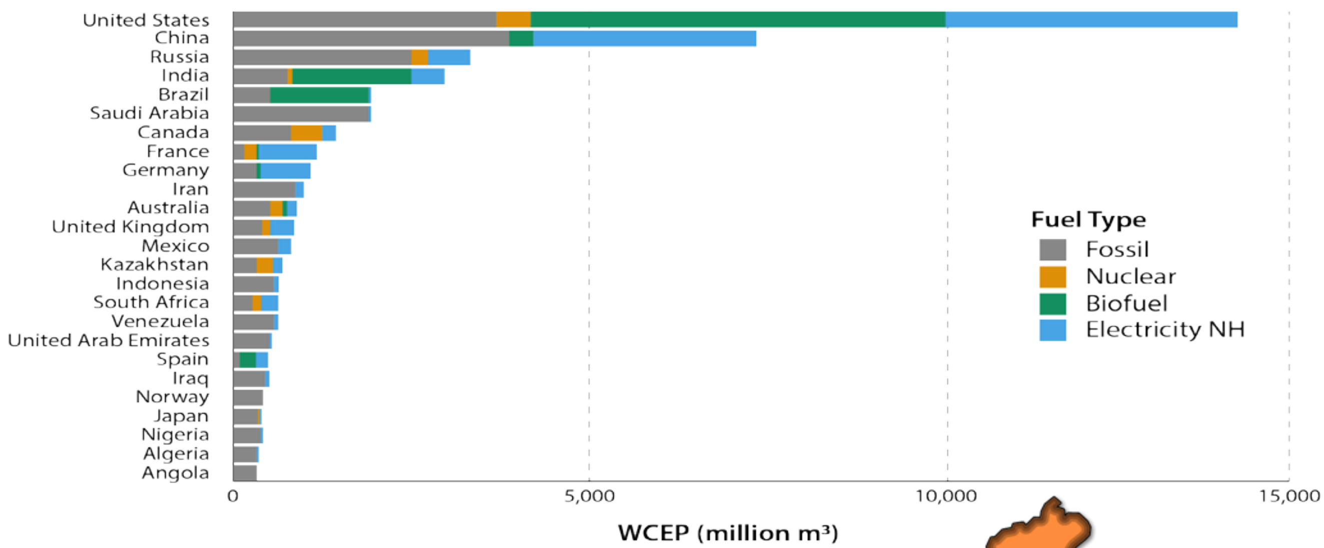
- Thermoelectric cooling
- Hydropower
- Extraction and mining
- Fuel Production
- Emission controls

Water production, distribution and treatment require energy

- Pumping
- Treatment
- Transportation
- Heating (End use)

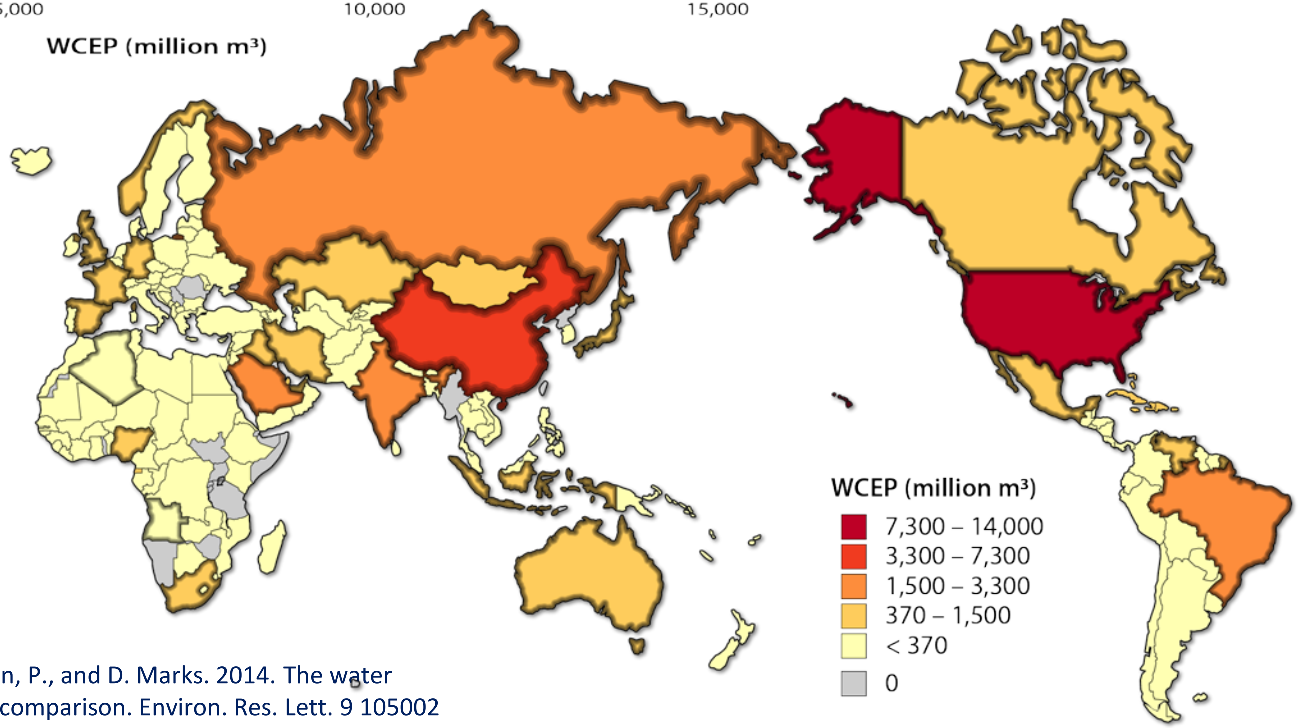
Source: The Water-Energy Nexus: Challenges and Opportunities, DOE, July, 2014

The APEC energy sector requires substantial amounts of water



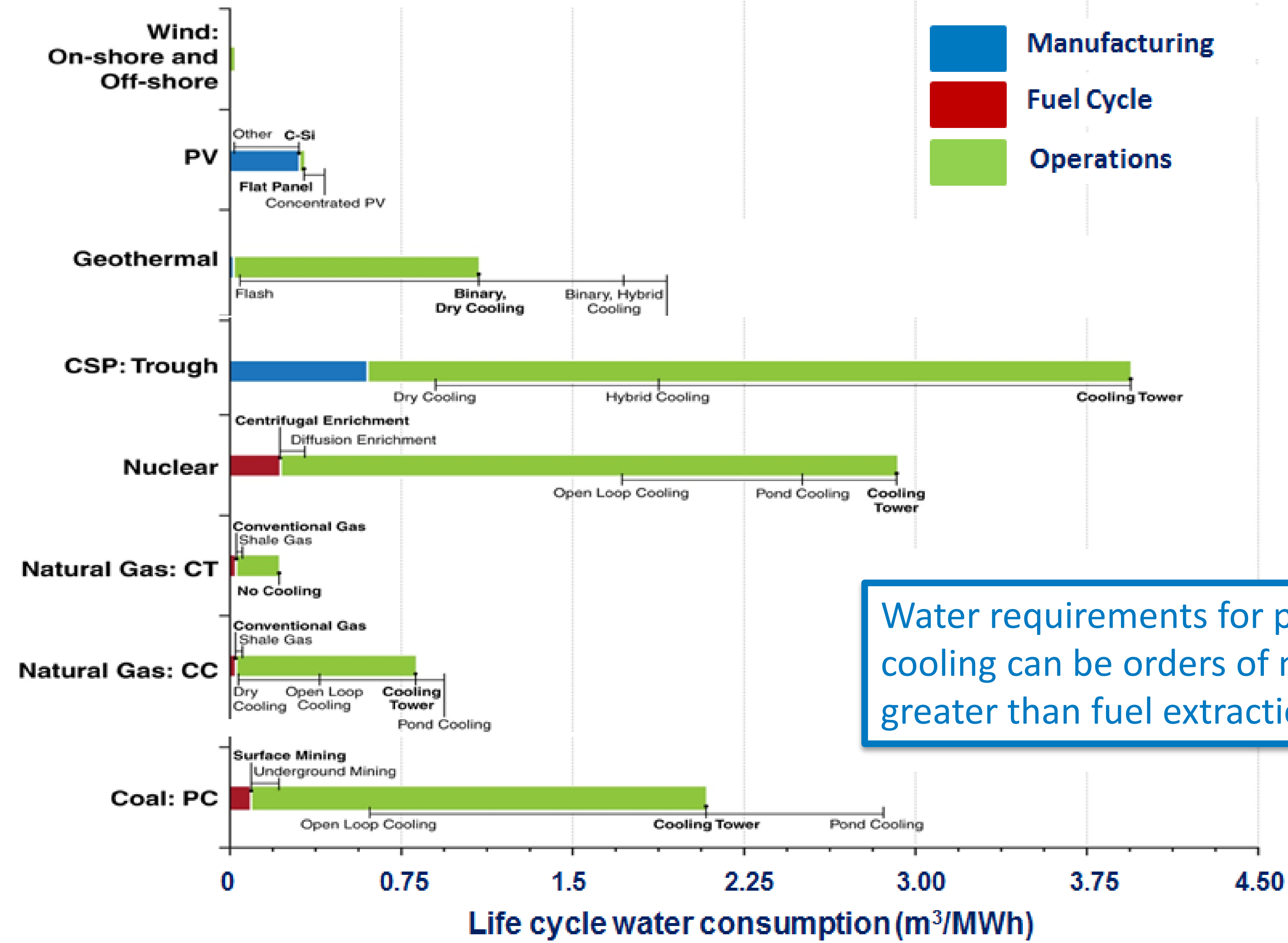
APEC nations are 8 of the top 25 water-for-energy users in the world

