



An Energy Water Nexus Research Agenda

NSF Workshop on the Energy Water Nexus

**Michael E. Webber, Ph.D.
June 10, 2013**

There Are Good and Bad Tradeoffs At the Energy Water Nexus (Quantity)

- **With sufficiently abundant, clean and affordable energy, our water problems are solved**
 - Long-haul transfer, desalination, deep wells,...
- **With sufficiently abundant, clean, and affordable water, our energy problems are solved**
 - Biofuels, hydro,...
- **Coupled infrastructures causes cascading vulnerabilities**
 - Water constraints become energy constraints
 - Energy constraints become water constraints



There Are Good and Bad Tradeoffs At the Energy Water Nexus (Quality)

- **Energy affects water quality (good and bad)**
 - Energy is used to treat (clean, move, heat,...)
 - Energy pollutes water (thermal, chemical,...)
- **Water affects energy quality (good and bad)**
 - Improved efficiency at power plants (thermoelectric, solar PV, ...)
 - Improved recovery for oil and gas production
 - Degraded performance in heat waves



We Use Water for Energy

- **We use water for the power sector**
 - Driving hydroelectric turbines
 - Driving steam turbines
 - Cooling power plants
- **We use water for fuels production**
 - Growing biofuels
 - Extracting oil and gas
 - Mining coal and uranium
 - Refining/upgrading fuels
- **We use water for transporting fuels**



The Thermoelectric Power Sector Is Water Intensive

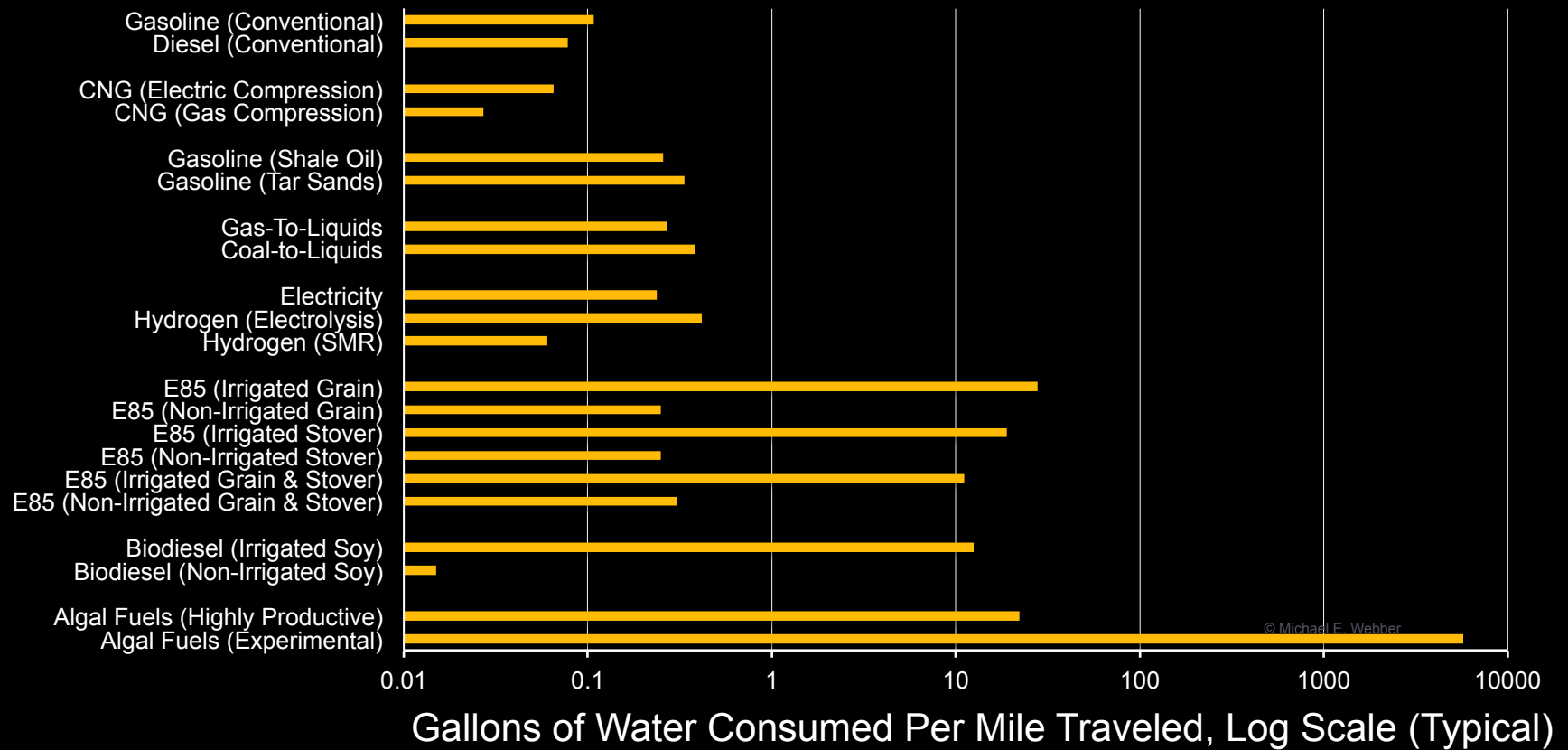
- *Non-Consumptive Use (Withdrawals):*
 - ~0.2 to 42.5 gal/kWh
 - 48% of total USA water withdrawals
 - 39% of total USA freshwater withdrawals
- *Consumptive Use:*
 - ~0.1 to 0.8 gal/kWh
 - 3% of USA consumption
- *Varies by fuel, power cycle, cooling technology*



Transportation Is Water Intensive & Growing

Water Intensity of Transportation

Source: Recreated from King & Webber (2008) and Twomey, Beal, King & Webber (2012)
 Graphic: Michael E. Webber, The University of Texas at Austin



