Energy and Water: Essential, Interdependent Commodities and Strategies

PANEL

25 July 13, 0900 - 1200

Energy Development & Power Generation Committee

Chair: Bill Leighty, The Leighty Foundation

Host: Energy Development & Power Generation Committee of IEEE

IEEE Power and Energy Society General Meeting

Vancouver, BC Canada

Panelists

1. Mike Hightower
Sandia National Laboratories, Energy Systems Analysis Department, Albuquerque, NM

2. Jordan Macknick
Energy and Environmental Analyst, NREL

3. Ms Kelly T. Sanders
University of Texas at Austin

4. Ms Lorraine White
In absentia
Water-Energy Program Manager, GEI Consultants, Inc., Rancho Cordova, CA

5. Ron Faibish
In absentia
- Principal Chemical and Nuclear Engineer, Argonne National Laboratory
- Science Fellow, U.S. Senate Committee on Energy and Natural Resources

6. Bill Leighty
The Leighty Foundation, Juneau, Alaska

Energy and Water: Essential, Interdependent Commodities and Strategies

- IEEE PES: Power and Energy – all sources, uses
- Water for Energy: elec, oil + gas, refining, renewables
- Energy for Water: pumping, desalinization
- Accelerate our response to:
  - Rapid climate change
  - Ocean acidification
  - Sea level rise
  - Other environmental degradation
  - Alternatives to electricity for transmission, storage, integration of stranded renewable energy (RE)

Energy and Water: Essential, Interdependent Commodities and Strategies

- Commodity: abundant, market price, fungible
- Strategy: use, conserve, control, synergy, good, profit
- Essential: survival
- Interdependent

"Linkage Between Energy and Water"   Panel

1500 – 1700 MAR Shaunessy II   (this room)

Recent Energy – Water Events

June 2013 National Science Foundation (NSF), Wash DC

June 2013 Energy-Water Research Work Group

- **Alliance for Water Efficiency**
- **American Council for an Energy Efficient Economy (ACEEE)**
- http://www.allianceforwaterefficiency.org/
  Water-Energy-Research-Group.aspx

Panelists

1. Mike Hightower
Sandia National Laboratories, Energy Systems Analysis Department, Albuquerque, NM

2. Jordan Macknick
Energy and Environmental Analyst, NREL

3. Ms Kelly T. Sanders
University of Texas at Austin

4. Ms Lorraine White
In absentia
Water-Energy Program Manager, GEI Consultants, Inc., Rancho Cordova, CA

5. Ron Faibish
In absentia
- Principal Chemical and Nuclear Engineer, Argonne National Laboratory
- Science Fellow, U.S. Senate Committee on Energy and Natural Resources

6. Bill Leighty
The Leighty Foundation, Juneau, Alaska

Panelist 1

Mike Hightower
Sandia National Laboratories

Energy Systems Analysis Department

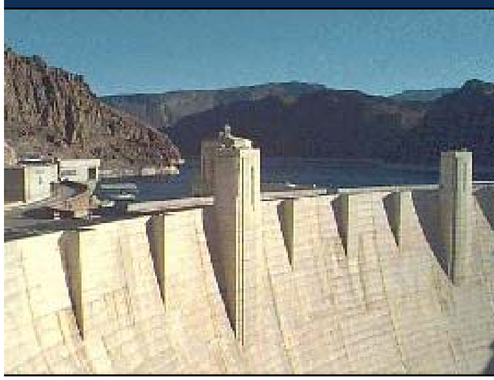
1515 Eubank SE, MS1108, Albuquerque, NM 87123

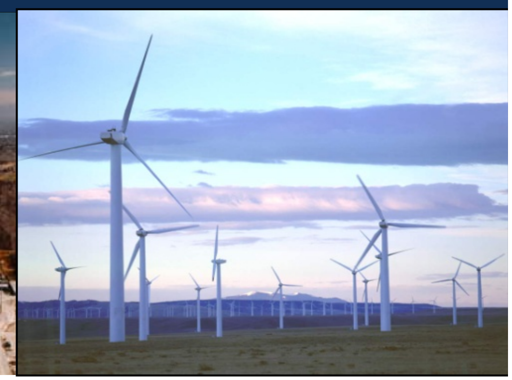
Telephone (505) 844-5499

mmhight@sandia.gov

Exceptional service in the national interest

Sandia National Laboratories



Water Trends and Impacts on Energy and Electric Power

Mike Hightower, Distinguished Member of the Technical Staff

Sandia National Laboratories – Albuquerque, NM

IEEE –PES Conference

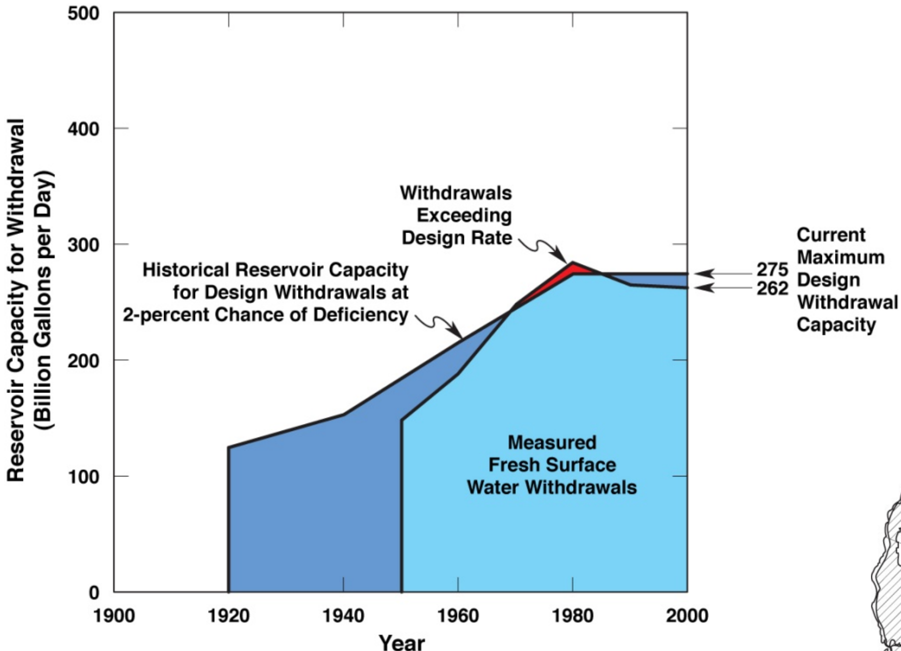
Vancouver, Canada

July 25, 2013

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

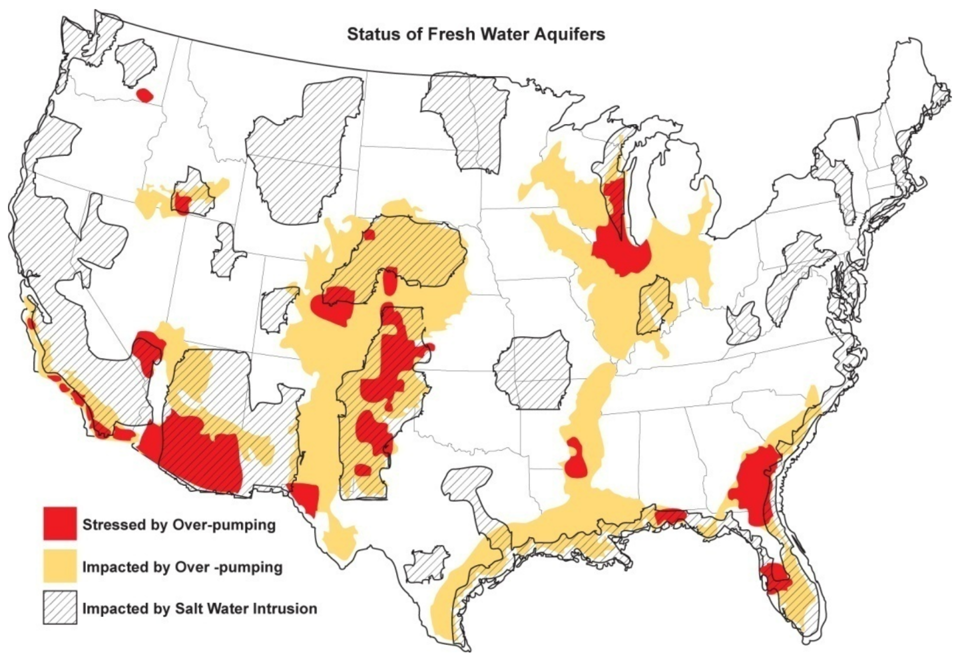
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Growing Limitations on Fresh Surface and Ground Water Availability



(Based on USGS WSP-2250 1984 and Alley 2007)

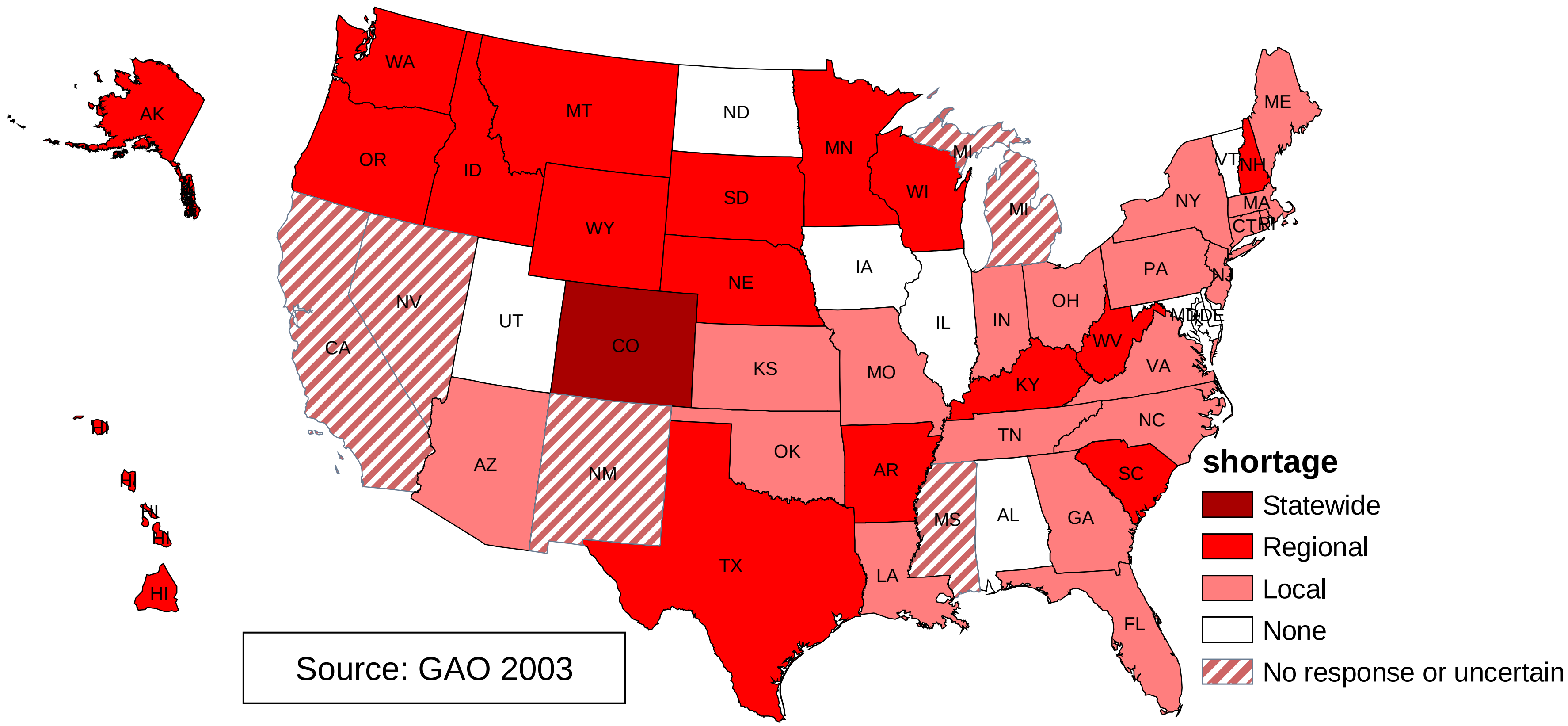
- Little increase in surface water storage capacity since 1980
- Concerns over climate impacts on surface water supplies



(Shannon 2007)