APEC nations use water for fossil fuel production, biofuels, nuclear technologies, and electricity generation



Source: Spang, E., Moomaw, W., Gallagher, K. Hirshen, P., and D. Marks. 2014. The water consumption of energy production: an international comparison. Environ. Res. Lett. 9 105002

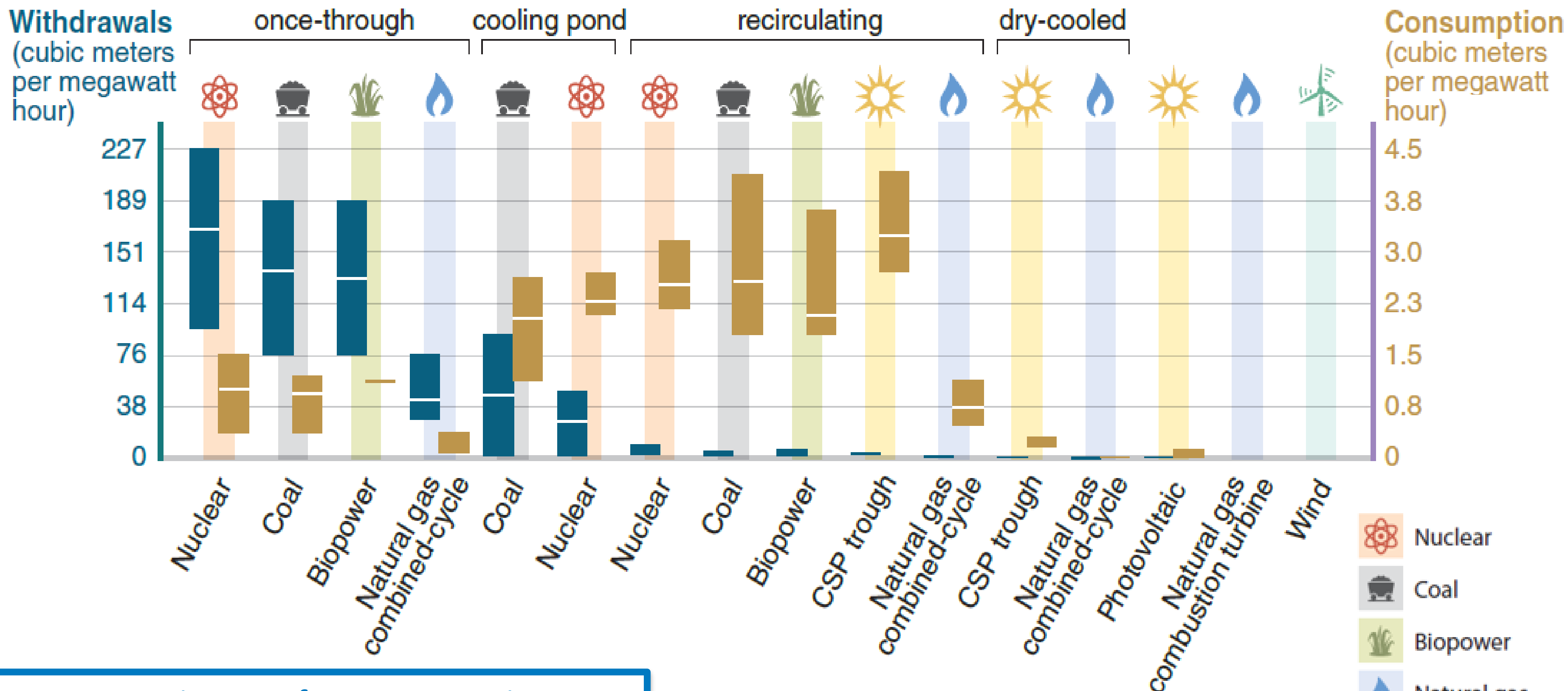
Life cycle water usage is dominated by water use at the power plant

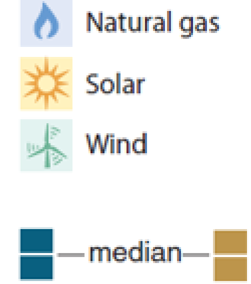


Water requirements for power plant cooling can be orders of magnitude greater than fuel extraction

Source: Meldrum, J., Nettles-Anderson, S., Heath, G., and J Macknick. 2013. Life cycle water use for electricity generation: a review and harmonization of literature estimates. Environ. Res. Lett. 8 015031

Energy technologies have widely different water use rates



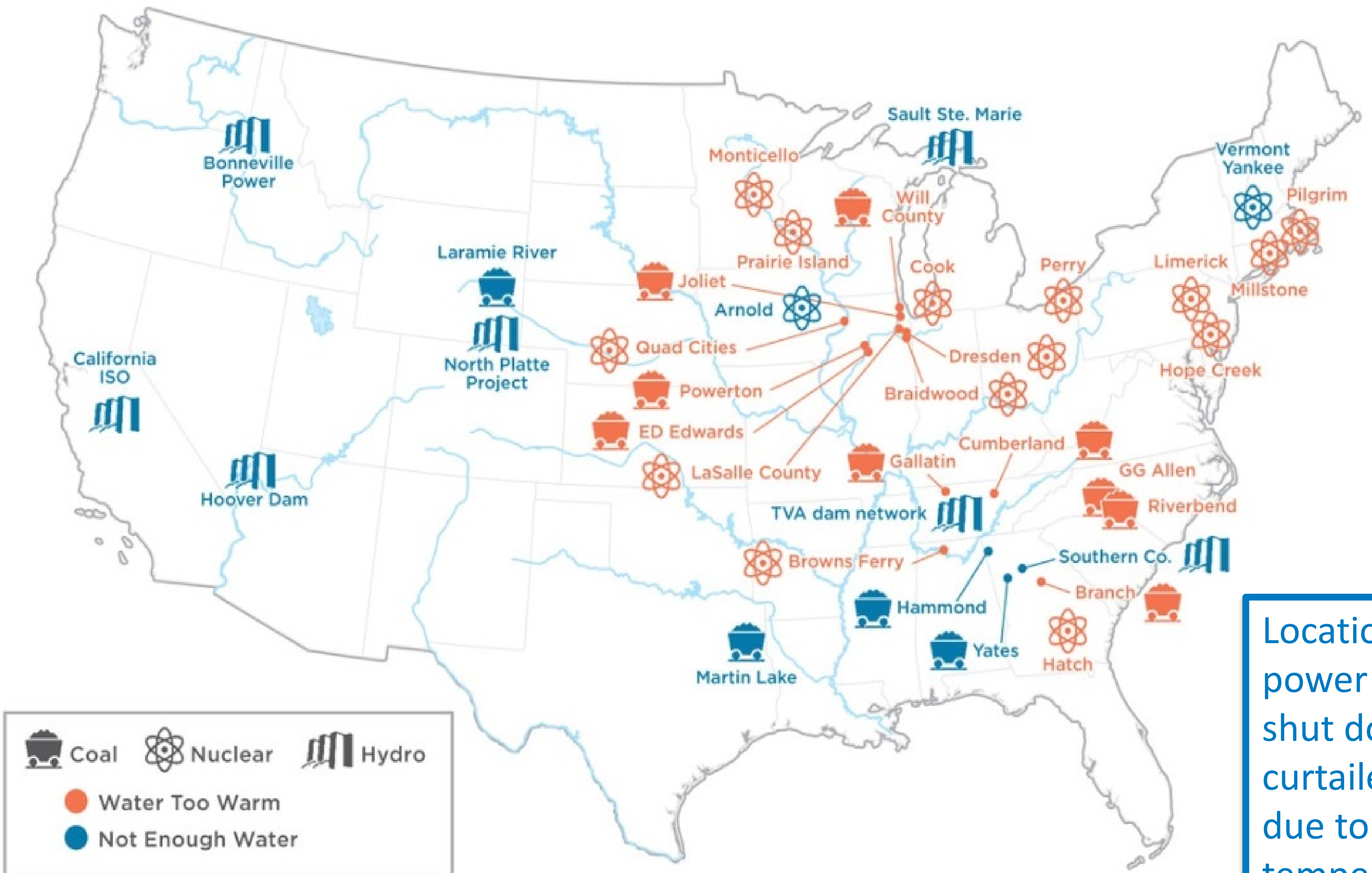


Key Determinants of Water Intensity

- Fuel type
- Generation Technology
- Cooling System

Source: Averyt, K., Fisher, J., Huber-Lee, A., Lewis, A., Macknick, J., Madden, N., Rogers, J., and Tellinghuisen, S. 2011. Freshwater use by U.S. power plants: Electricity's thirst for a precious resource. Union of Concerned Scientists, Cambridge, MA.
Macknick, J., Newmark, R., Heath, G., and Hallett, KC. 2012. Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. Environ. Res. Lett. 7 045802.