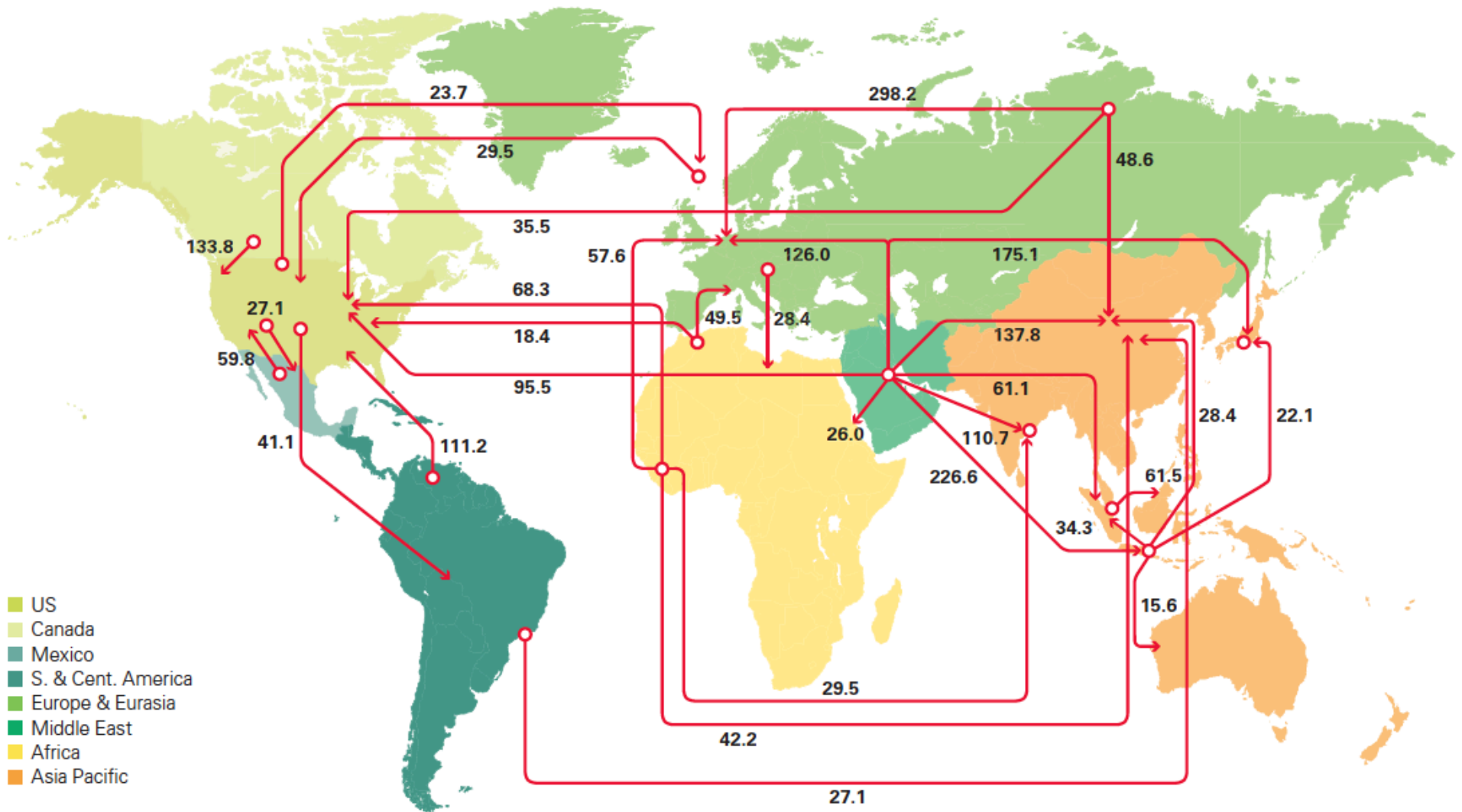
We Use Water For Transporting Energy



Nearly Half of Global Oil Production Is Traded Across Borders, Much of It By Water

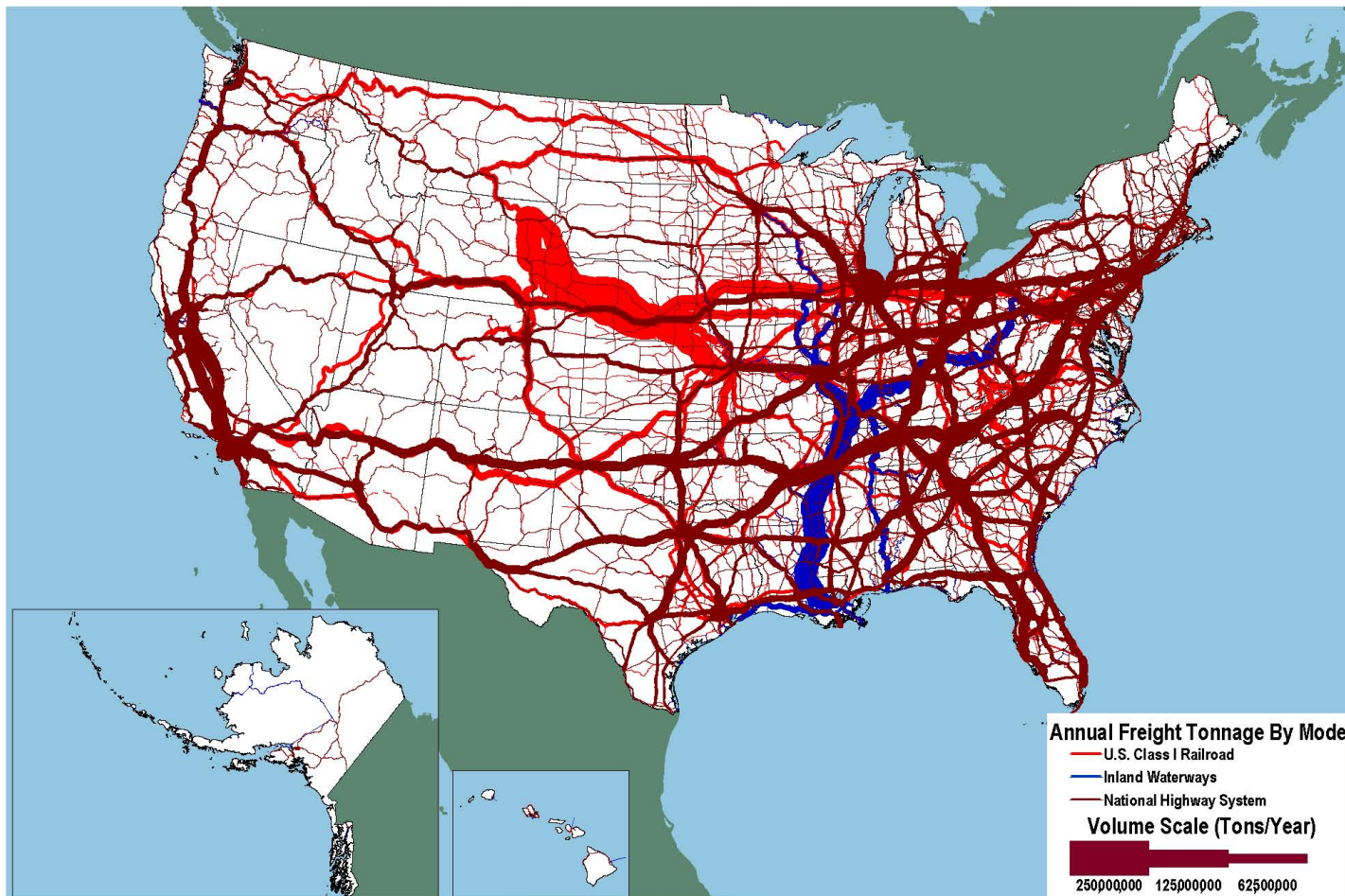
Major trade movements 2011
Trade flows worldwide (million tonnes)