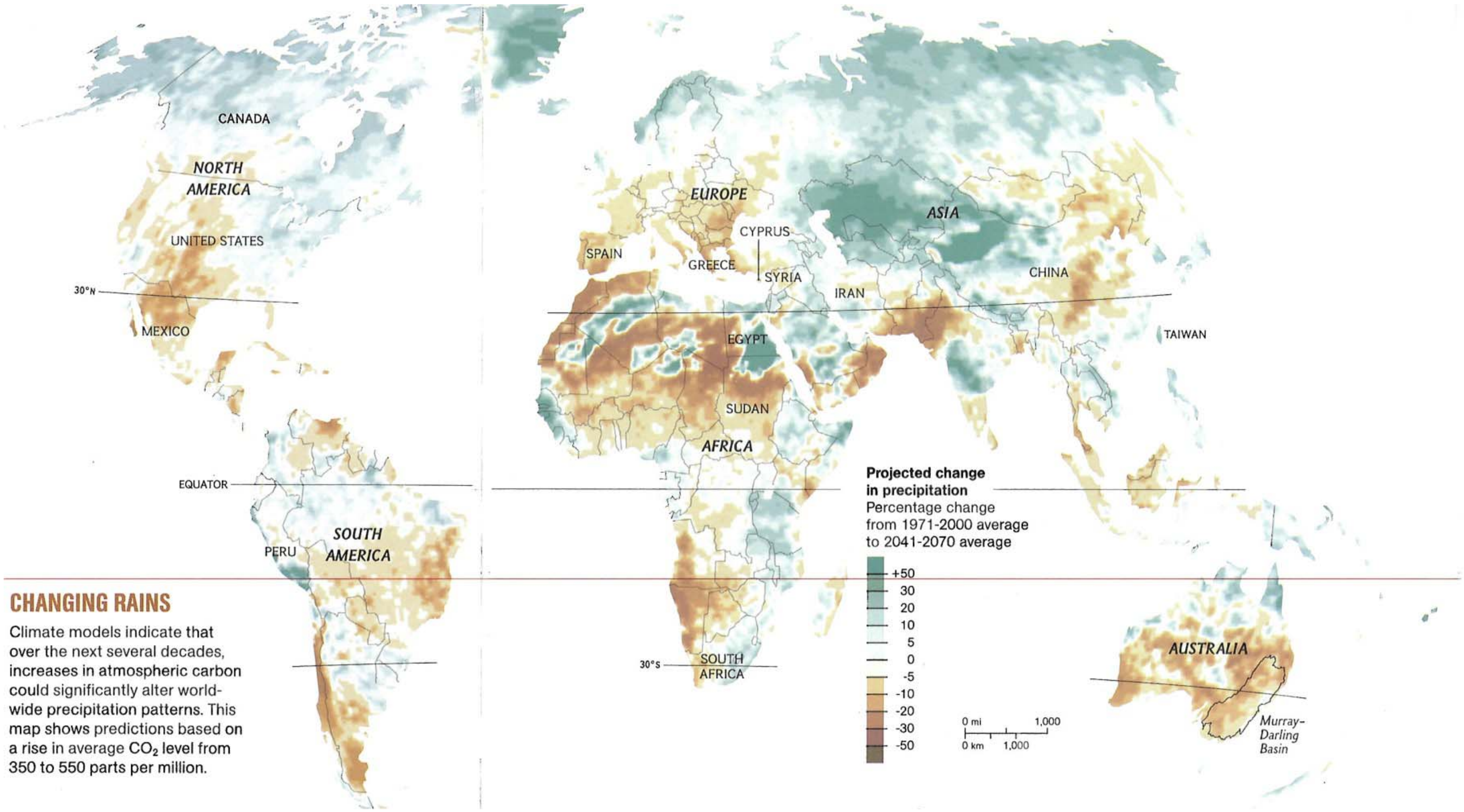
- Many major ground water aquifers seeing reductions in water quality and yield

Most State Water Managers Expect Some Shortages by 2013 Under Average Conditions



Source: GAO 2003

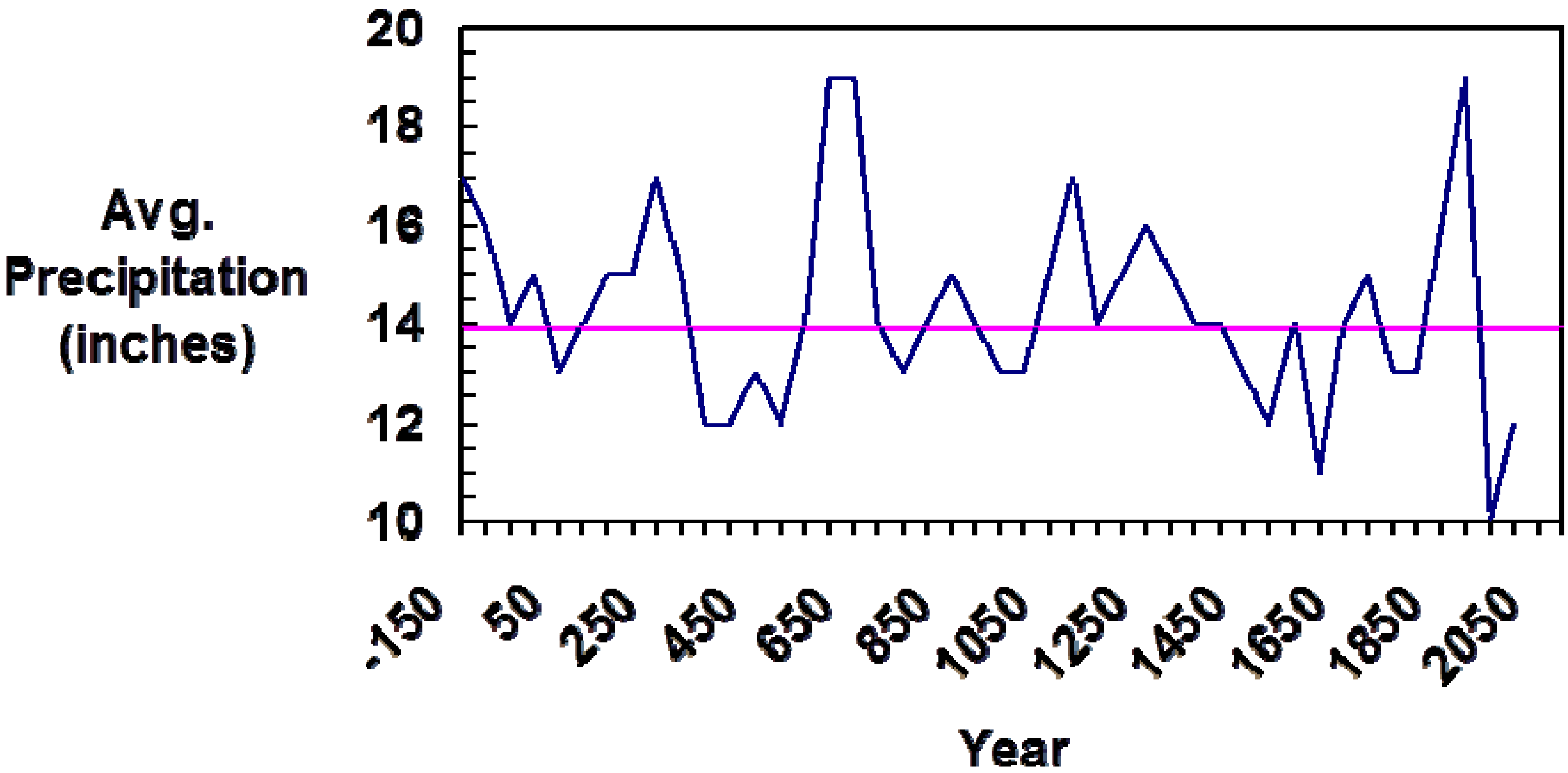
Climate Change will Impact Precipitation, Evapotranspiration, and Runoff



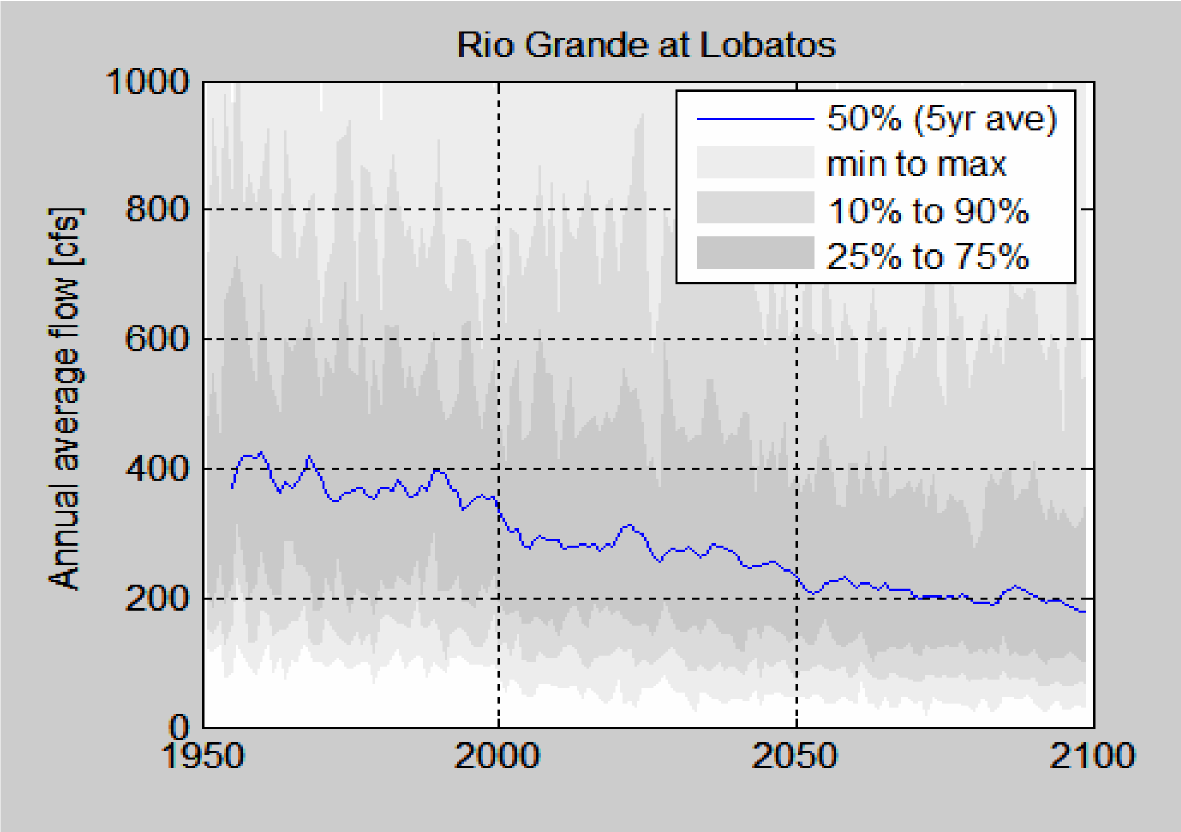
Nat. Geo. April 2009 from IPCC

Mid-latitude population belt will be strongly affected

Southwest U.S.Precipitation Patterns Based on Tree Ring Data



Projected Rio Grande Flows through 2100



"Results are not predictions, but rather a starting point for dialogue and increased awareness of potential impacts of climate change."

Roach et al.

Water Use and Consumption for Electric Power Generation Technologies

Plant-type	Cooling Process	Water Use Intensity (l/MWh$_e$)		
		Steam Condensing		Other Uses
		Withdrawal	Consumption	Consumption
Fossil/ biomass steam turbine	Open-loop	80,000–200,000	~800-1200	~120
	Closed-loop	1200–2400	1200–2000	
Nuclear steam turbine	Open-loop	100,000–240,000	~1600	~120
	Closed-loop	2000–4400	1600–2900	
Natural Gas Combined-Cycle	Open-loop	30,000–80,000	400	40
	Closed-loop	900	700	
Integrated Gasification Combined-Cycle	Closed-loop	800	700	600
Carbon sequestration for fossil energy generation	~85% increase in water withdrawal and consumption			
Geothermal Steam	Closed-loop	8000	1000-5000	200
Concentrating Solar	Closed-loop	3000	2900	40
Wind and Solar Photovoltaic	N/A	0	0	10

Water Consumption of Transportation Fuels

Fuel Type and Process	Relationship to Water Quantity	Relationship to Water Quality	Water Consumption	
			Water consumed per-unit-energy [gal / MMBTU] †	Average gal water consumed per gal fuel
Conventional Oil & Gas - Oil Refining	Water needed to extract and refine; Water produced from extraction	Produced water generated from extraction; Wastewater generated from processing;	7 – 20	~ 1.5
- NG extraction/Processing			2 – 3	~ 1.5
Biofuels - Grain Ethanol Processing	Water needed for growing feedstock and for fuel processing;	Wastewater generated from processing; Agricultural irrigation runoff and infiltration contaminated with fertilizer, herbicide, and pesticide compounds	12 - 160	~ 4
- Corn Irrigation for EtOH			2500 - 31600	~ 980*
- Biodiesel Processing			4 – 5	~ 1
- Soy Irrigation for Biodiesel			13800 – 60000	~ 6500*
- Lignocellulosic Ethanol and other synthesized Biomass to Liquid (BTL) fuels	Water for processing; Energy crop impacts on hydrologic flows	Wastewater generated; Water quality benefits of perennial energy crops	24 – 150 ‡§ (ethanol) 14 – 90 ‡§ (diesel)	~ 2 - 6 ‡§ ~ 2 - 6 ‡§
Oil Shale - In situ retort	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff	1 – 9 ‡	~ 2 ‡
- Ex situ retort			15 - 40 ‡	~ 3 ‡
Oil Sands	Water needed to Extract / Refine	Wastewater generated; Leachate runoff	20 - 50	~ 4 - 6
Synthetic Fuels - Coal to Liquid (CTL)	Water needed for synthesis and/or steam reforming of natural gas (NG)	Wastewater generated from coal mining and CTL processing	35 - 70	~ 4.5- 9.0
- Hydrogen RE Electrolysis			20 – 24 ‡	~ 3 ‡
- Hydrogen (NG Reforming)			40 – 50 ‡	~ 7 ‡