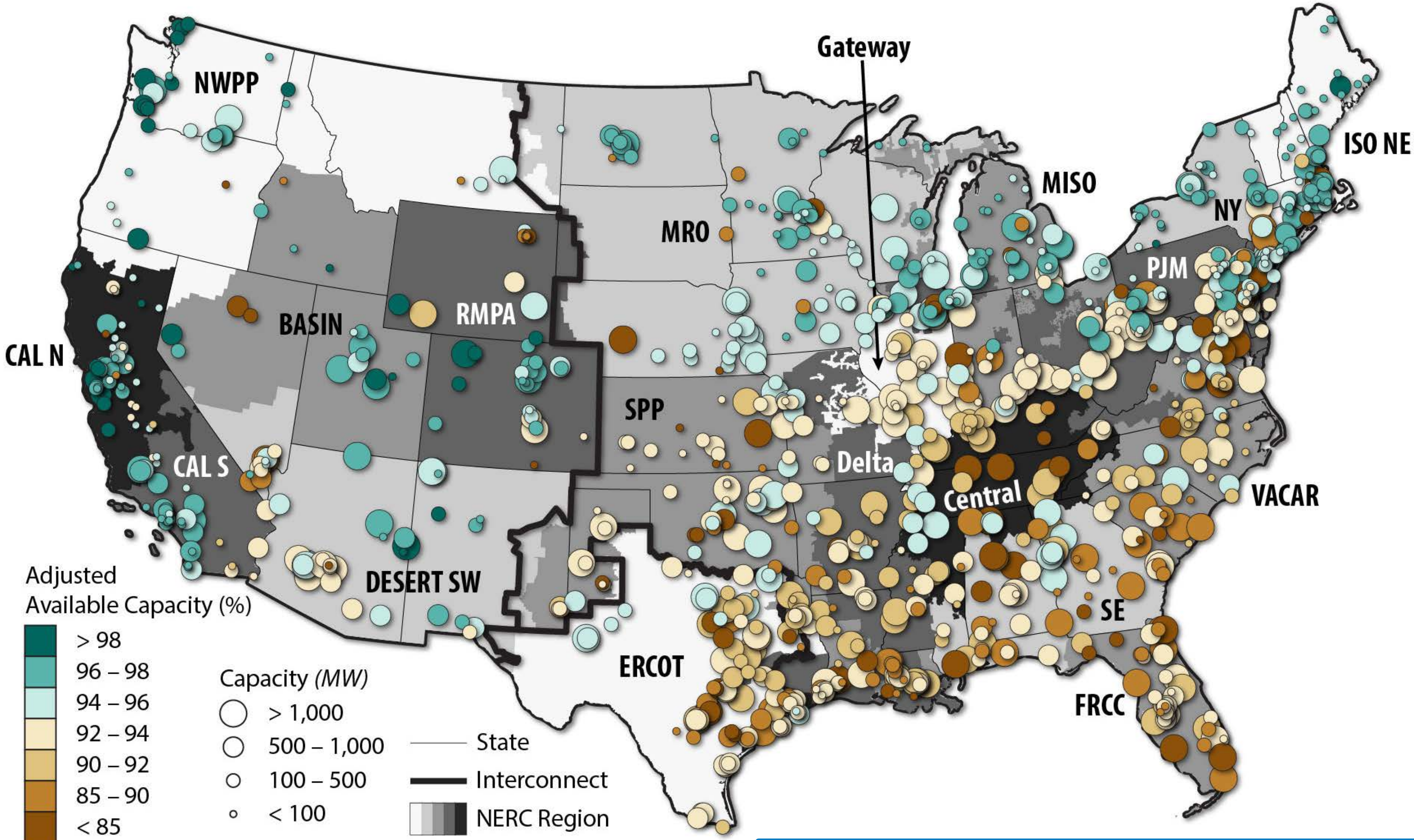
Reliance on water can lead to power sector vulnerabilities



Locations of power plants that shut down or curtailed output due to high water temperatures or lack of water

Source: Rogers, J., Averyt, K., Clemmer, S., Davis, M., Flores-Lopez, F., Frumhoff, P., Kenney, D., Macknick, J., Madden, N., Meldrum, J., Overpeck, J., Sattler, S., Spanger-Siegfried, E., and Yates, D. (2013). Water-smart power: Strengthening the U.S. electricity system in a warming world. Cambridge, MA: Union of Concerned Scientists.
Macknick, J.; Zhou, E.; O'Connell, M.; Brinkman, G.; Miara, A.; Ibanez, E.; Hummon, M. (2016). Water and Climate Impacts on Power System Operations: The Importance of Cooling Systems and Demand Response Measures. NREL/TP-6A20-66714. National Renewable Energy Laboratory, Golden, CO

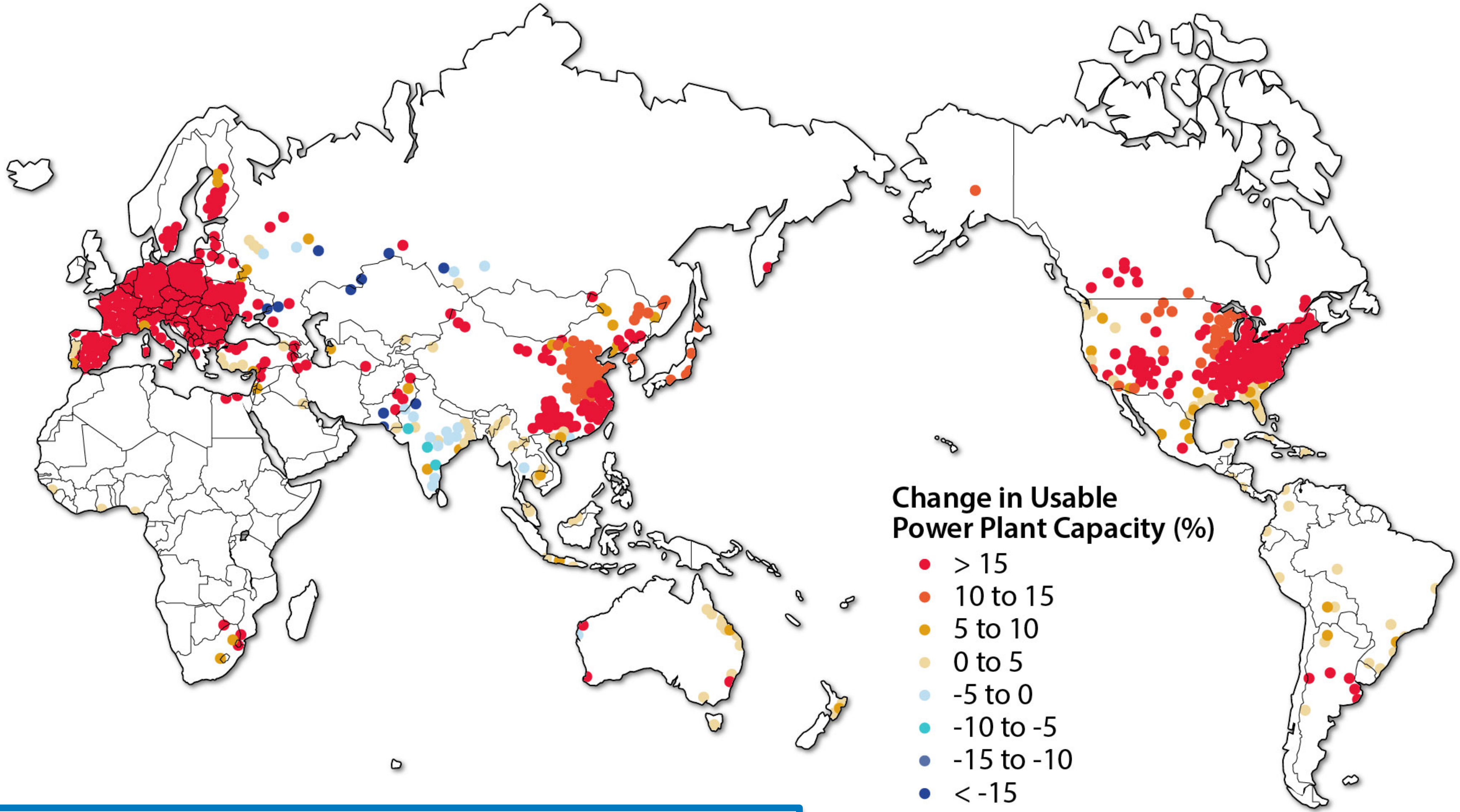
Future water and temperatures will affect existing power plants



U.S. national power capacity could be reduced by 2.5% by 2050 (range: -31% to +6%)

Source: Miara, A., Macknick, J.E., Vörösmarty, C.J., Tidwell, V.C., Newmark, R., Fekete, B., 2017. Climate and water resource change impacts and adaptation potential for US power supply. Nature Climate Change 7, 793–798.