Source: BP Statistical Review 2012



Most Inland USA Water-Based Transportation Is In the Mississippi River Basin

Tonnage on Highways, Railroads and Inland Waterways: 2002



Barges are used to move coal along the Mississippi River

Source:
U.S. DoT, FHWA

Sources: Highways: U.S. Department of Transportation, Federal Highway Administration, Freight Analysis Framework, Version 2.2, 2007. Rail: Based on Surface Transportation Board, Annual Carload Waybill Sample and rail freight flow assignments done by Oak Ridge National Laboratory. Inland Waterways: U.S. Army Corps of Engineers (USACE), Annual Vessel Operating Activity and Lock Performance Monitoring System data, as processed for USACE by the Tennessee Valley Authority; and USACE, Institute for Water Resources, Waterborne Foreign Trade Data, Water flow assignments done by Oak Ridge National Laboratory.

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Water Shipping Is Relatively Energy Efficient

Freight Mode	Energy Intensity [BTU per ton-mile]
Heavy Trucks*	850 to 1075
Freight Railroad	289
Waterborne	217

*Typical loads for heavy trucks are 20-25 tons

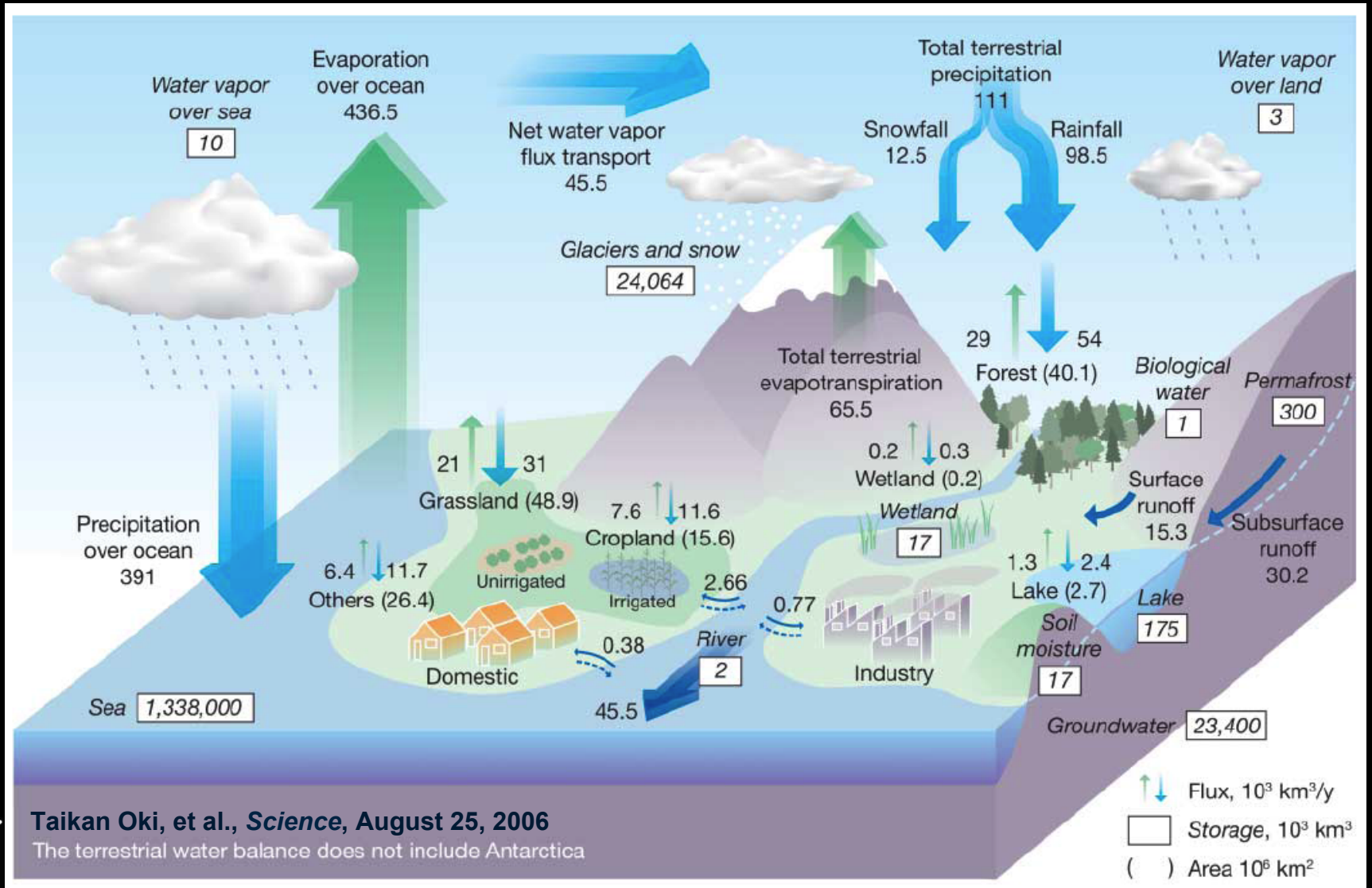
Source: DoE Transportation Energy Data Book 2012
(2010 Data)



We Use Energy for Water



The Hydrological Cycle is Global and Has Plenty of Water, But In the Wrong Place, Form, or Time of Year