† Ranges of water use per unit energy largely based on data taken from the Energy-Water Report to Congress (DOE, 2007)
* Conservative estimates of water use intensity for irrigated feedstock production based on per-acre crop water demand and fuel yield
‡ Estimates based on unvalidated projections for commercial processing; § Assuming rain-fed biomass feedstock production

Research Directions for Electric Power Sector

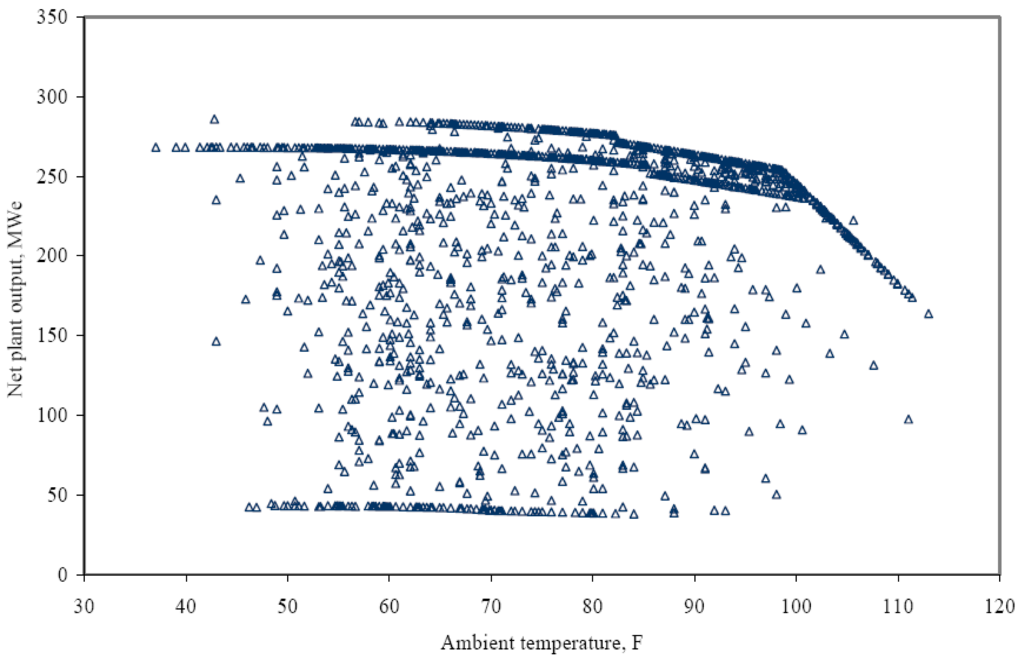


Figure 5 Net Plant Output as a Function of Ambient Temperature; Dry Heat Rejection

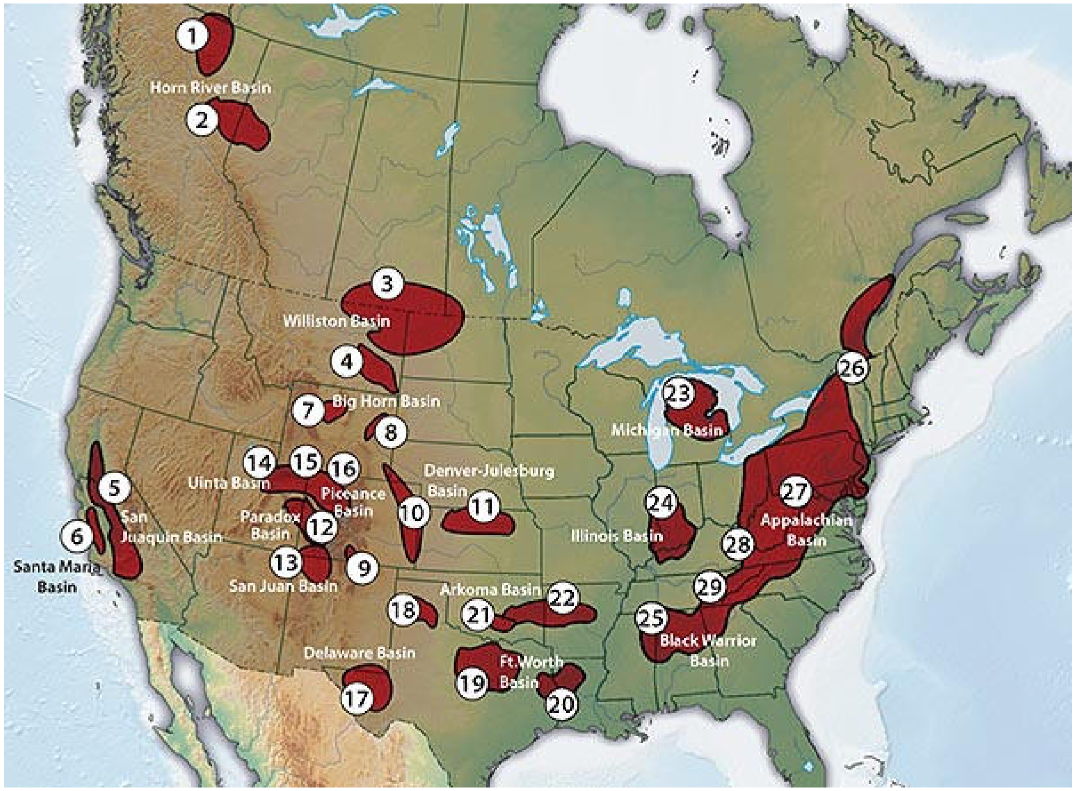
Dry Cooling Performance

- Improved dry and hybrid cooling system performance and cost
- Reduced ecological damage from intake structures for hydro, once-through, and ocean cooling
- Improved materials and cooling approaches compatible with use of degraded water
- Electric grid infrastructure upgrades to improve low water use distributed technology integration

Shale gas is extensive in North America, but development limited by water issues

- Water is used in drilling, completion, and fracturing
- 2-5 million gallons of water is needed per well
- Water recovery can be 20% to 70%
- Recovered water quality varies – from 10,000 ppm TDS to 100,000 ppm TDS
- Recovered water disposal or treatment can be problematic in some areas
- Well pads can be up to 5 km apart

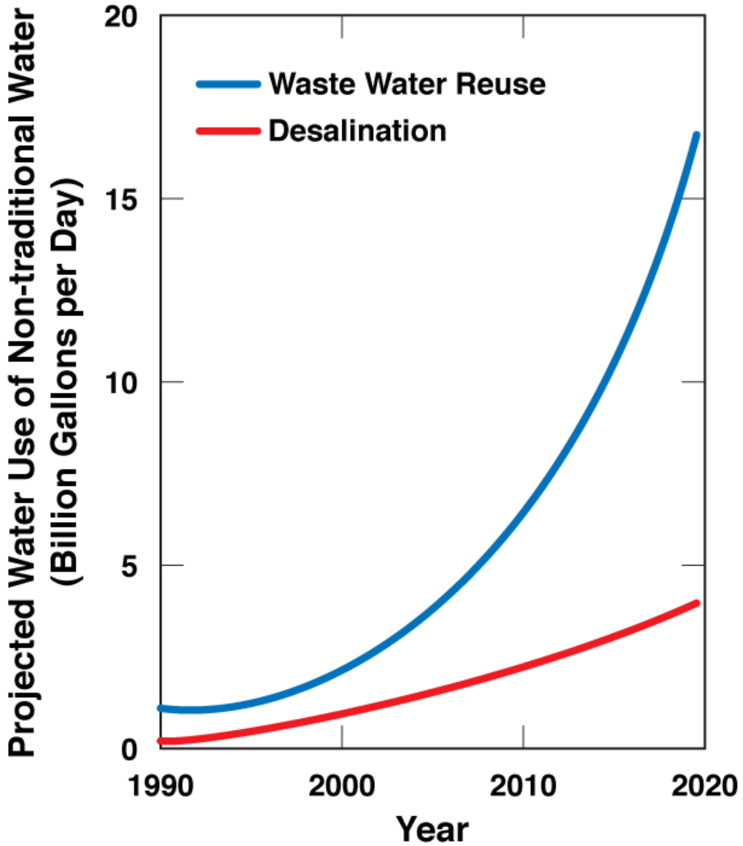
Extensive North American Reserves



Can now use 200,000 ppm TDS water for fracing

Nontraditional Water/Energy Trends

- **Relook at coastal power plants and sea water cooling**
  - Costs, reliability, of 17,000 MW retrofit of California coastal power plants to hybrid fresh water cooling whereas Texas considering large sea water cooled coastal power plants
- **Relook at EPA 316b to allow thermal ecological mitigation?**
- **Growing use of waste water for cooling (over 50 plants nationally)**
- **Fracing now loves all water – waste, evap pond, ZLD, brackish, etc.**
- **Large energy production from waste water – algae biofuels**
- **Wind energy and water treatment**



Panelist 2

Jordan Macknick

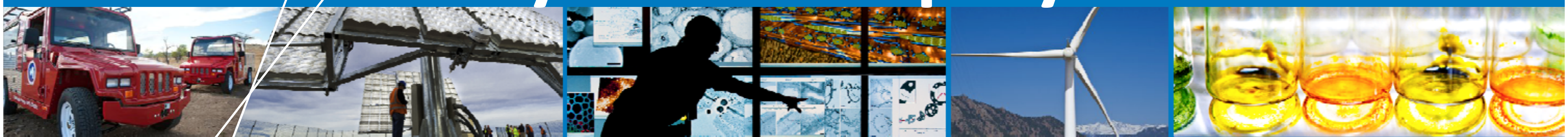
National Renewable Energy Laboratory (NREL)