Future water and temperatures will affect existing power plants

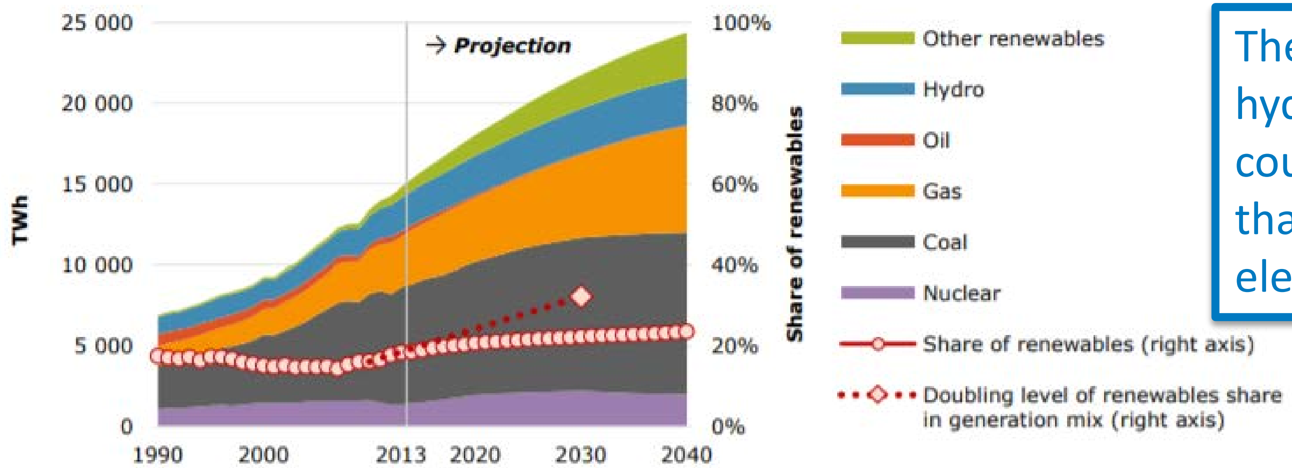


Many APEC nations have existing power plants that could be affected by higher temperatures and droughts

Source: van Vliet MTH, Wiberg D, Leduc S, Riahi K (2016) Power-generation system vulnerability and adaptation to changes in climate and water resources. Nat Clim Change 6:375–380.

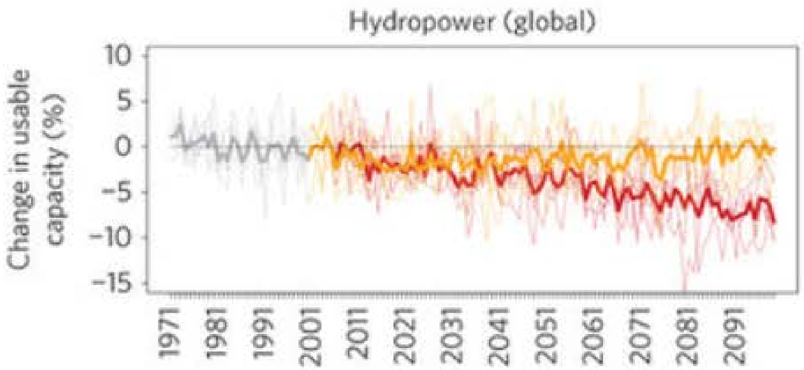
What will the APEC electricity portfolio be in the future and how will it be affected by water?

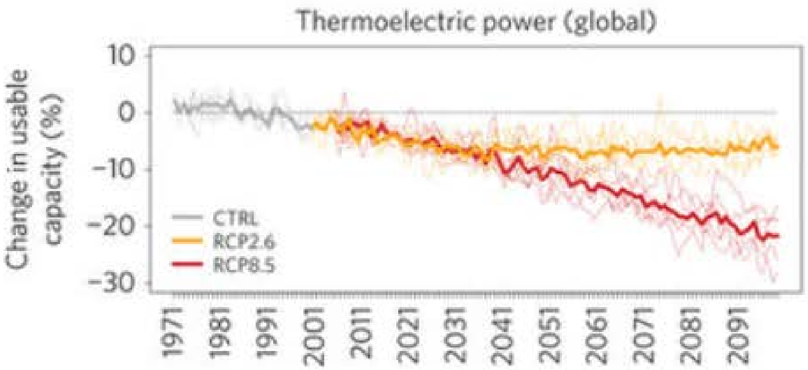
Figure 4.8 • Electricity generation and share of renewables by fuel, 1990-2040



Thermoelectric and hydropower resources could account for more than 80% of the APEC electricity portfolio in 2040

Higher air and water temperatures combined with reductions in water availability could reduce global hydropower capacity by 5% and thermoelectric capacity by 10% by 2040



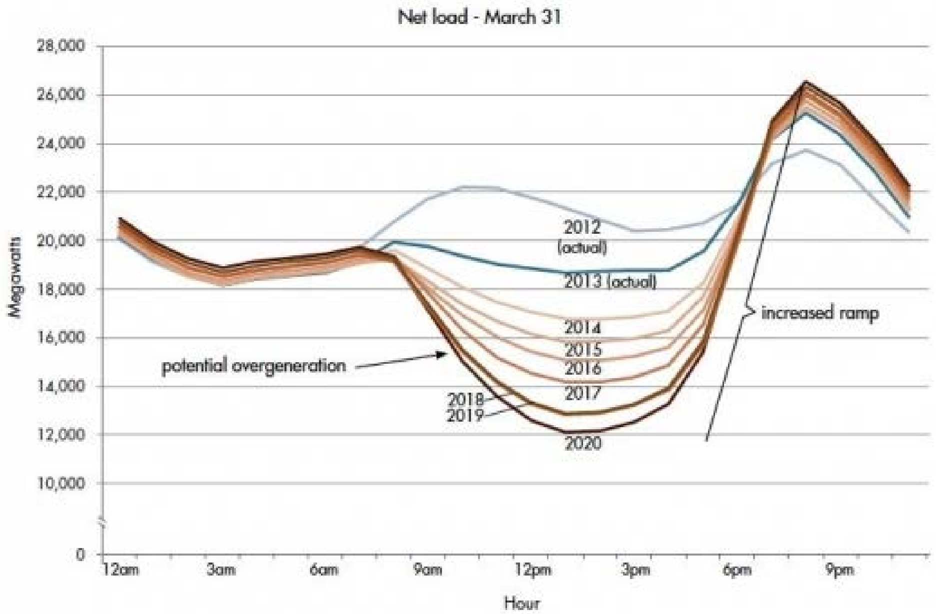


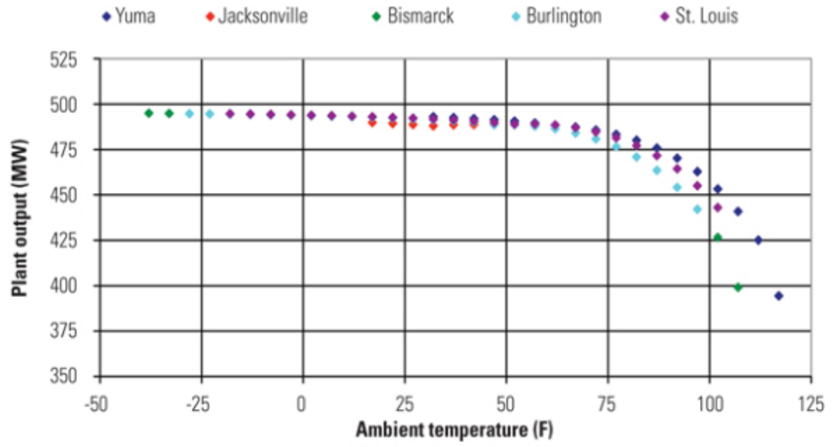
Source: van Vliet MTH, Wiberg D, Leduc S, Riahi K (2016) Power-generation system vulnerability and adaptation to changes in climate and water resources. Nat Clim Change 6:375–380.
APEC Energy Demand and Supply Outlook. 6th Edition. 2016.