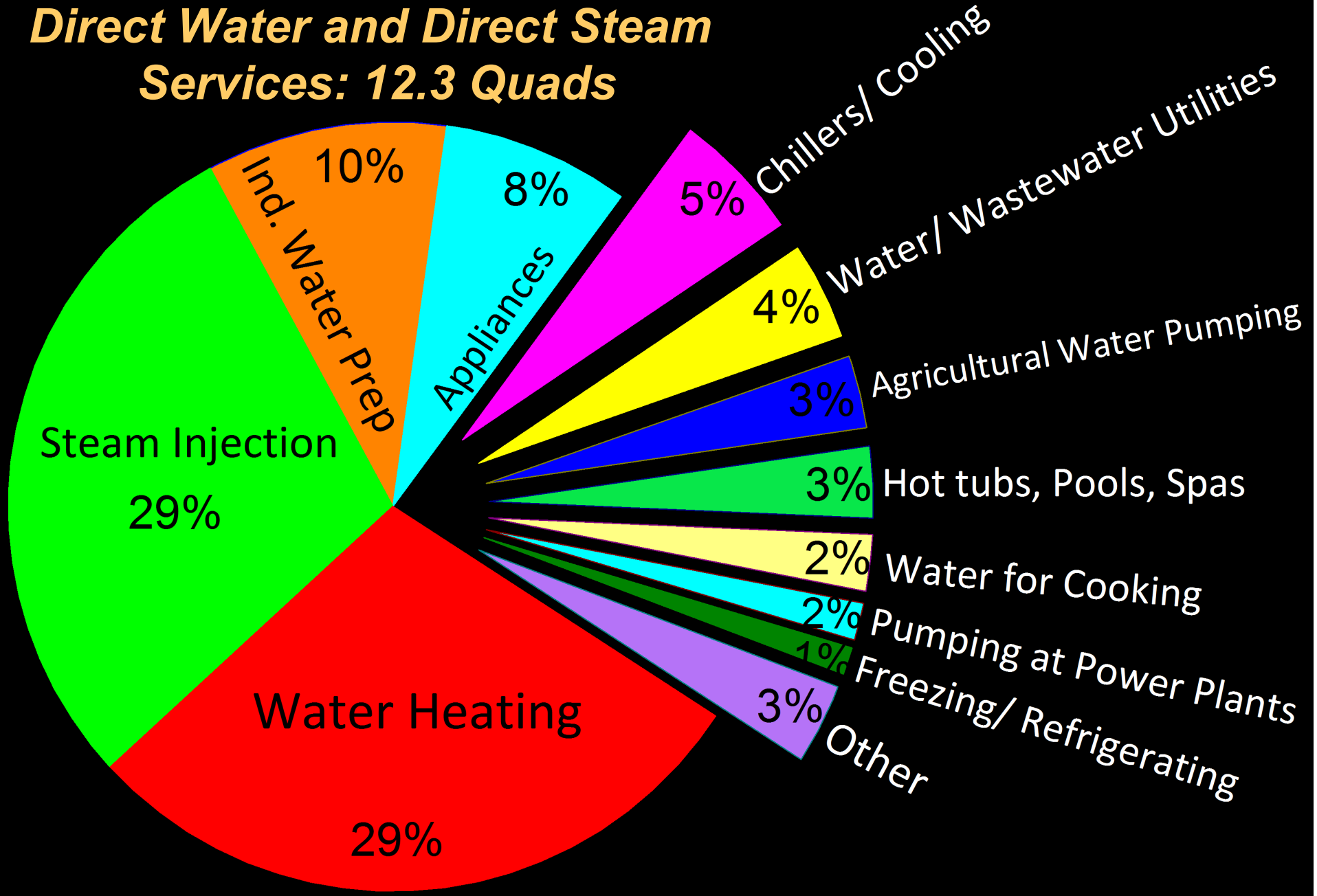


Consequently, We Use Energy for Water

- Conveyance
- Treating
- Heating, pressurizing, chilling



Direct Water and Direct Steam Services: 12.3 Quads



[Sanders and Webber 2012]

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The Energy-Water Relationship Is Already Under Strain

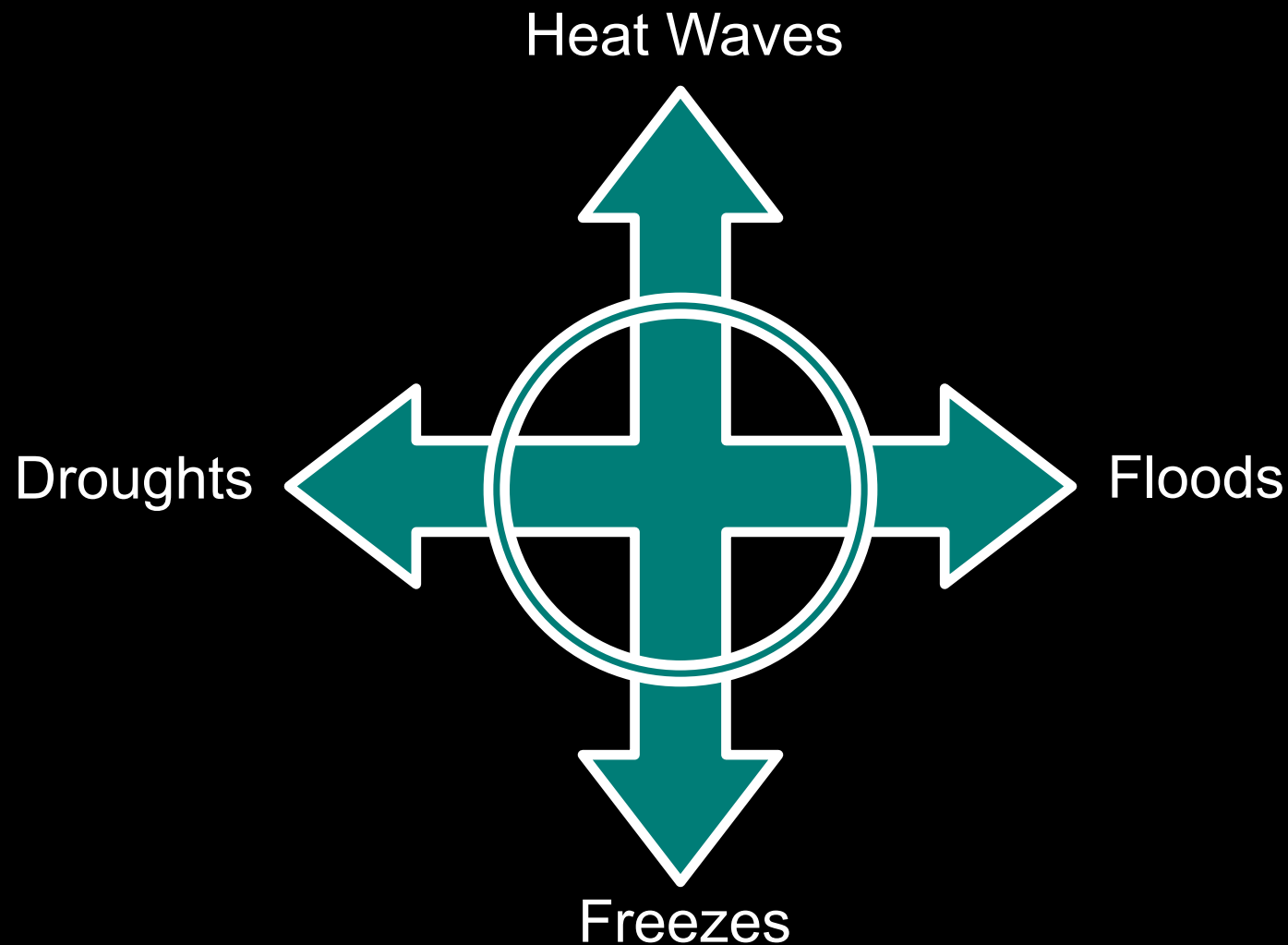


The Energy-Water Relationship Is Already Under Strain

- **Water Constraints Become Energy Constraints**
- **Energy Constraints Become Water Constraints**