Energy and Environmental Analyst

303-275-3828

jordan.macknick@nrel.gov

Water as a constraint for future electricity sector deployment



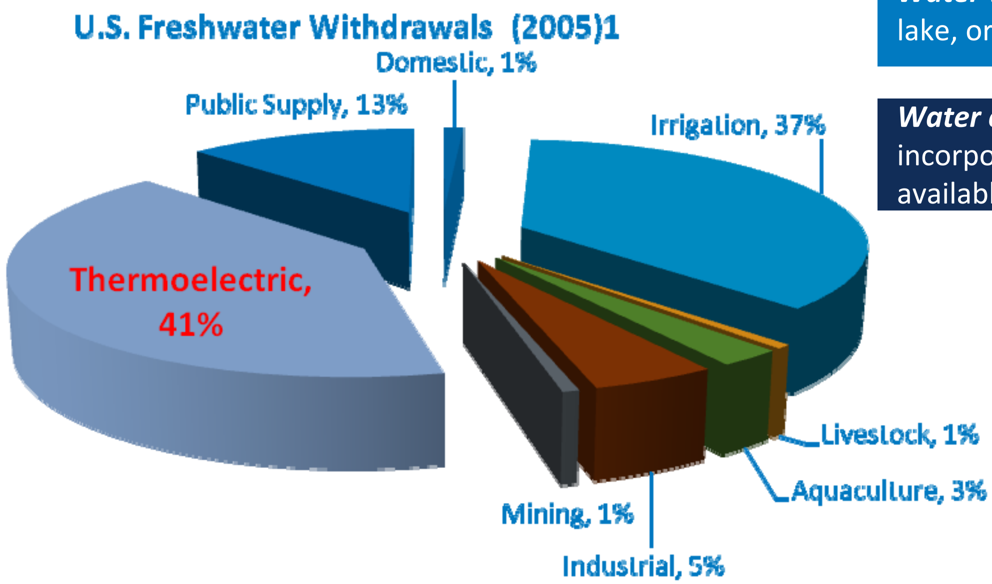
Jordan Macknick

IEEE Power and Energy Society General Meeting

Vancouver, BC, Canada

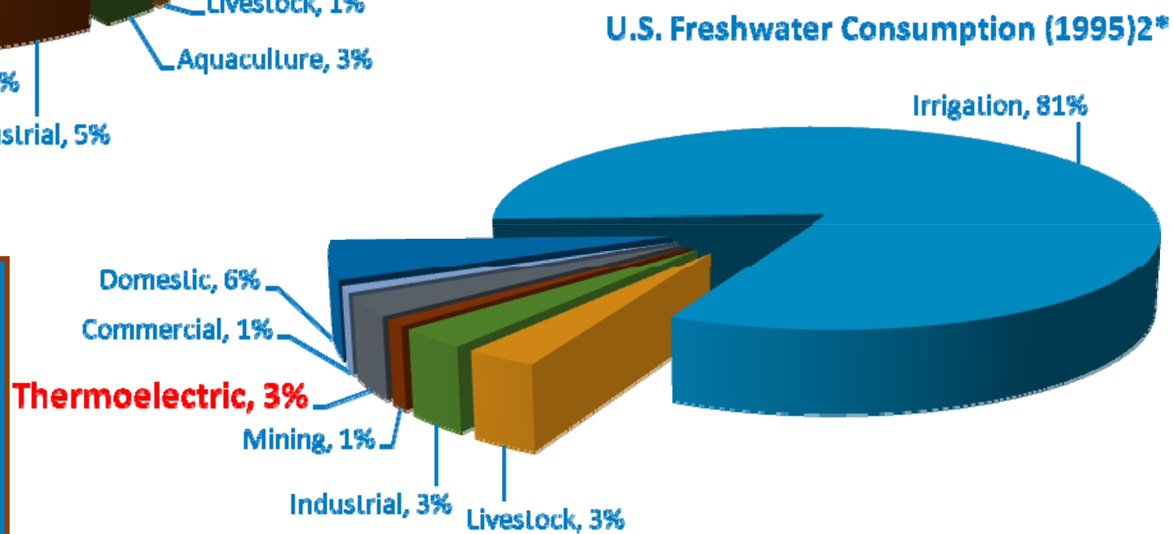
July 25, 2013

In the United States, the electricity sector is a major end-user of water



Water withdrawals: water removed from the source (e.g. aquifer, river, lake, or ocean) for use

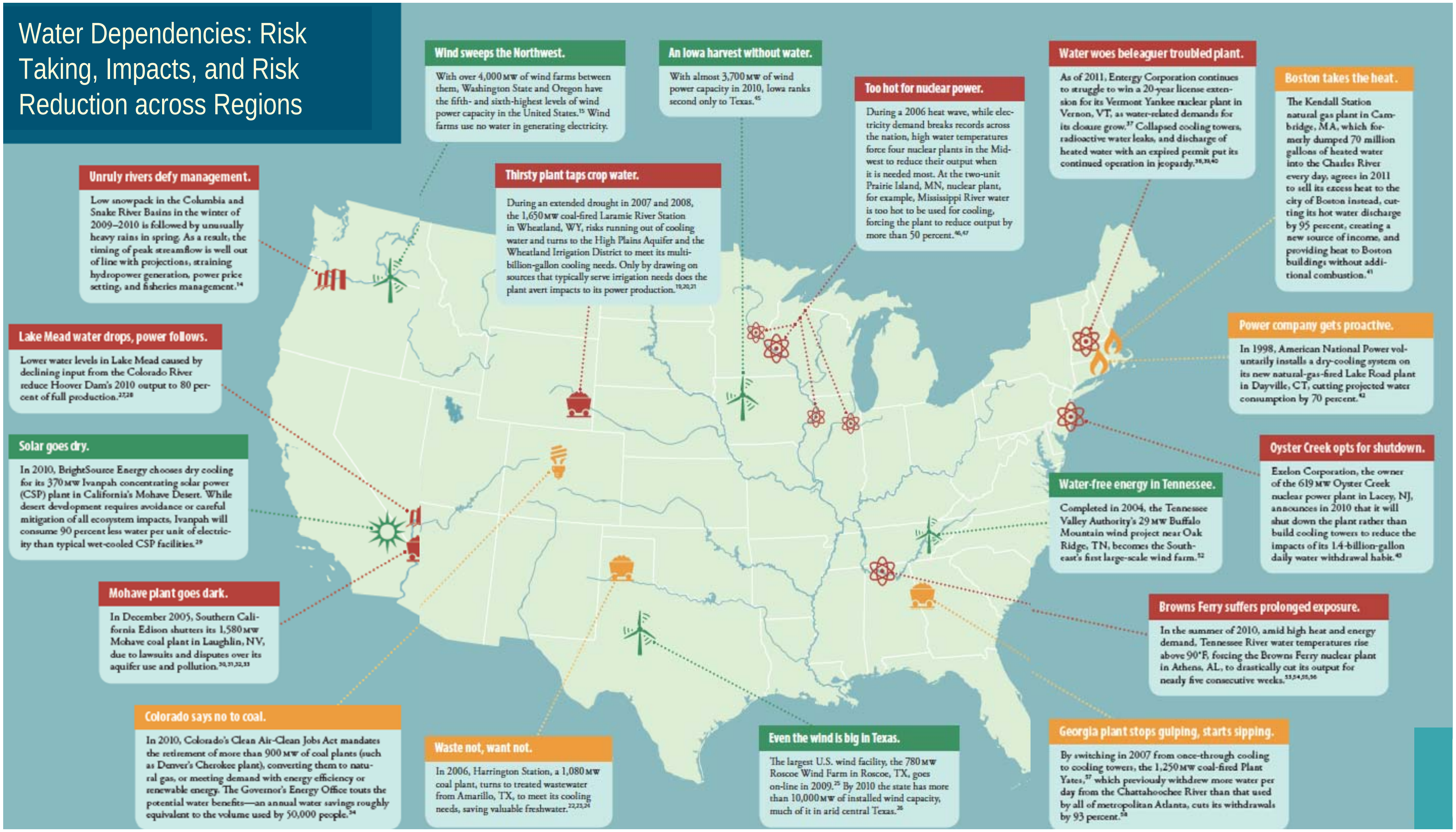
Water consumption: water that is evaporated (or swallowed, incorporated into a product, or otherwise used) such that it is not available for reuse at the same location



- **Thermoelectric water requirements (USGS):**
  - **Withdrawal: ~ 540 Mm^3 /day (41%)**
  - **Consumption: ~ 15 Mm^3 /day (3%)**

Sources: [1]USGS, Estimated Use of Water in the United States in 2005, USGS Circular 1344, 2009
[2]USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998
*1995 is the most recent consumption data collected by the USGS

Multiple examples of current or emerging impacts at the energy-water nexus

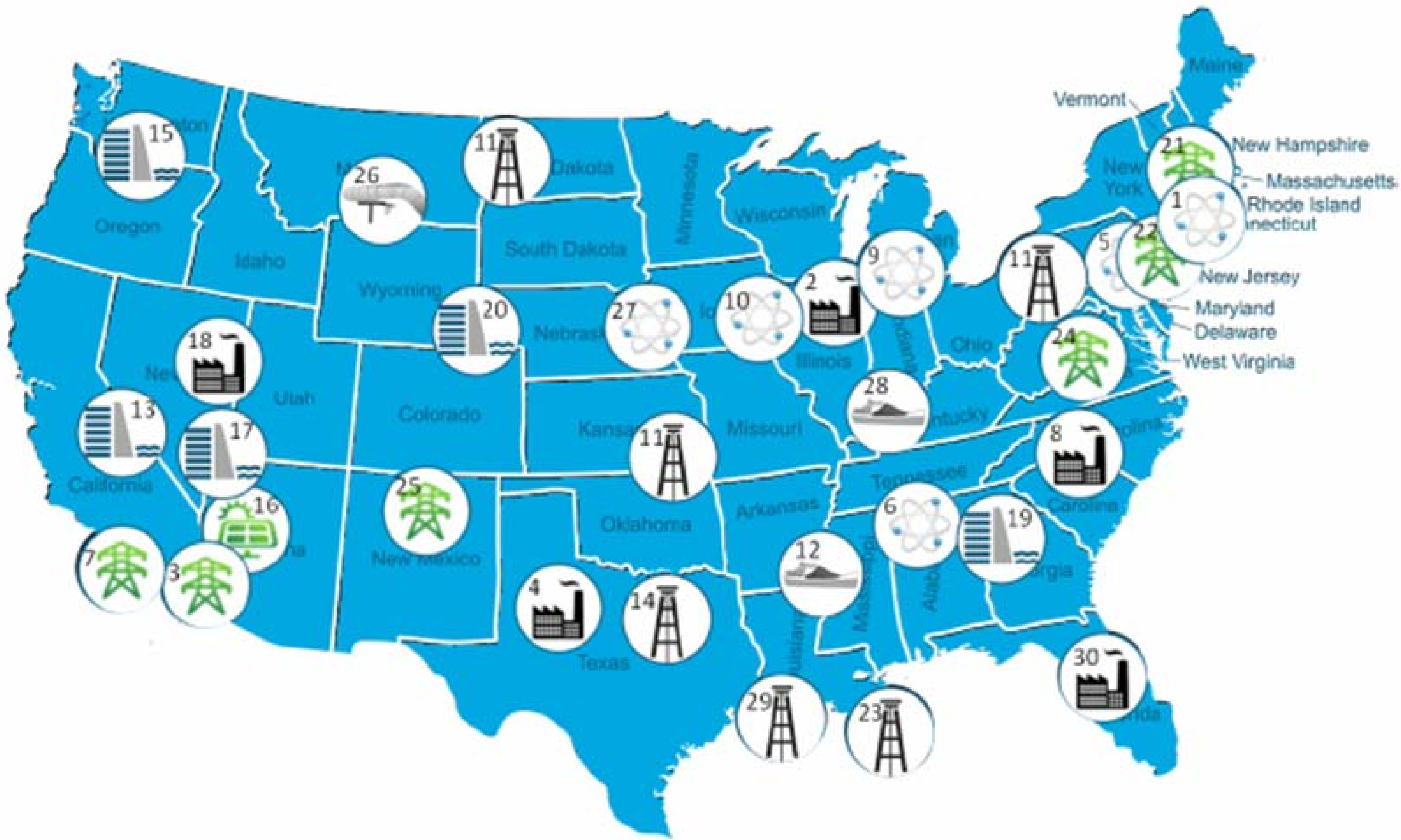


Risk Taking and Impacts · Risk Reduction · Water-Smart Energy

Source: **Power and Water At Risk:** The Energy-Water Collision, UCS, 2012

See also Averyt et al., 2011, Freshwater Use by U.S. Power Plants, Electricity's Thirst for a Precious Resource

Multiple examples of current impacts at the energy-water nexus

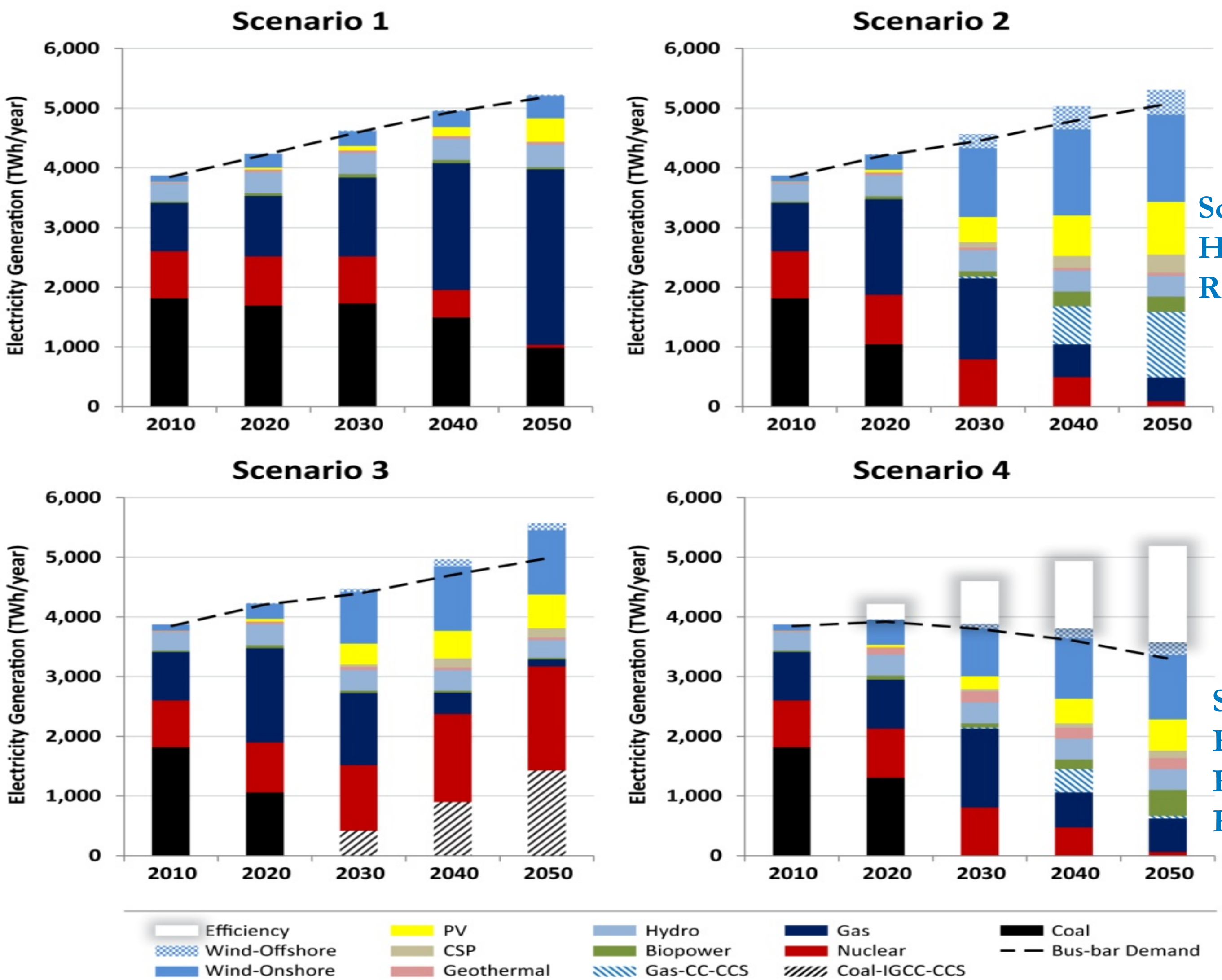


Source: Department of Energy. U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather. DOE/PI-0013. July 2013.