Low-water technologies have unique sets of challenges

Low-water variable renewable technologies can have grid integration challenges

Low-water cooling systems have reduced performance under hot conditions





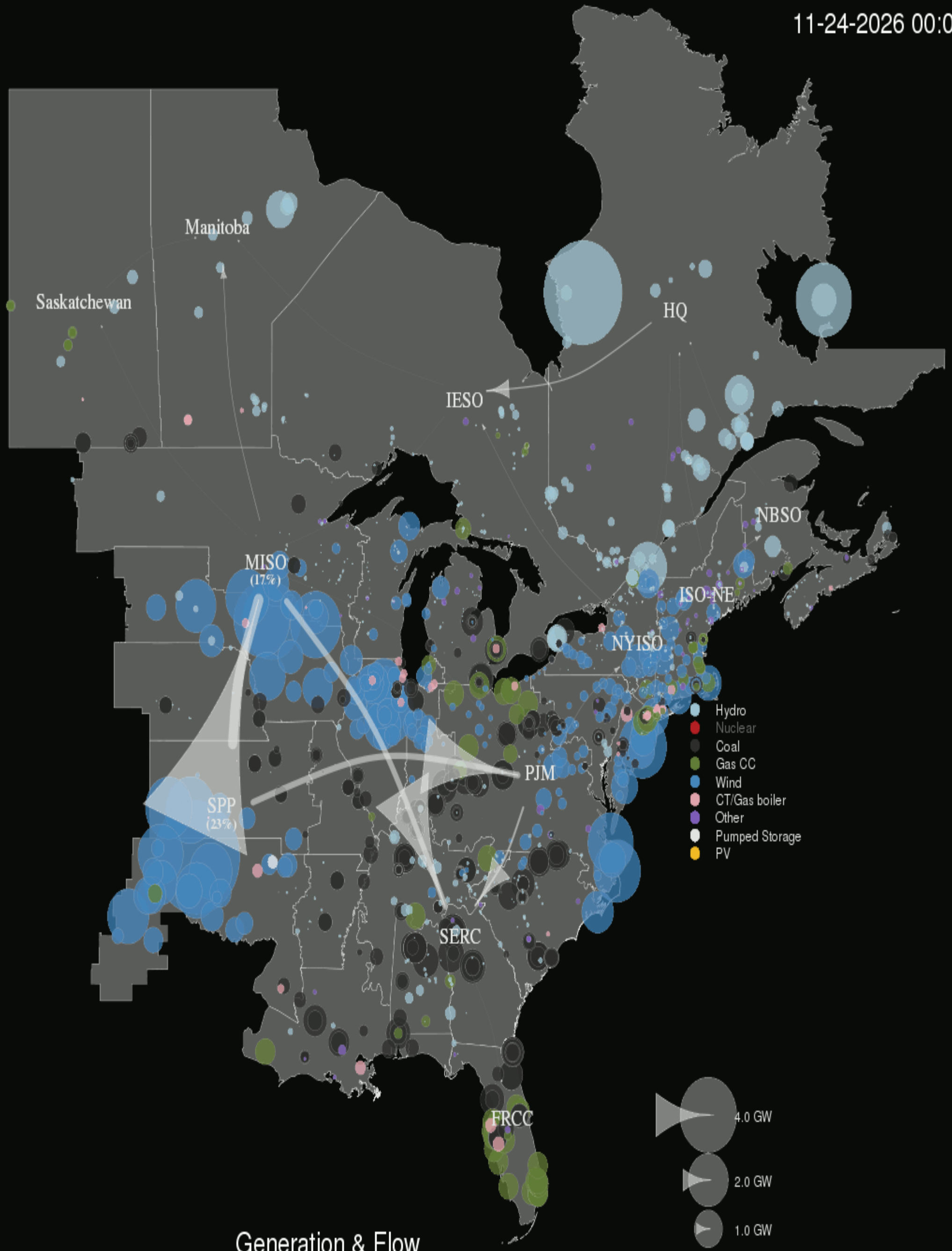
7. Hot day power loss. The performance of a typical 500-MW coal-fired plant using dry cooling is highly temperature-dependent; therefore, expected plant performance will vary considerably, based on location. *Source: EPRI*

But recent work has demonstrated that we can achieve high penetrations of variable renewable energy technologies on the grid safely and cost-effectively

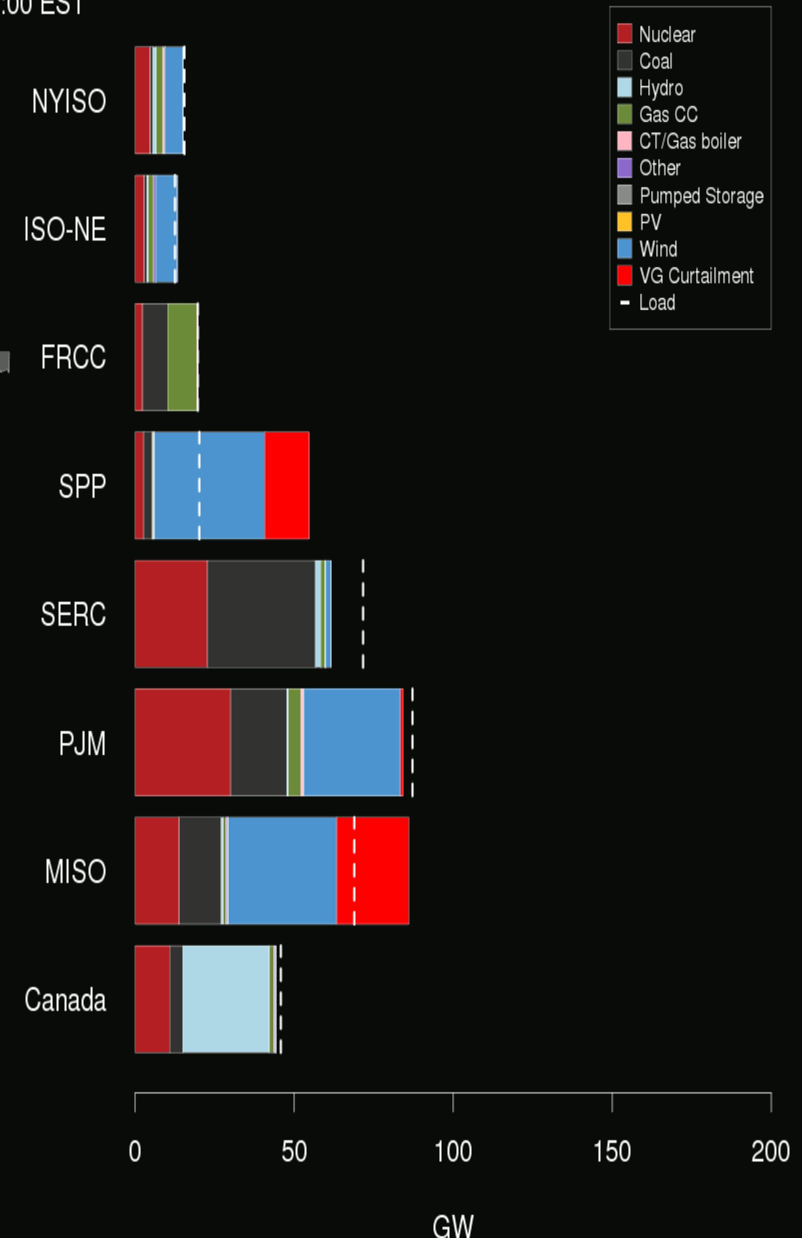
Source: California ISO.2013. Fast Facts: What the duck curve tells us about managing a green grid.
Denholm, P., O'Connell, M., Brinkman, G., and J. Jorgenson. 2015. Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart. NREL/TP-6A20-65023. National Renewable Energy Laboratory, Golden, CO
Zammit, K. 2012. Water Conservation Options for Power Generation Facilities. Power Magazine.

Eastern Renewable Generation Integration Study (ITx30)