Water Constraints Become Energy Constraints



Water Constraints Become Energy Constraints

- **Record heat wave in France in 2003**
 - nuclear power plants dialed back because of inlet water temperatures (less cooling capability) and rejection water temperature limits
- **Freeze in Texas in February 2011 shut down two coal plants causing statewide rolling blackouts**
- **Droughts:**
 - Nuclear power plants within days of shutting in SE 2008
 - TX power plants at risk of shutting in early 2012
 - Western Hydropower down in drought years
 - Competition for water for hydraulic fracturing
 - Some bans in Texas on water use for fracking
- **Floods:**
 - Nebraska nuclear power plant nearly shut down because of flooding of the Missouri River in June 2011



The 2012 Indian Blackout Affected 600 Million People and Was Triggered Partly by Drought

- 1) Increased power demand from irrigation
- 2) Decreased power generation at dams

The New York Times

2nd Day of Power Failures Cripples Wide Swath of India



Adnan Abidi/Reuters

Passengers waited Tuesday for train service to be restored in New Delhi. [More Photos »](#)

By JIM YARDLEY and GARDINER HARRIS
Published: July 31, 2012 | [429 Comments](#)

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Drought Hurts the Ability to Ship Energy By Inland Waterways

The New York Times

After Drought, Reducing Water Flow Could Hurt Mississippi River Transport



Jeff Roberson/Associated Press

Barges on the Mississippi River in St. Louis on Friday. A plan approved by Congress for maintaining irrigation systems is likely to affect shipping in the region.

By JOHN SCHWARTZ

Published: November 26, 2012

\$7 billion of coal, petroleum products, fertilizer, and agriculture products could not ship in Jan and Feb 2013 because of low water

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Energy Constraints Become Water Constraints

- Hurricane Ike knocked out power to the water system in Houston in 2008

“Our restoration priorities had been established beforehand. First, we secured downed power lines and restored service to key facilities vital to public safety, health and welfare such as hospitals, *wastewater treatment plants and water treatment facilities, including the Trinity River water pumping station: a major source of water for the greater Houston area.*”



Source: Centerpoint Energy, “Hurricane Ike Outage And Restoration Details”

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There Are Technical, Social and Policy Solutions



Research Agenda Should Enhance the Good and Mitigate the Bad of Energy Water Nexus

- **Reduce the energy-intensity of water**
- **Reduce the water-intensity of energy**
- **Make energy less vulnerable to water constraints**
- **Make water less vulnerable to energy constraints**
- **Solve cross-cutting problems (data, sensing, modeling, conservation...)**
- **Solve issues related to social, planning, policy, timescale, and spatial scales**



Possible Solutions to Pursue

- **Source Switching: Fuel & Water source switching**
- **Enhanced Technologies**
 - **Water/Energy lean technologies**
 - **Distributed energy/water technologies**
 - **Smart Technologies**
- **Cross-Sectoral Problem Solving**
 - **Using the water sector to solve energy problems**
 - **Using the energy sector to solve water problems**
- **Improve data and multi-user, -resource, -modeling**
- **Social, policy, market innovations**



Source Switching Can Save Energy and Water

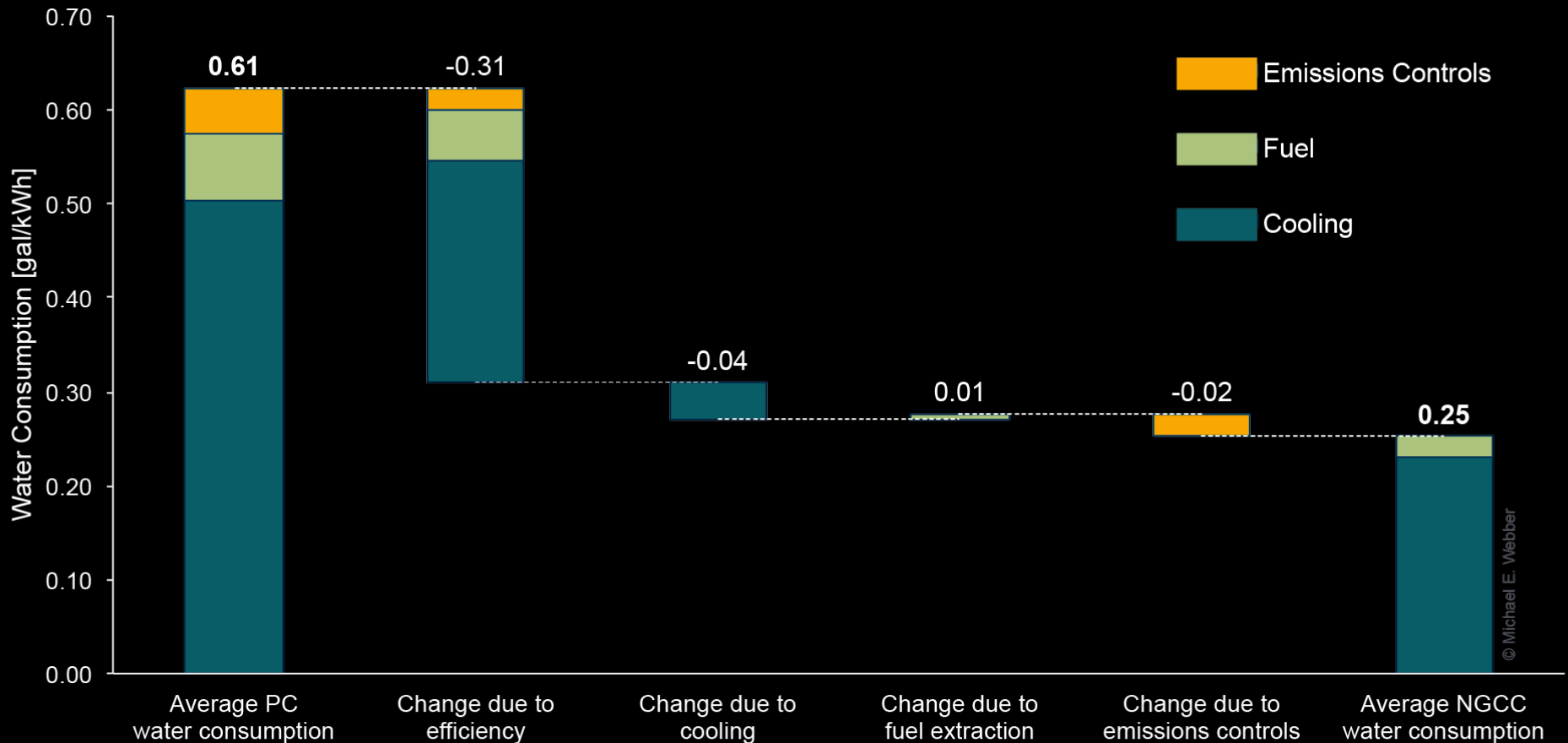
- **Fuel Switching:** Use fuels that require less water
 - Less water intensive: natural gas, solar PV, wind
 - More water intensive: nuclear, coal
- **Water Source Switching:** use water sources that compete less with freshwater
 - Brackish, saline or reclaimed water for power plant cooling and oil/gas extraction
 - Reclaimed or greywater reuse for irrigation or cooling