How do our electricity sector choices affect potential energy-water impacts?

Scenario 1:
High Natural Gas
No carbon cap

Scenario 2:
High Renewable



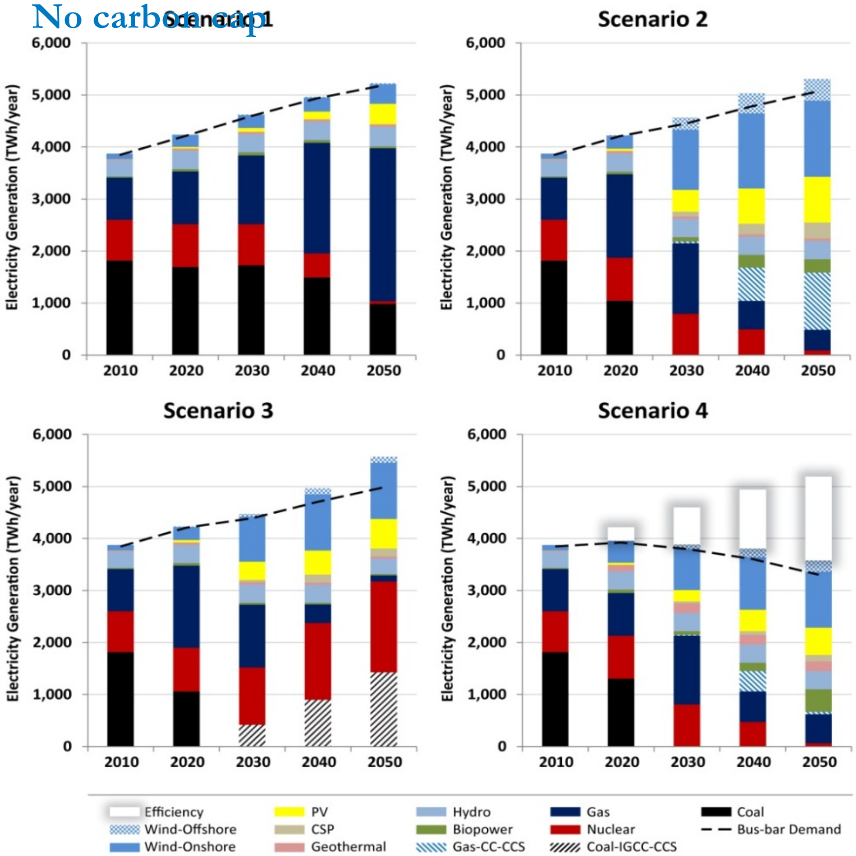
Scenario 3:
High Nuclear and Coal with CCS

Scenario 4:
Energy Efficiency and Renewable

Different clean energy scenarios have different water use profiles

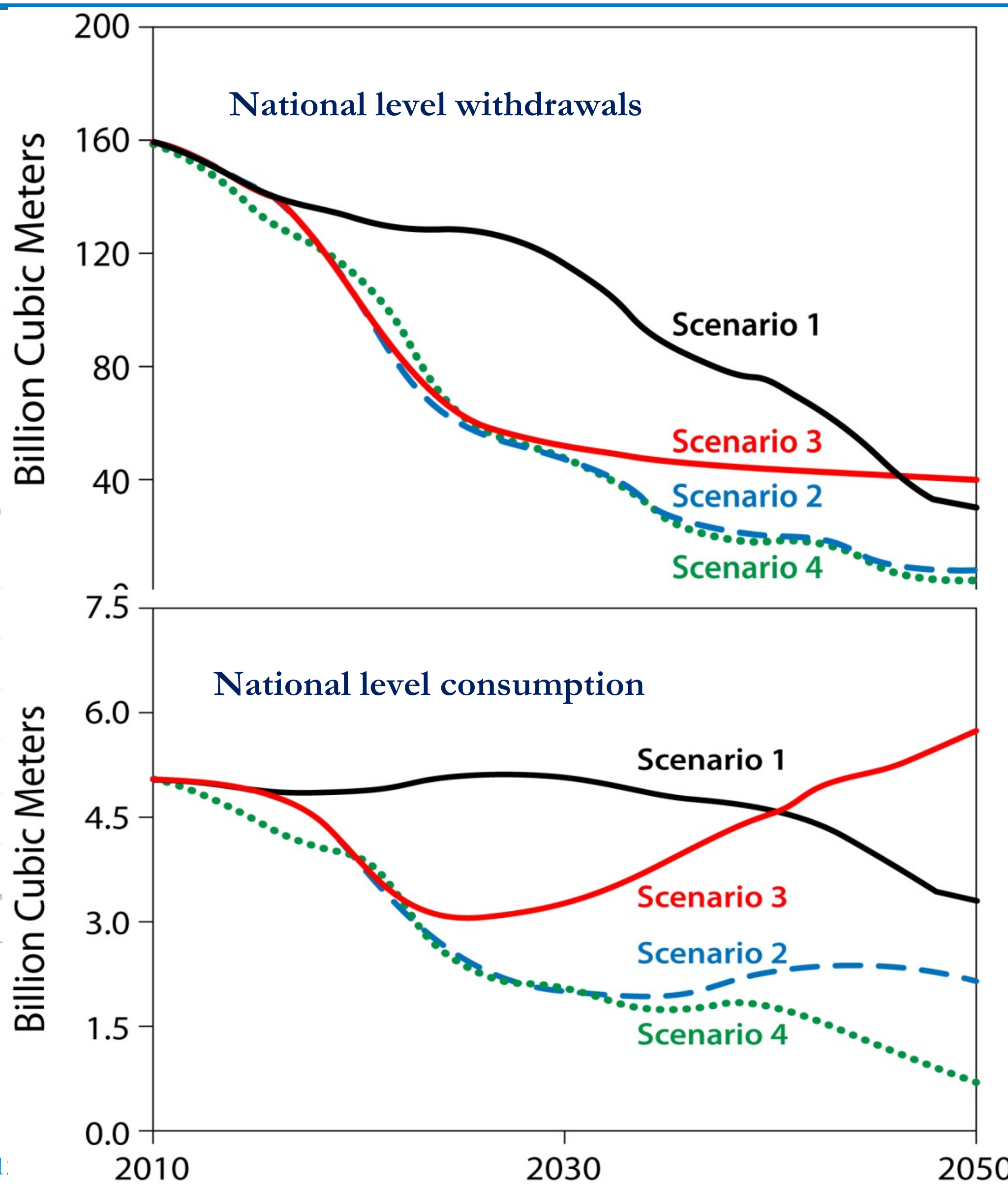
Scenario 1:
High Natural Gas
No carbon cap

Scenario 2:
High Renewable



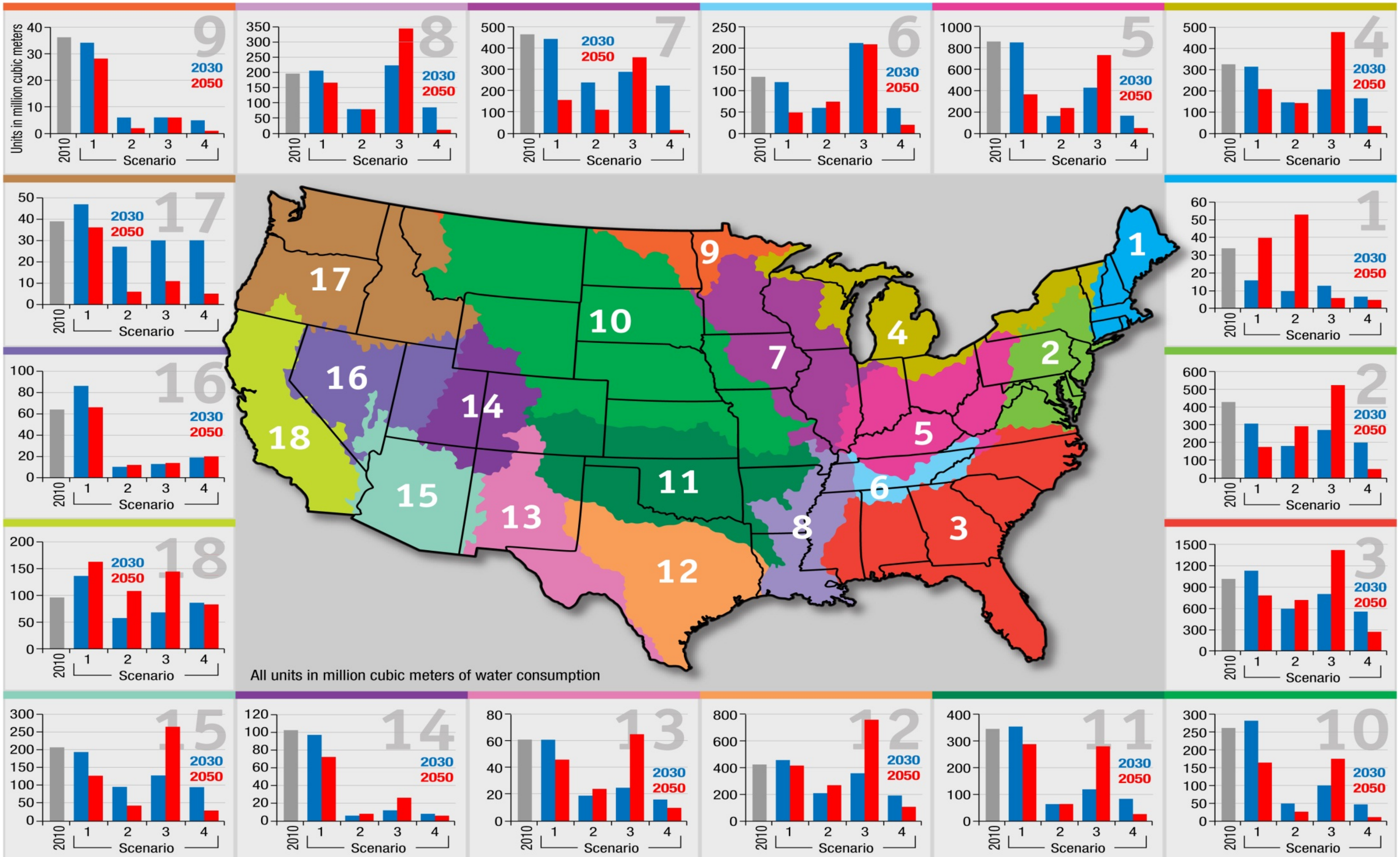
Scenario 3:
High Nuclear and Coal with CCS