11-24-2026 00:00 EST



Generation & Flow

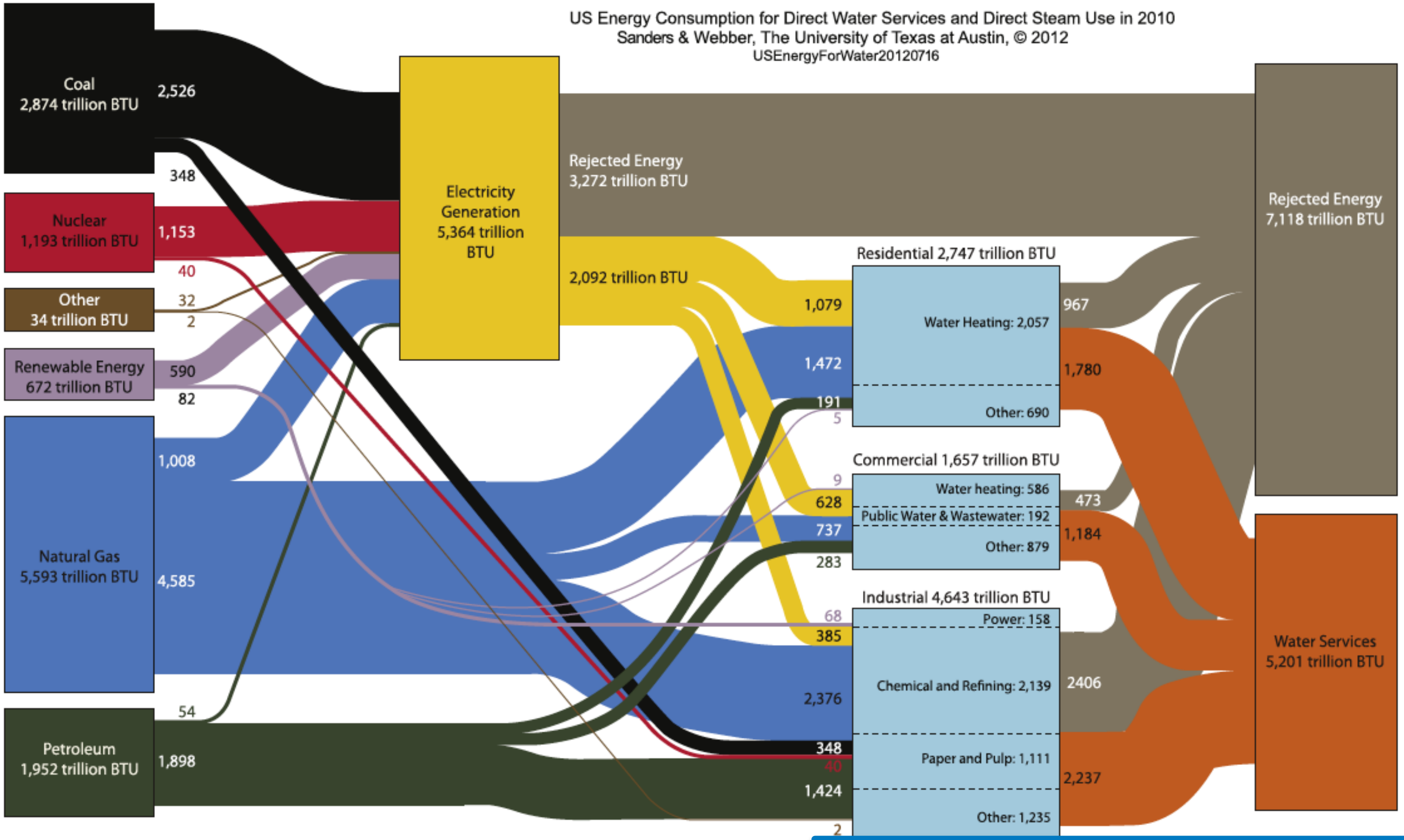


Regional dispatch

Bloom et al., 2016. Eastern Renewable Generation Study. NREL/TP-6A20-64472. National Renewable Energy Laboratory, Golden, CO

Energy Requirements of Water

Primary energy embedded in water infrastructure: US national

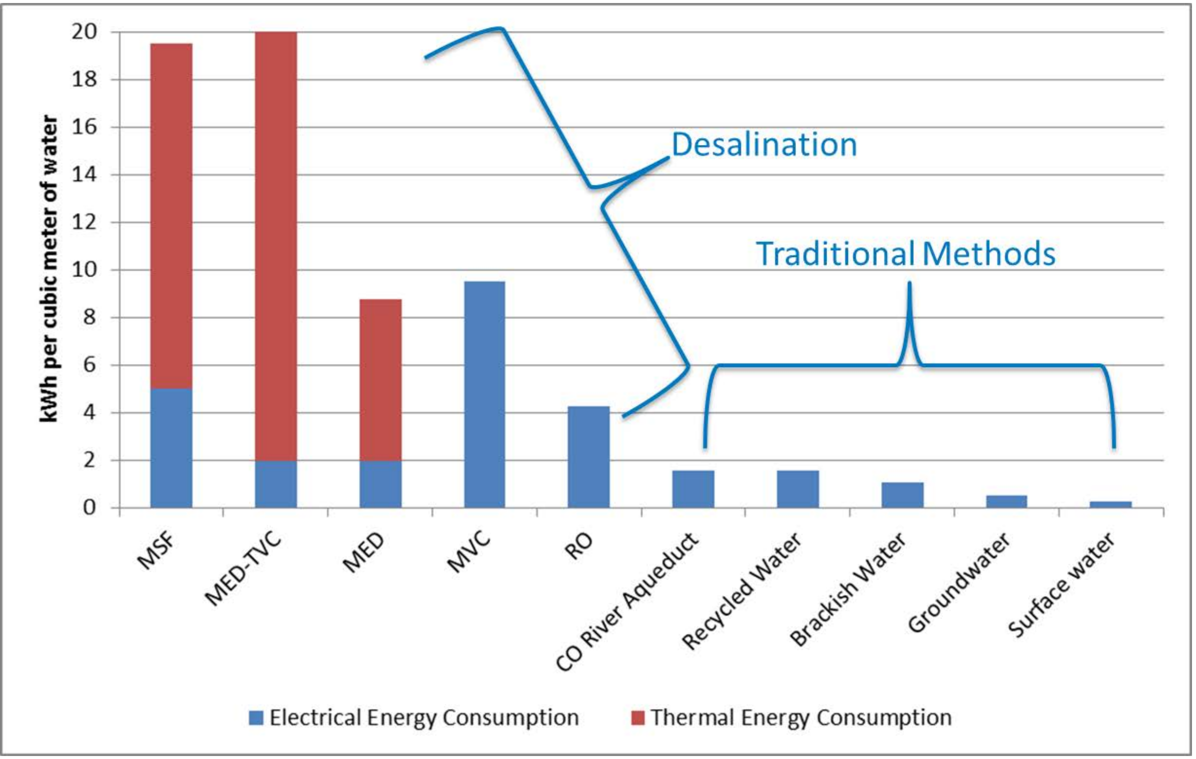


Energy use in the residential, commercial, industrial and power sectors* for direct water and steam services was approximately 13 Exajoules or ***12.6% of the 2010 annual primary energy consumption in the US***

*Residential, Commercial, Industrial and Power sectors, (~70% of total US primary energy consumption). Transportation sector not included.

Source: Sanders, K. and M. Webber, 2012. Evaluating the energy consumed for water use in the United States. 2012. Environ. Res. Lett. 7 034034.

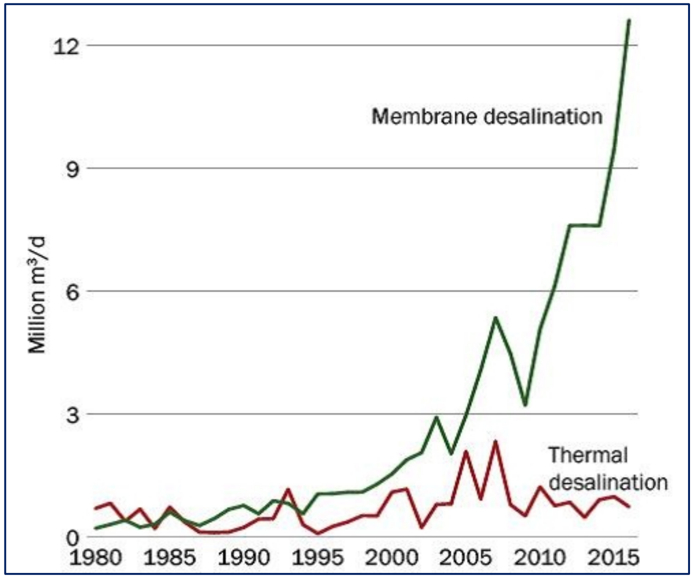
Energy Intensity of Desalination Technologies—Compared with Traditional Treatment Methods



Desalination technologies can orders of magnitude more energy than traditional water treatment technologies

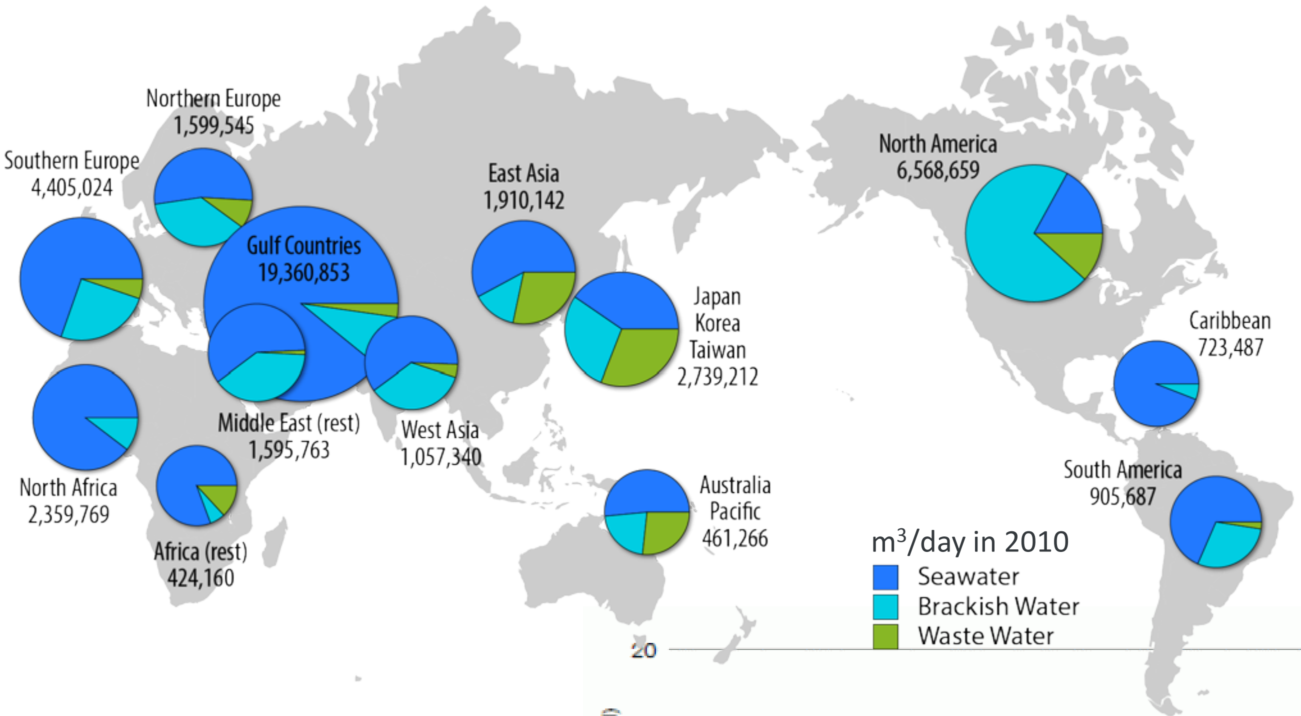
MSF: Multi-Stage Flash Distillation
MED: Multi-Effect Distillation
MED-TVC: Multi-Effect Distillation with Thermal Vapor Compression
MVC: Mechanical Vapor Compression
RO: Reverse Osmosis