Despite Water Needs of Hydraulic Fracturing, Switching From Coal to NGCC Saves Water

Pulverized Coal to Natural Gas Combined Cycle Water Savings

Source: Grubert, Beach, Webber (2012) • Graphic: Michael E. Webber, The University of Texas at Austin



Texas Fleet Average

Enhanced Technologies Can Save Energy and Water

- **Water lean energy technologies:** dry cooling at power plants, waterless fracking, low-water biofuels
- **Energy lean water technologies:** better membranes (with less fouling), using waste heat for water treatment, VFD pumps
- **Distributed energy and water technologies:** rooftop solar PV, microharvesters for energy, rain harvesters, on-site water treatment for oil and gas producers
- **Smart Technologies:** better meters and sensors for tracking uses and losses



There Are Biological Approaches to Desalination



- **Mangroves grow in seawater, producing freshwater with pressure-driven ultrafiltration**
 - “How Mangroves Desalinate Seawater,” *Physiologia plantarum* (1968)



Photo Credit: Wikipedia Commons

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Water Systems Will Get Smarter

- **Today's meters are dumb**
- **Need to know:**
 - **Use by sector**
 - **Use by time of day**
 - **Delivered vs. Used (e.g. leaks)**
 - **Use by function**
 - **Indoor vs. outdoor**
 - **Heated vs. unheated**
 - **Greywater vs. blackwater**
 - **Piped vs. collected**



Cross-Sectoral Integration Holds Promise For Saving Energy and Water

- **Using the water sector to solve energy problems**
- **Using the energy sector to solve water problems**



Power plants can use reclaimed water for cooling

- Many thermoelectric power plants use non-fresh water for cooling
- In 2010, 46 U.S. power plants used reclaimed water for cooling
- Reclaimed water has advantages
 - Drought-resistant
 - Can be abundant
 - Can be safe
- Reclaimed water can pose operational challenges



Courtesy: Ashlynn Stillwell

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Power Plants Can Use Reclaimed Water for Cooling



Sand Hill Energy Center, Austin, TX
Credit: Austin Energy

Palo Verde Nuclear Plant, Arizona
Credit: Wiki Commons

The Water Sector Can Be Used To Solve Energy Problems

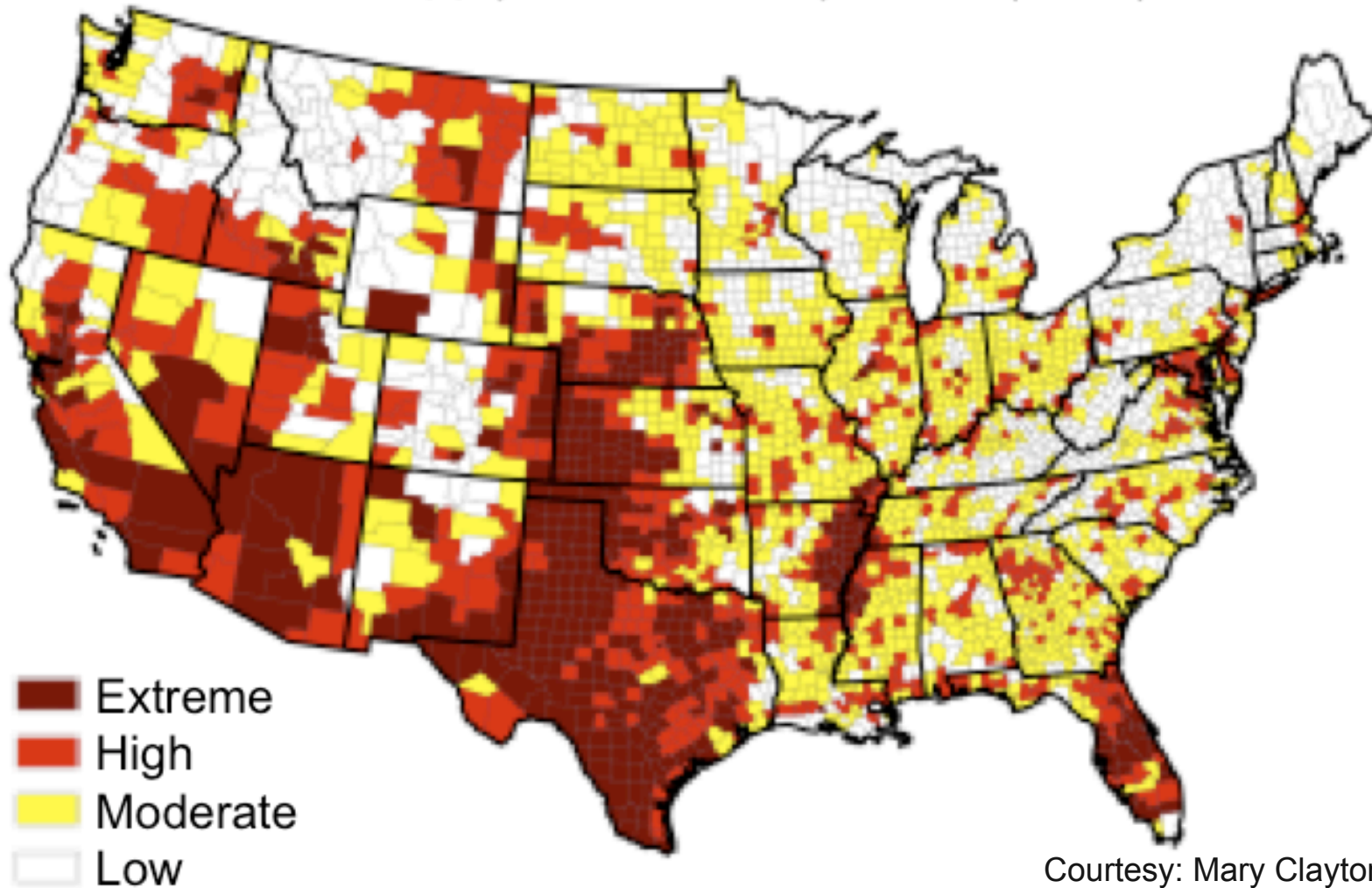
- ***Energy Recovery from WWTPs***
 - Use wastewater treatment to generate biogas
- ***Integrating Renewables with Water Treatment & Desal***
 - Abundant saline/brackish water
 - Abundant wind and solar radiation
 - 1000 hours of negative pricing in Texas because of abundant wind
 - Provide solutions to challenges of each technology
 - Water addresses intermittent, off-peak nature of wind
 - Wind addresses high marginal energy of desal/treatment