Scenario 4:
Energy Efficiency and Renewable



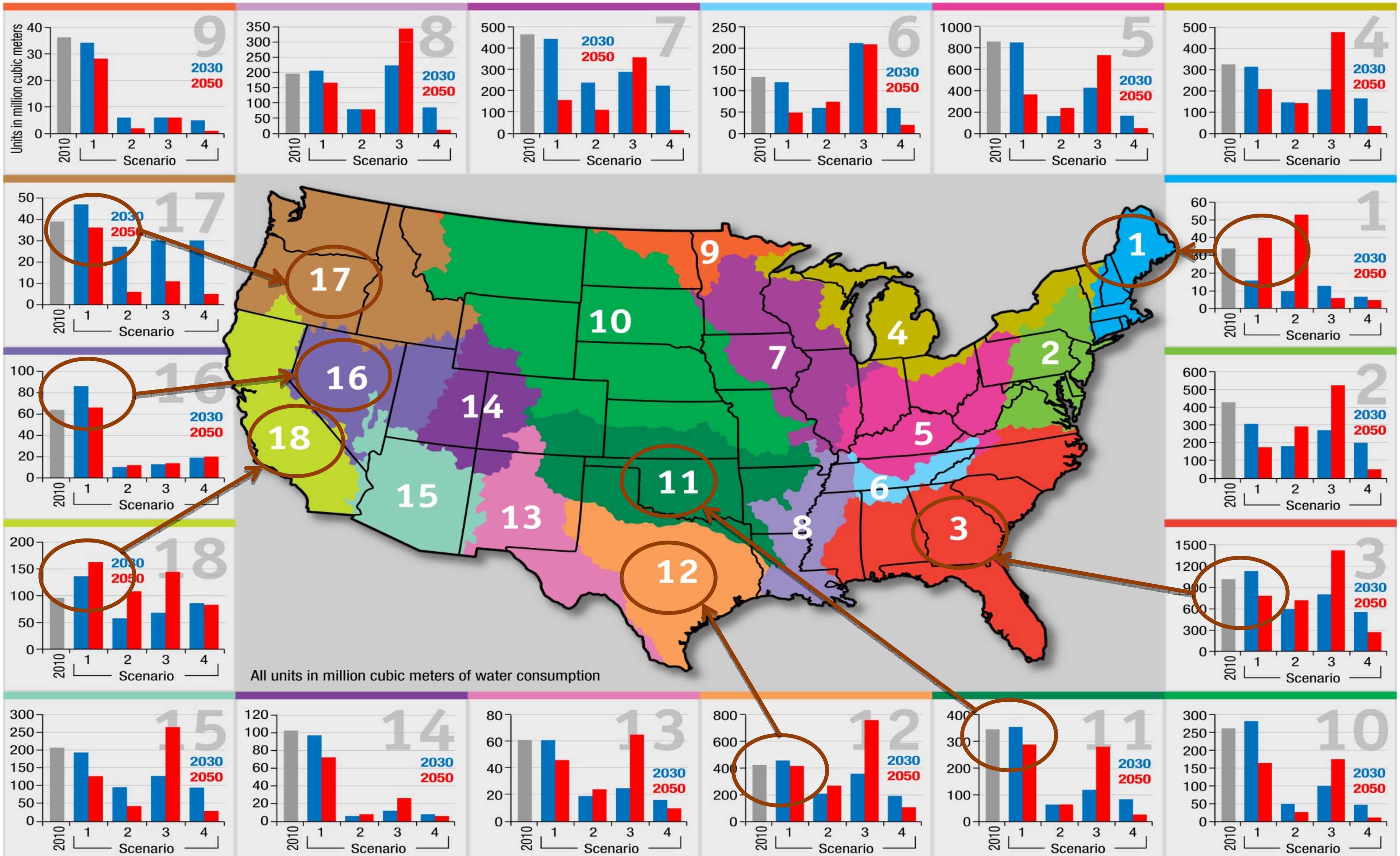
Source: Macknick, J., Sattler, S., Averyt, K., Clemmer, S., and Rogers, J. 201[illegible] different electricity pathways through 2050. Environmental Research Letters. 7 (045803).

Regional trends in water use may differ from national trends (consumption)



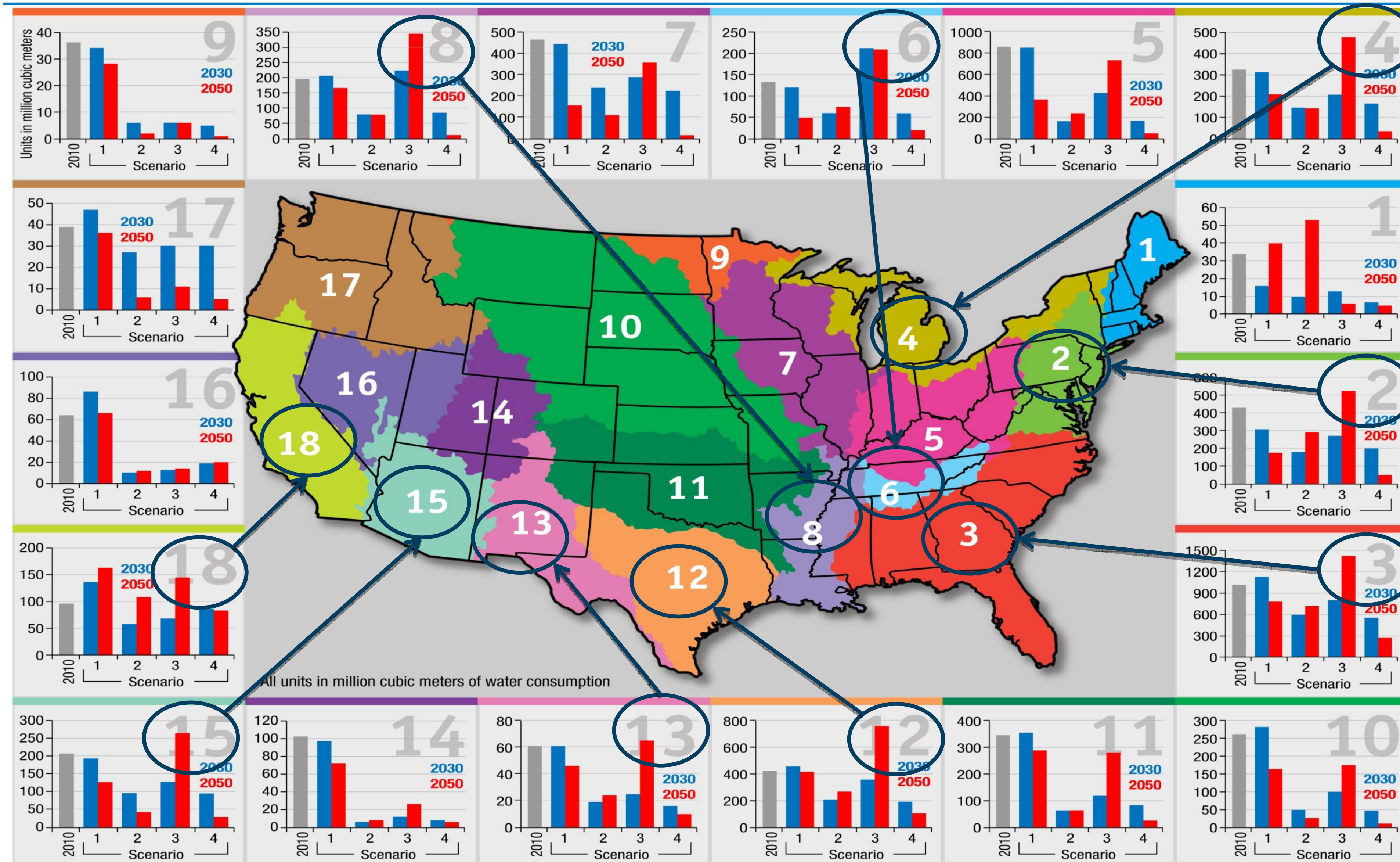
Source: Macknick, J., Sattler, S., Averyt, K., Clemmer, S., and Rogers, J. 2012. The water implications of generating electricity: water use across the United States based on different electricity pathways through 2050. Environmental Research Letters. 7 (045803).

Regional trends in water use may differ from national trends (consumption)
Scenario 1: Business-As-Usual (high natural gas)



Source: Macknick, J., Sattler, S., Averyt, K., Clemmer, S., and Rogers, J. 2012. The water implications of generating electricity: water use across the United States based on different electricity pathways through 2050. Environmental Research Letters. 7 (045803).

Regional trends in water use may differ from national trends (consumption)
Scenario 3: High coal with carbon capture and nuclear



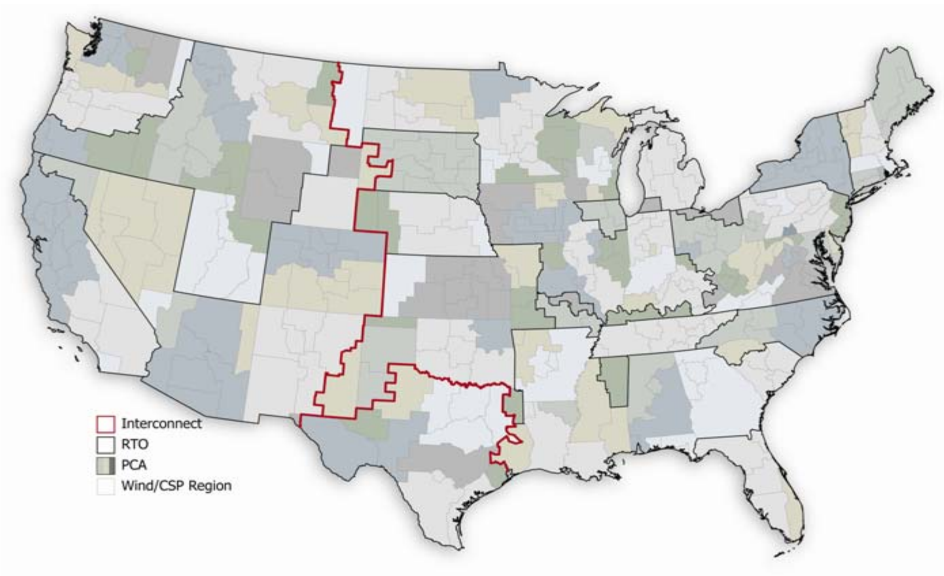
Source: Macknick, J., Sattler, S., Averyt, K., Clemmer, S., and Rogers, J. 2012. The water implications of generating electricity: water use across the United States based on different electricity pathways through 2050. Environmental Research Letters. 7 (045803).

What if water was a constraining factor in electricity sector modeling?

- **Prior modeling efforts consider *impacts* of the electricity sector on water resources, but do not consider water as a *constraint***

- **Ongoing NREL research has implemented water resource availability as a constraint into the ReEDS model**

Electricity Sector-ReEDS Model



•**R**e**g**ional **E**nergy **D**eployment **S**ystem (ReEDS)
•Electricity sector capacity expansion model
•Cost-optimization linear program
•GAMS
•17 intra-annual time slices
•Cost minimization routine every 2 years
•Flexible time horizon
•High geographic resolution

134 Power Control Areas
356 Solar and Wind Resource Regions

Constraints:
•Electricity demand
•Reserve requirements
•Regional resource supply
•State and Federal policy
•Transmission
•**Water**

Resources/Technologies:
- Conventional (fossil and nuclear)
- Renewables
- Storage
- Demand-side technologies

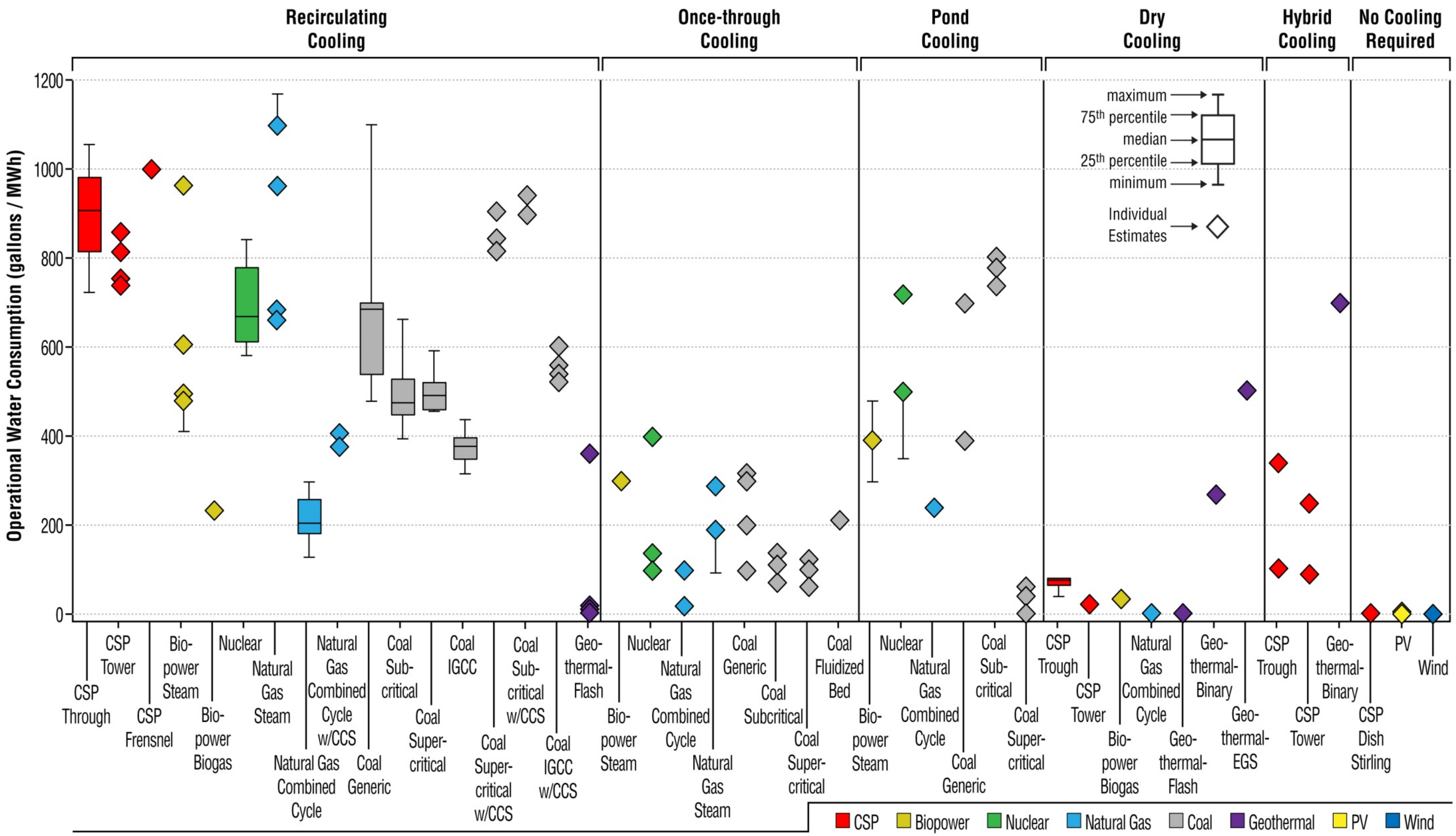
Relevance to energy-water modeling
- Water may be a limiting factor for the electricity sector
- Fuel type differences
  - e.g., coal vs. natural gas vs. PV
- Cooling system differences
  - e.g., once-through vs. cooling towers vs. dry-cooling
- Costs of different water sources
  - e.g., groundwater vs. surface vs. brackish
- Life cycle water uses
  - e.g., fuel extraction vs. operations