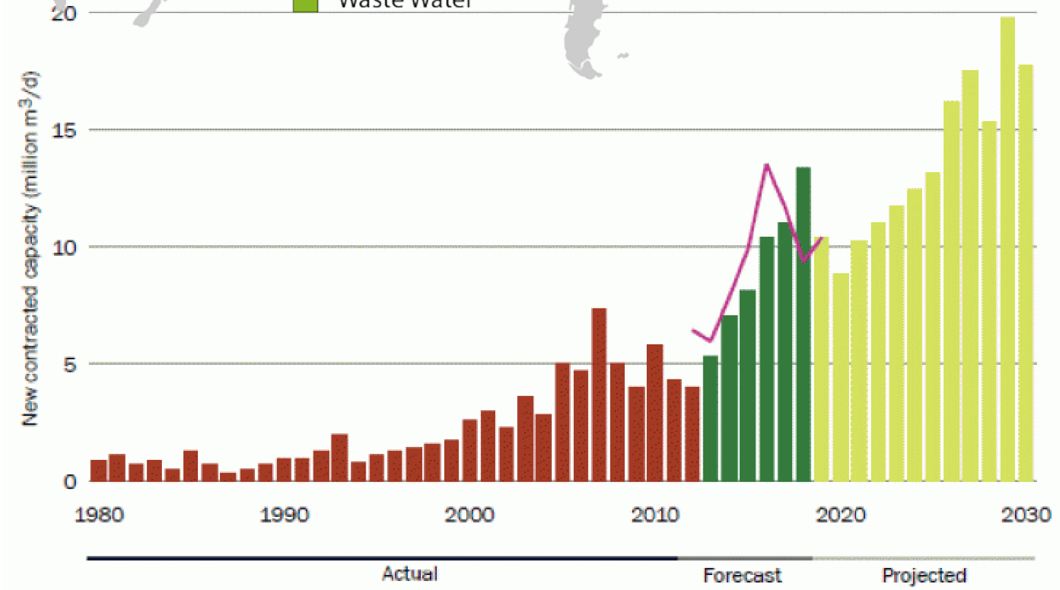
Membrane desalination technologies, which have higher electrical requirements than thermal desalination technologies, have been rapidly increasing



Source*:* Wangnick Consulting. 2010. IDA Worldwide Desalting Plants Inventory
Cooley, H. and Heberger, M. 2013. Key Issues in Seawater Desalination in California: Energy and Greenhouse Gas Emissions. Pacific Institute.
Desal Data

Desalination is rapidly increasing, including in the APEC region





APEC nations have substantial desalination capacity for seawater, brackish water, and waste water and are likely to see increases in capacity

Source: Next Big Future
Yates Environmental Services
Desal Data
Sustainability Science and Engineering, Volume 2, 2010

Integrated Energy and Water Opportunities and Planning

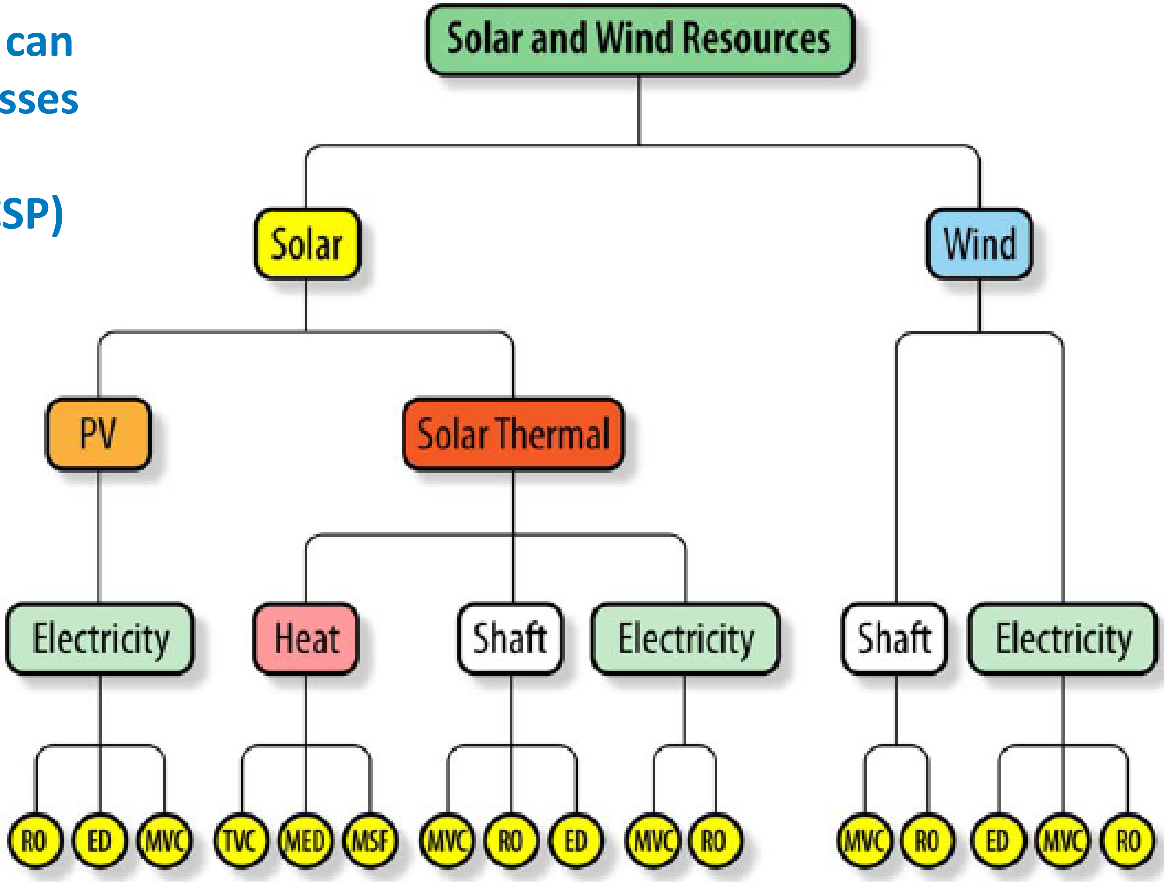
Integrated Opportunity: Renewable-Powered Desalination Technologies

Renewable energy technologies can be utilized in desalination processes to provide thermal energy:

- **Concentrating solar power (CSP)**
- **Geothermal**
- **Bioenergy**

and electrical energy:

- **CSP**
- **Geothermal**
- **Solar PV**
- **Wind**
- **Hydro**
- **Marine hydrokinetic**
- **Bioenergy**



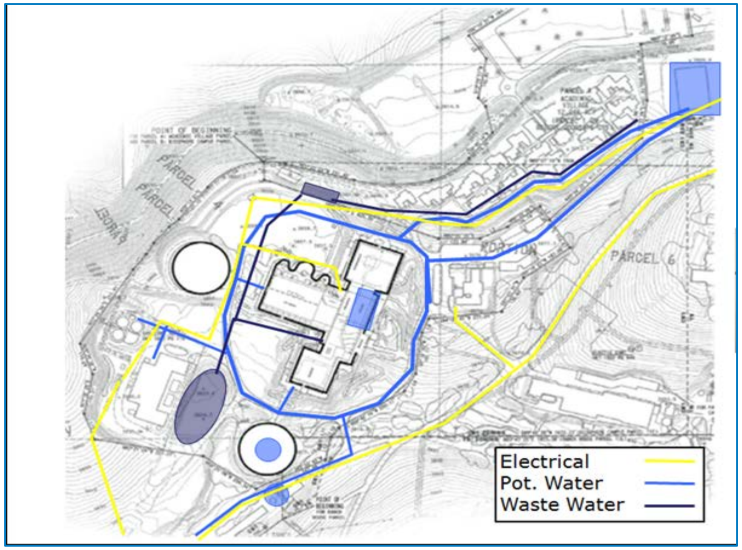
ED: Electrodialysis
MSF: Multi-Stage Flash Distillation
MED: Multi-Effect Distillation
MVC: Mechanical Vapor Compression
RO: Reverse Osmosis
TVC: Thermal Vapor Compression

Source: Al-Karaghouli, A., Renne, D., and Kazmerski, L. 2009. Solar and wind opportunities for water desalination in the Arab regions. Renewable and Sustainable Energy Reviews. Vol. 13.