Water Problems and Wind/Solar Resources Are Often Co-Located

[NRDC]

Water Supply Sustainability Index (2050)



Courtesy: Mary Clayton

Integrating Power Plants and Desalination Saves Energy

- ***Powerplants can preheat water feedstream***
 - Increases throughput for membrane systems
 - Reduces energy for distillation systems
 - Example: Abu Dhabi's desal plant
- ***Saline/brackish water for cooling solar PV systems***
 - Improves PV performance
 - Preheats water for higher throughput
 - Example: El Paso, TX test systems



The Energy Sector Can Be Used To Solve Water Problems

- ***Dry- and/or hybrid cooling At Large-Scale Implementation***
 - Spares water for many other users
 - An economical approach for drought resiliency
- ***Integrating Energy, Air Quality & Water For Dispatching***
- ***Incorporating Water Into Grid Planning***
- ***Energy Industry's Needs as a Driver for Water Efficiency***
 - Towards efficient water markets



The Oil & Gas Industry Could Become the Oil, Gas and Water Industry

- *Daily liquids production:*
 - Oil extraction: 7 MMBD
 - Wastewater injection: 47 MMBD
 - 2 billion gallons per day (~2% of daily consumption)
- *Capturing Flared Gases for On-Site Water Treatment*
 - Up to 1/3 of gas production is flared (N. Dakota)
 - 3 wastewater streams: muds, flowback, produced
 - Flow rates decrease, TDS levels increase with time
 - Using flared gases for treatment via thermal distillation: reduces trucks, increases water supply, reduces flares, ...



There Are Also Non-Technical Challenges



There Are Also Non-Technical Challenges

- **Disaggregated policymaking**
- **Mismatched timescales**
- **Mismatched spatial scales**
- **Data problems**



Example of Disaggregated Energy and Water Policymaking In the USA

- **Funding and oversight mechanisms are separate**
 - **Energy planners assume they have the water they need**
 - **Water planners assume they have the energy they need**
- **Multitude of agencies, committees, etc. w/o clear authority**
- **Hierarchy of policymaking is dissimilar**
 - Energy*: top-down**
 - **powerful federal energy agencies**
 - Water*: bottom-up**
 - **powerful local water agencies**



Timescales Do Not Match for Energy and Water Policymaking

- **Water**
 - Water plans are 50-100 years
 - Austin, TX debated a water plant for 40 years
 - Water data are backwards-looking
- **Energy**
 - Energy plans are 2-30 years
 - Energy data are backwards- and forward-looking



Spatial Scales Do Not Match for Energy and Water Policymaking

- **Water**
 - **Natural: spans many cities and/or states**
 - **Built:**
 - **Usually at the municipal scale**
 - **Some locations (CA, AZ,...) at the state scale**
- **Energy**
 - **Electricity: continental via grid**
 - **Oil/gas: continental via pipeline systems**
 - **Coal: continental by train**
 - **Biofuels: regional by truck**



Water Data Are Sparse, Error-prone, and Inconsistent in the USA

- **USGS data-collection is infrequent**
 - Last survey on water consumption: 1995
 - Last survey on water withdrawals: 2000 (2005)
- **Errors in national databases (Egrid, etc.)**
 - Differences between state and federal reporting
 - Unclear definitions:
 - Use vs. Withdrawal vs. Consumption vs. Diversion
 - Different units
 - **East:** gallons
 - **West:** acre-feet



Solving the Data Problem: Invest Aggressively In Comprehensive Data Collection

- **Government**
 - Water quantities in natural systems (NASA? USGS?)
 - Water quantities in energy systems (EIA?)
 - Energy quantities in water systems (EIA?)
 - Before and after water quality studies (EPA?)
- **Industry**
 - Need more data from industry for upstream AND downstream water uses AND powerplants
- **Academia/Innovators**
 - Better sensors, flow meters, remote sensing,...
 - Robust multi-resource modeling platforms



There Are Policy Solutions and Challenges



In 1961, President John F. Kennedy gave the USA two great technical challenges



May 1961

“No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish.”

April 1961

“If we could ever competitively—at a cheap rate—get fresh water from salt water, that would be in the long-range interest of humanity and would really dwarf any other scientific accomplishment.”