Sh... del Documentation: Base Case Data and Model Description. NREL Report. 2009.

Thermal power plant types have been expanded by cooling technology

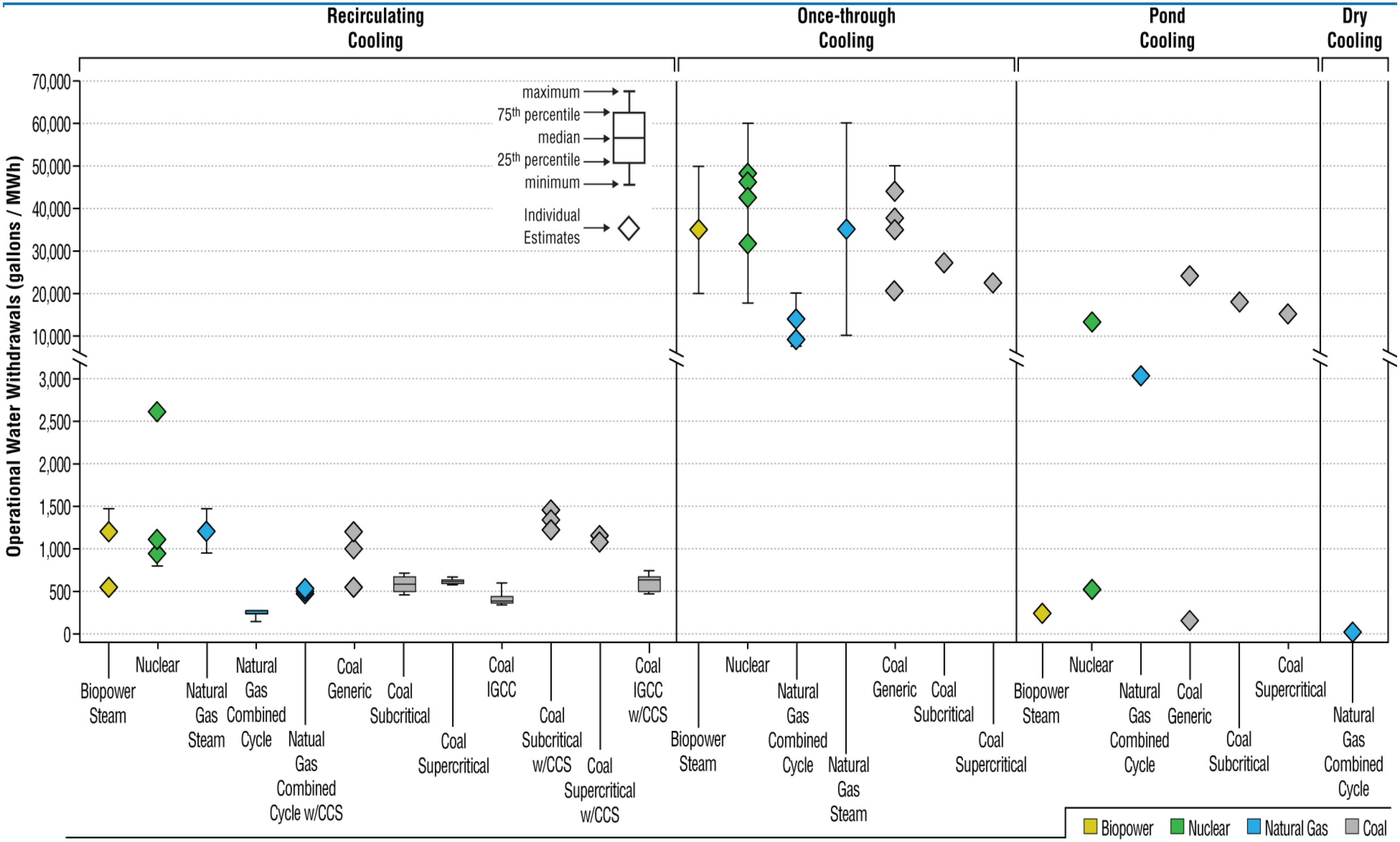
- **Available cooling technologies:**
  - Once-through
  - Cooling pond
  - Recirculating tower
  - Dry cooling
- **Plant type – cooling tech combinations are characterized by:**
  - Water withdrawal and consumption rate (gal/MWh)
  - Multipliers on capital cost, power output, heat rate, O&M cost

Operational Water Consumption



Source: 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. Environmental Research Letters. 7 (045802).

Operational Water Withdrawal



Source: 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. Environmental Research Letters. 7 (045802).

Cost and performance across cooling tech varies by relatively small fractions

- **Cost and heat rate: once = pond < recirc < dry**
  - Capital cost multipliers

	Once	Recirc	Dry	Pond
Gas-CC	0.978	1.000	1.102	0.978
Coal	0.981	1.000	1.045	0.981
Nuclear	0.981	1.000	n/a	0.981

  - Heat rate multipliers

	Once	Recirc	Dry	Pond
Gas-CC	0.980	1.000	1.050	0.98
Coal	0.985	1.000	1.050	0.985
Nuclear	0.973	1.000	n/a	0.973

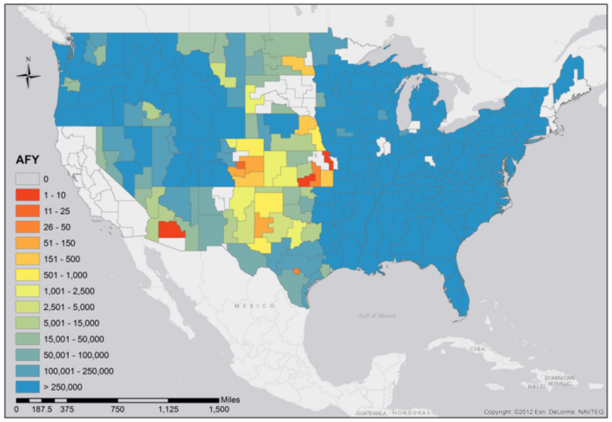
- **Power output: once = pond > recirc > dry**

	Once	Recirc	Dry	Pond
Gas-CC	1.004	1.000	0.983	1.004
Coal	1.017	1.000	0.930	1.017
Nuclear	1.017	1.000	n/a	1.017

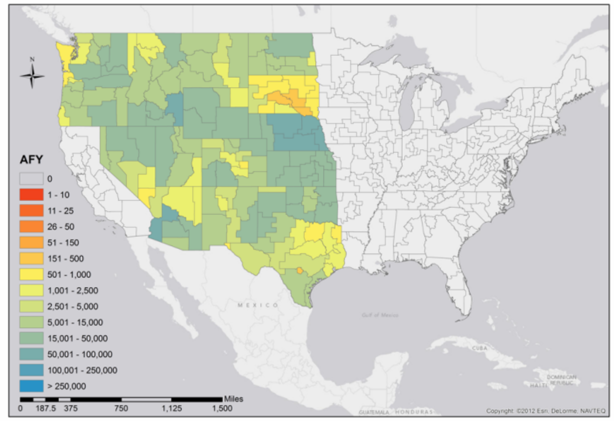
Source: Woldeyesus, T. and Macknick, J. Review of Cost and Performance Characteristics of Cooling Systems for Thermal Electric Power Plants. NREL Technical Report. *Forthcoming 2013.*

Model considers freshwater availability and costs

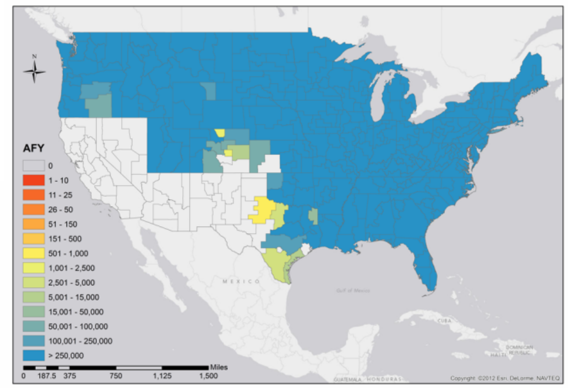
Potable Groundwater Availability Metric



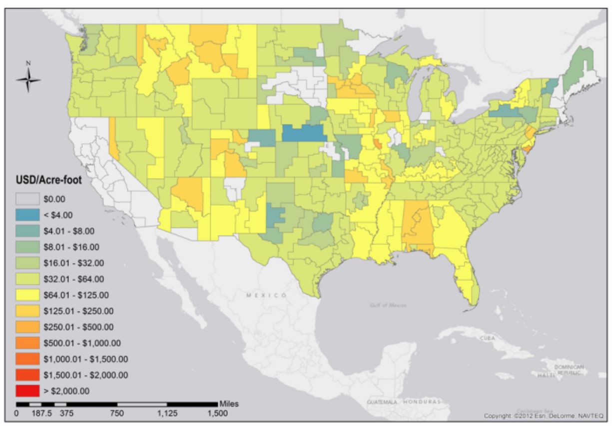
Appropriated Water Availability Metric



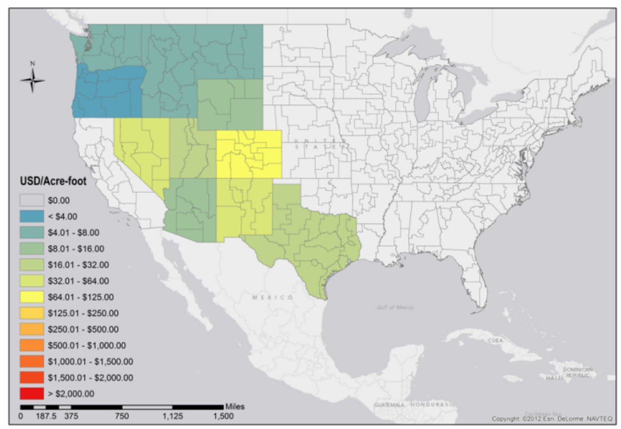
Unappropriated Surface Water Availability Metric



Potable Groundwater Cost



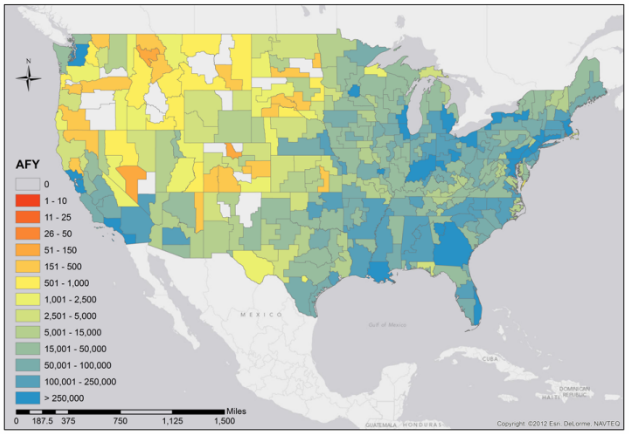
Appropriated Water Cost



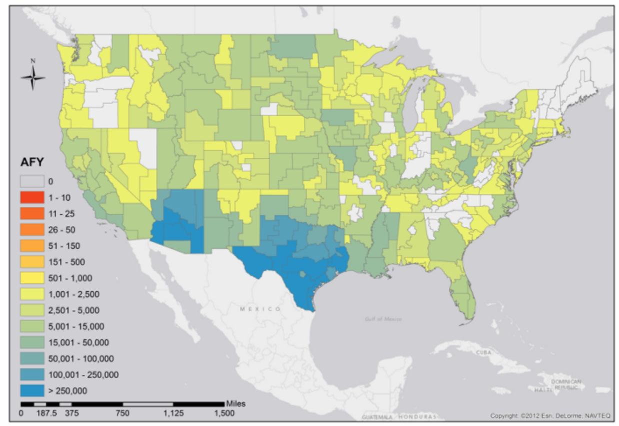
Source: Tidwell et al., *forthcoming 2013*.