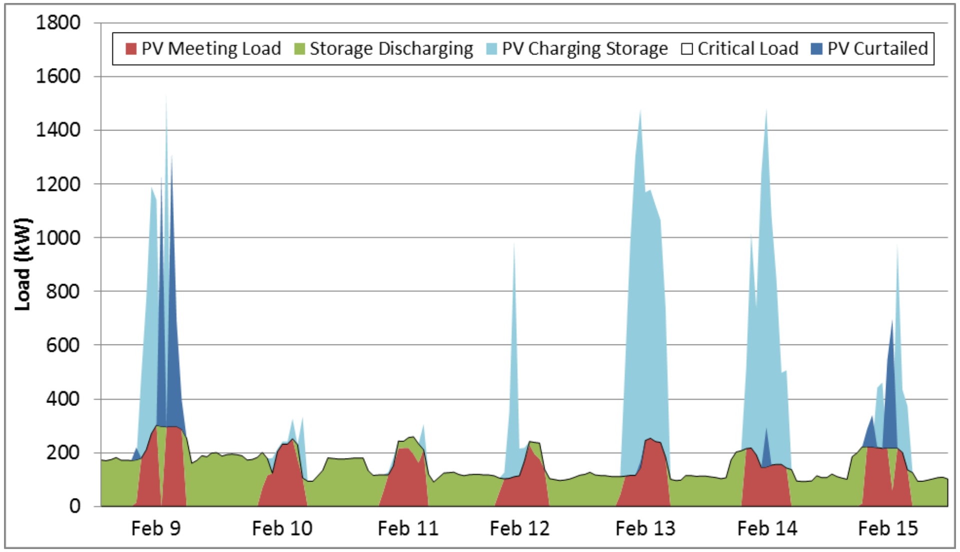
Integrated Opportunity: Energy-Water Microgrids

Renewable-powered energy-water microgrid at the Biosphere 2 Facility in Arizona.

- ✓ Water-related loads have large energy requirements
- ✓ Desire for flexibility and optimized operations
- ✓ Commercial, residential, and industrial components within the complex
- ✓ Active research site
- ✓ Quantifying the technical potential for water-related loads to provide services in a microgrid



PV and Storage Sustain Critical Load in 100% RE microgrid



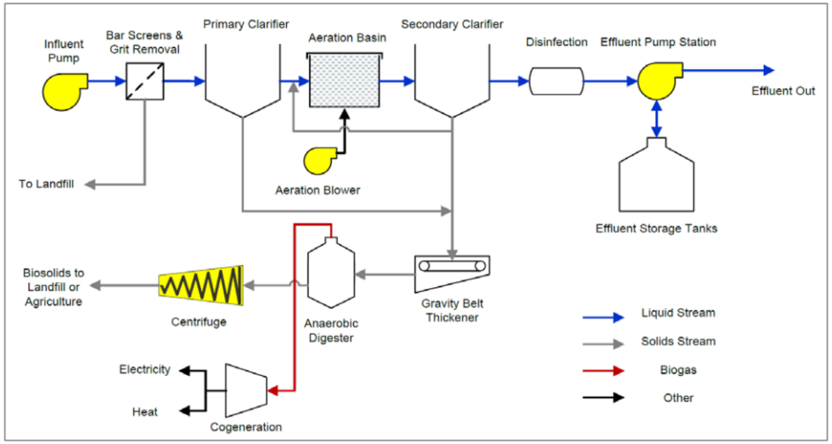
Source: Daw, J., Kandt, A., Giraldez, J., Macknick, J., Anderson, K., Armstrong, N., and J Adams. Energy-Water Microgrid Opportunity Analysis at the University of Arizona's Biosphere 2 Facility. NREL/TP-7A40-71294

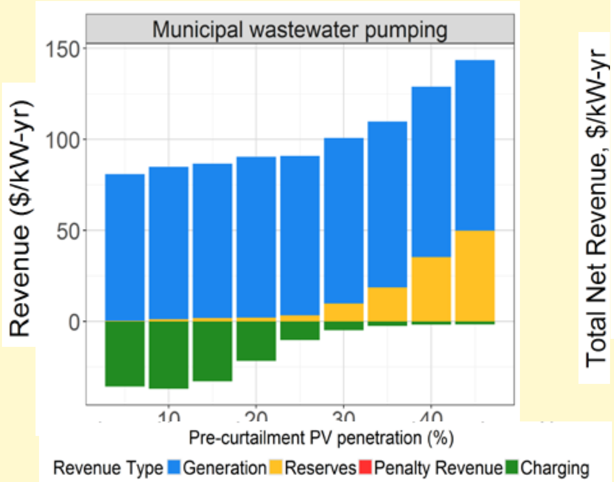
Integrated Opportunity:
Water Infrastructure Providing Electric Grid Services

Yellow areas highlight locations where water infrastructure can either produce energy or provide grid services:

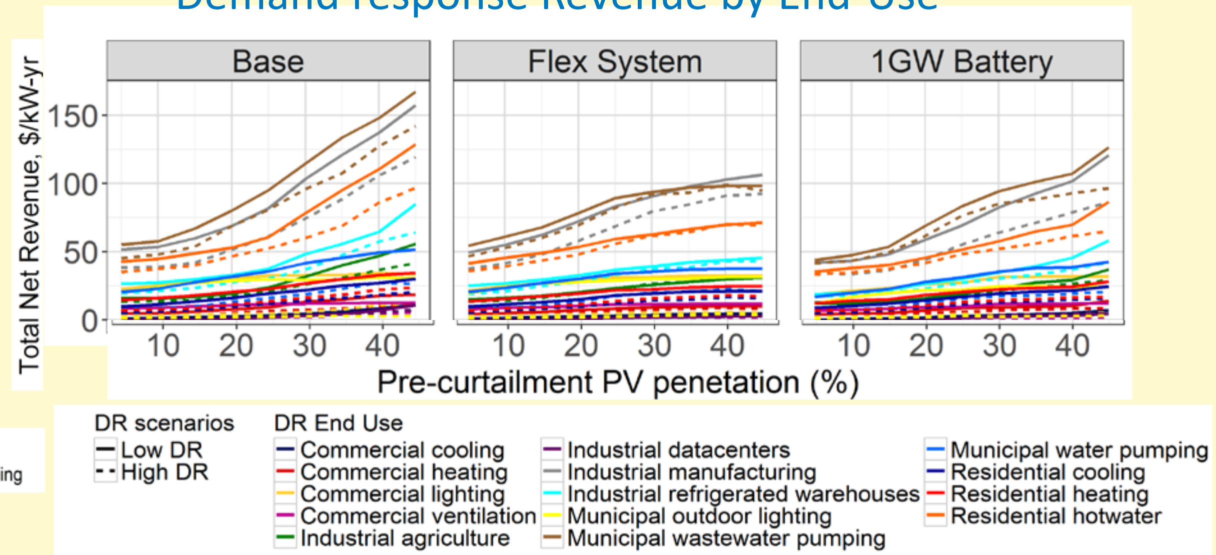
- *Capacity*
- *Frequency Regulation*
- *On-site generation*

Wastewater Treatment Plant (schematic)





Demand response Revenue by End-Use



Source: Sparn, B. and R. Hunsberger. 2015. Opportunities and Challenges for Water and Wastewater Industries to Provide Exchangeable Services. NREL/TP-5500-63931.
Stoll, B., Buechler, E., and E. Hale. 2017. The value of demand response in Florida. The Electricity Journal. 30:9. 57-64.

The Next Frontier: Integrated Energy and Water Planning

There are many independent tools, but linking models and data across sectors will be necessary for a comprehensive risk assessment

- Challenges
  - Data availability
  - Inherent model spatial, temporal, and structural differences
  - Infrastructure flexibility
  - Workforce capacity

The role of water availability in power system planning

- Considering water in planning for future construction as well as current operations can improve comprehensive risk assessment
- Higher temperatures and water availability could affect the available capacity of 99% of individual power plants, but regional impacts and adaptation strategies will differ substantially
- Solar, wind, and geothermal can be “drought proof technologies” that can be more resilient than water-dependent systems, but they can bring their own set of challenges to grid integration
- Power systems are inherently connected and adaptable and can address varying conditions
- A power systems context is necessary to understand regional connectivity and vulnerabilities to fully understand extent of power system resilience and vulnerability

The role of energy in water system planning

- Water systems can have large thermal and electrical energy demands throughout the entire life cycle
- Energy requirements for water infrastructure are expected to increase with the rise of desalination
- Water systems can produce electrical and thermal energy that can be used on-site or put into distribution systems
- Water systems can operate flexibly to provide grid services to the power sector to provide additional value to both sectors
- Water systems can be integrated with renewable energy technologies and can be operated in microgrids

Thank you

Jordan.Macknick@nrel.gov

www.nrel.gov/analysis/water

www.nrel.gov

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Acknowledgments: This work was supported by the Office of Science of the U.S. Department of Energy, Office of Biological and Environmental Research as part of the Integrated Assessment Research Program. Graphics support: Billy Roberts.