By 1969, we put a man on the moon



Source: Web

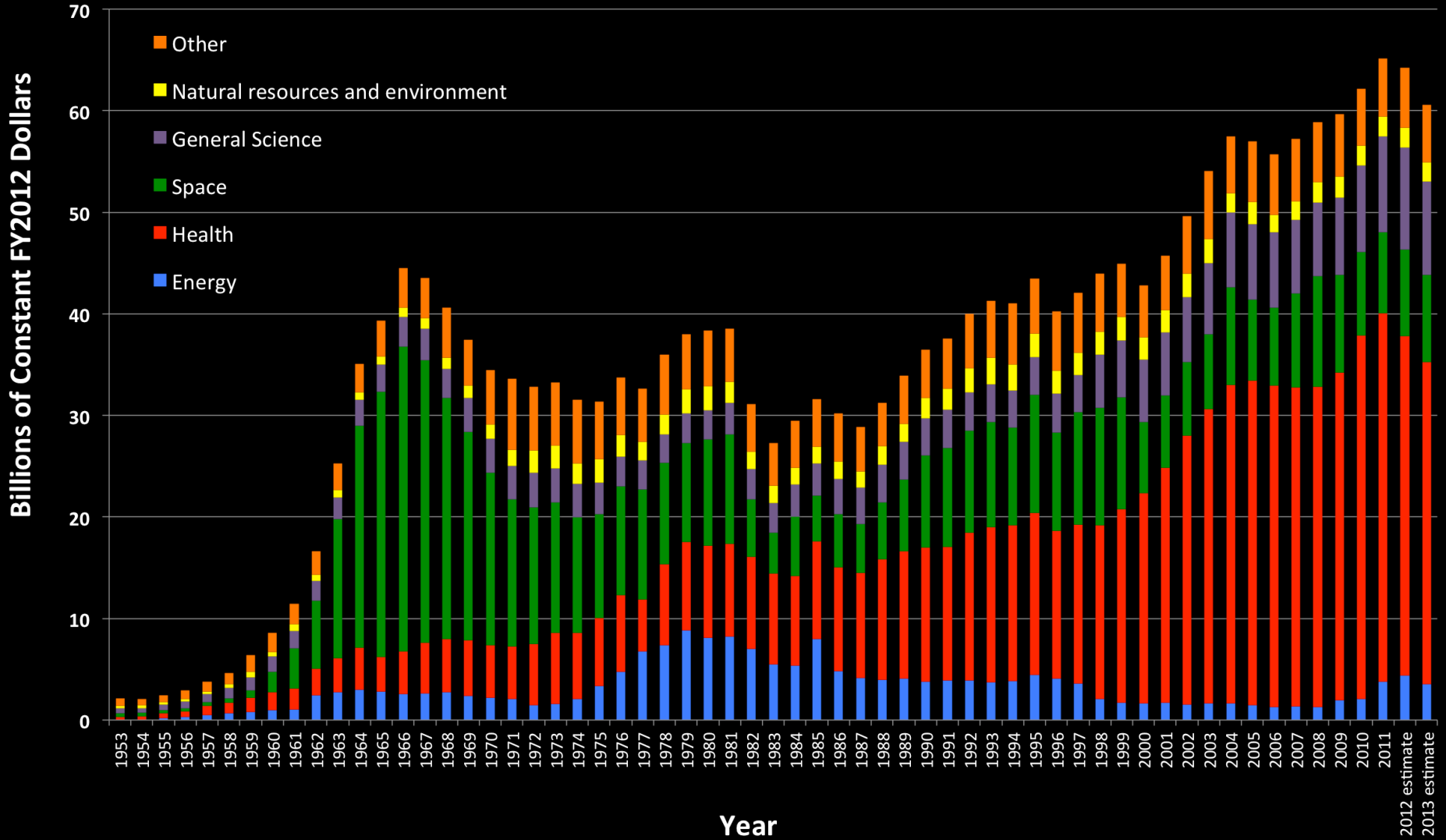
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***If We Spent As Much Effort and Money
Looking for Water on Earth As We Do
Looking for Water on the Moon and Mars,
the Outcomes Might Be Very Different!***



Energy R&D Is Drastically Underinvested

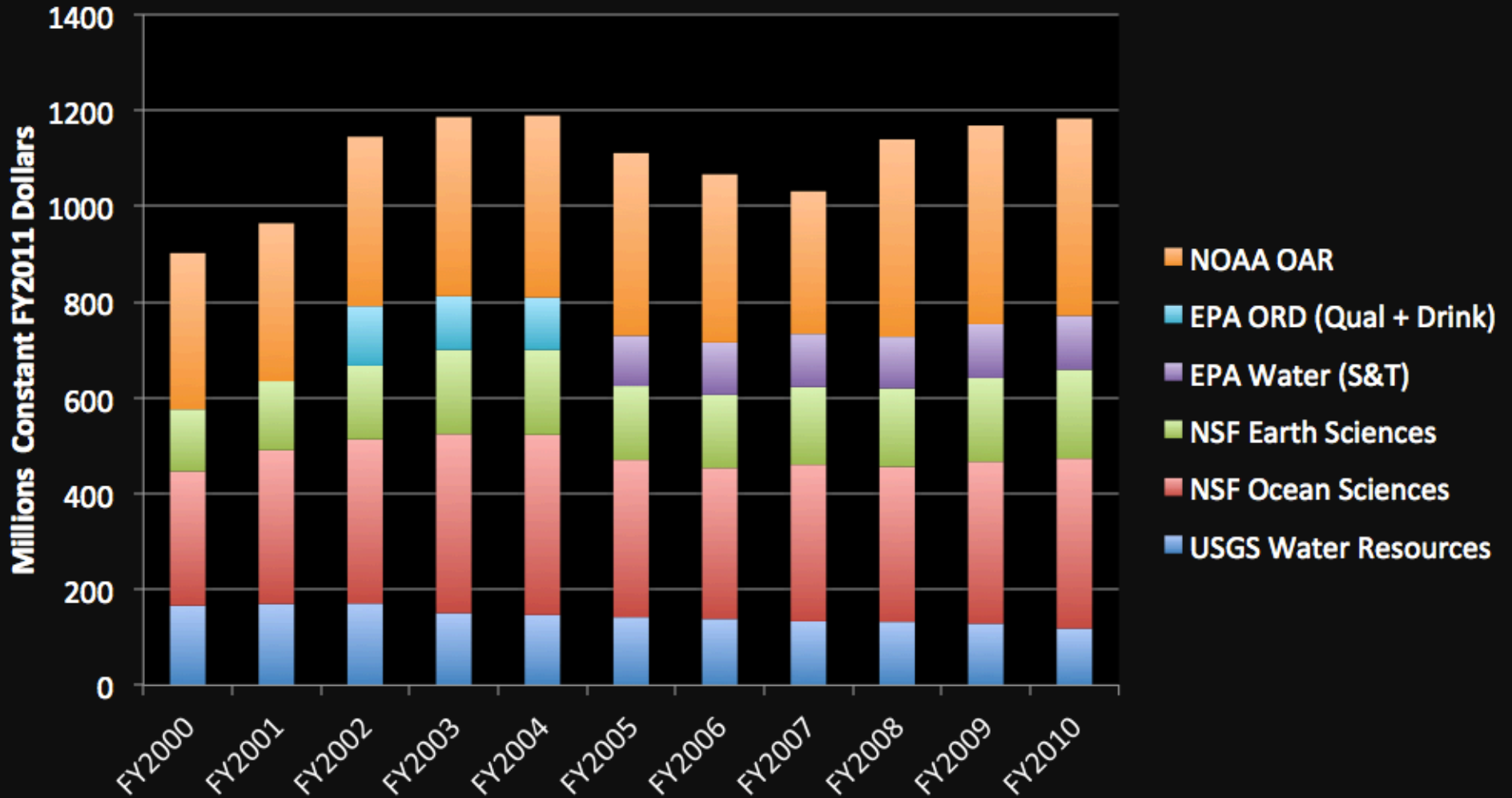
Federal Nondefense R&D



Source: AAAS

Water R&D Is Even Lower

Available Data for Water R&D By Agency



Source: Kirshenbaum & Webber, 2012

***There Is Justifiable Cause for A Healthy
Dose of Realistic Pessimism That This
Could Take A While***





***It's Not A Good Sign
When We Have To
Warn Ourselves Not
To Drink Toilet
Water***

Source: Stillwell

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Good news: energy conservation and water conservation are synonymous

“Turn off the water, Daddy. The scientists need time.”
– Evelyn Webber, 7 years old, March 2007

- **Conserving water will conserve energy**
- **Conserving energy will conserve water**



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