Model considers alternative water resource availability and costs

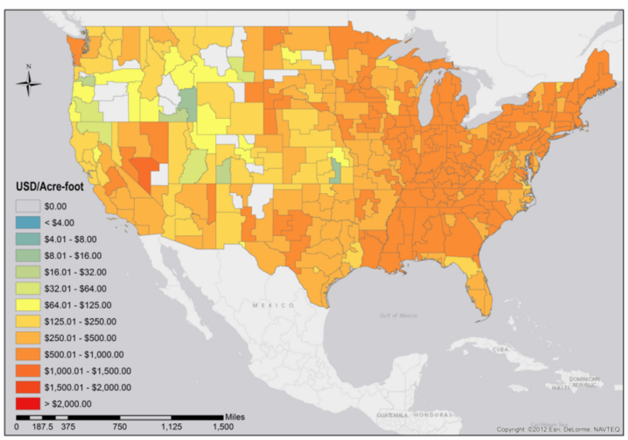
Wastewater Availability Metric



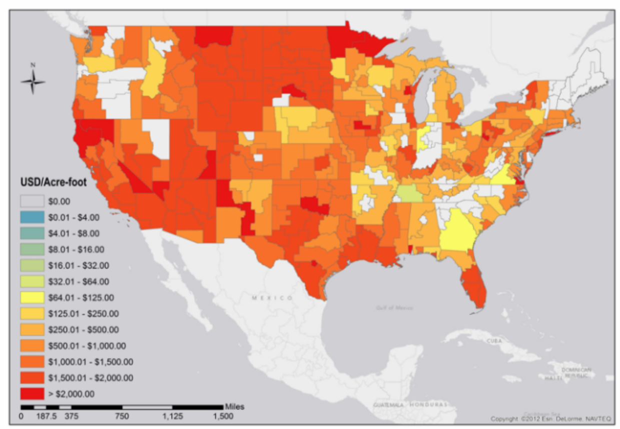
Brackish Groundwater Availability Metric

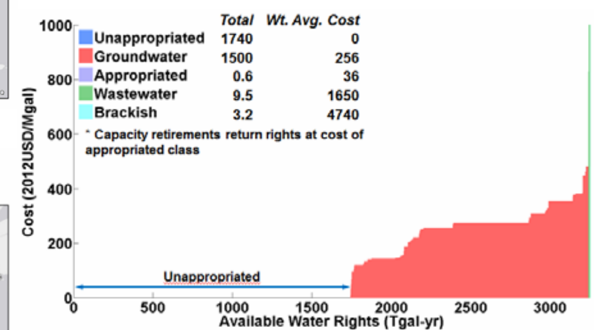


Wastewater Cost



Brackish Groundwater Cost





Source: Tidwell et al., *forthcoming 2013*.

Water rights are based on available water at annual low flow

- **Worst-case approach purchases enough rights for 100% capacity to operate during annual low flow**
- **In each solve year**

$$\forall n, \sum_{q,ct,n} C_{q,ct,n} W_{q,ct,n} \left(\frac{8760}{1e6}\right) \leq \sum_{cl} N_{cl}$$

$$\forall n, cl, N_{cl} \leq A_{cl}$$

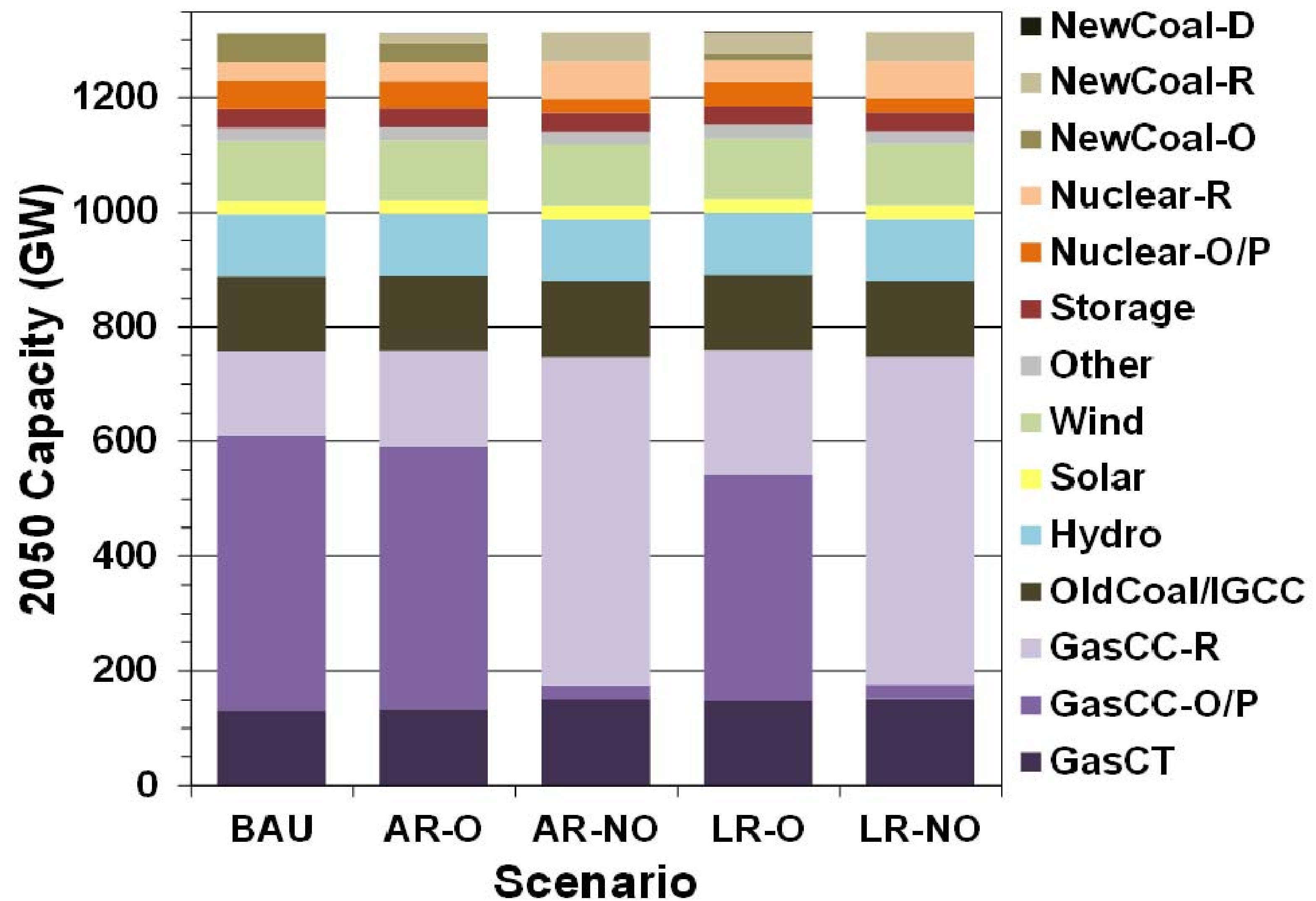
  - Sets: n = regions, q = plant type, ct = cooling tech, cl = water rights class
  - C = new capacity (MW)
  - W = withdrawal rate (gal/MWh)
  - N = new water rights (Mgal/yr)
  - A = available water rights (Mgal/yr)
  - 8760/1e6 converts gal/h to Mgal/yr
  - Terms for retirements and upgrades are not shown
  - Costs of N_{cl} are assessed in the objective
- **A_{cl} is then updated for new builds, retirements, and upgrades for each year**
- **In each solve year, new water rights cannot exceed available water rights in each balancing region**

Five initial scenarios to test model

Scenario	Water Rights constraint Active?	Water Rights Available	Cooling Technology Constraints
BAU	No	N/A	None
AR-O	Yes	All	None
AR-NO	Yes	All	No once-through cooling
LR-O	Yes	Limited	None
LR-NO	Yes	Limited	No once-through cooling

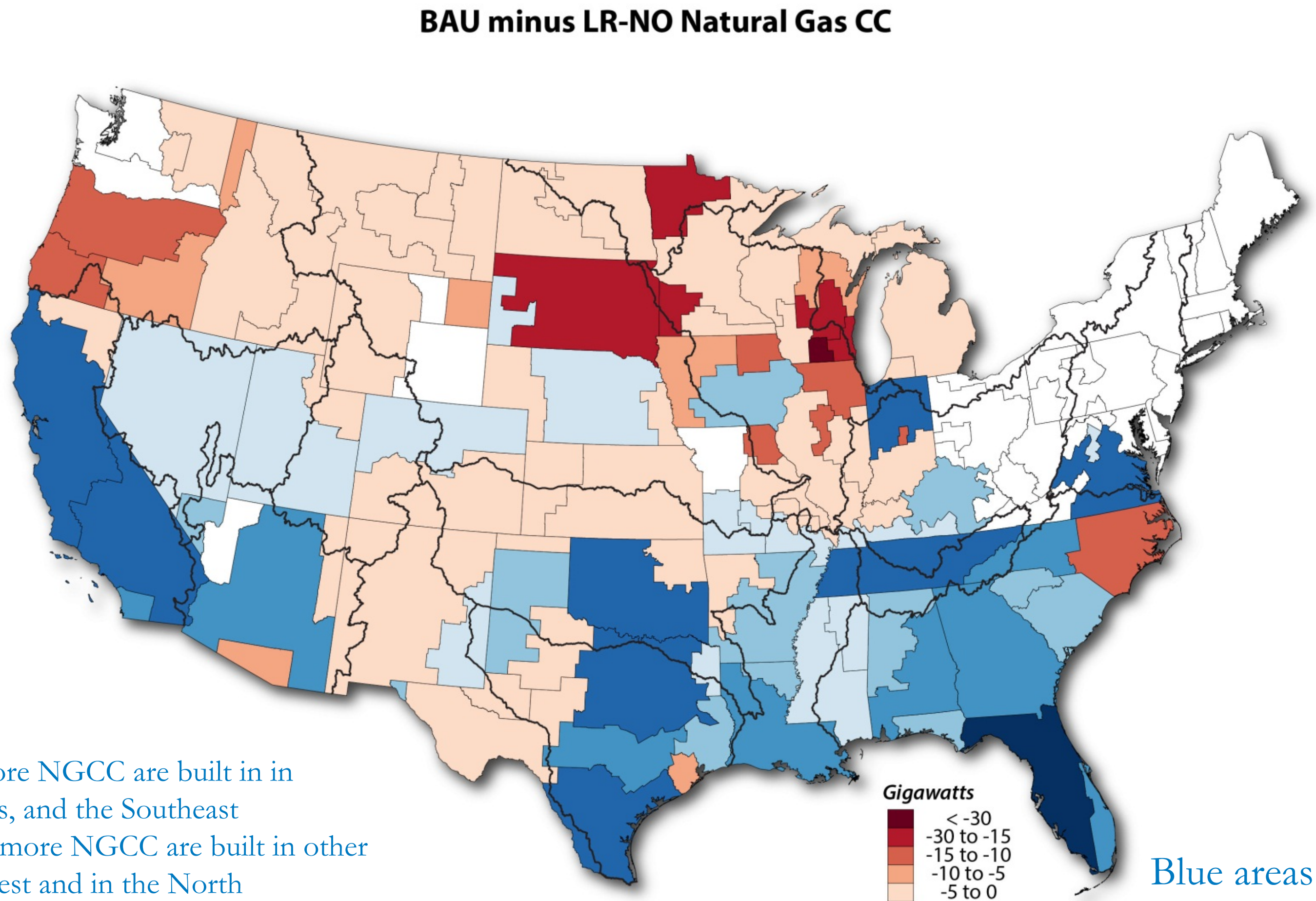
Limited Water rights indicate that no new freshwater resources are available for use in the power sector. Retired freshwater rights can be used, along with shallow brackish groundwater and municipal wastewater.

National Electricity Sector Capacity (GW) in 2050 under multiple scenarios



- Fuel choice does not vary greatly across scenarios
- Cooling system choices change substantially

Regional changes in new natural gas combined cycle (NGCC) builds (GW) due to water availability constraints

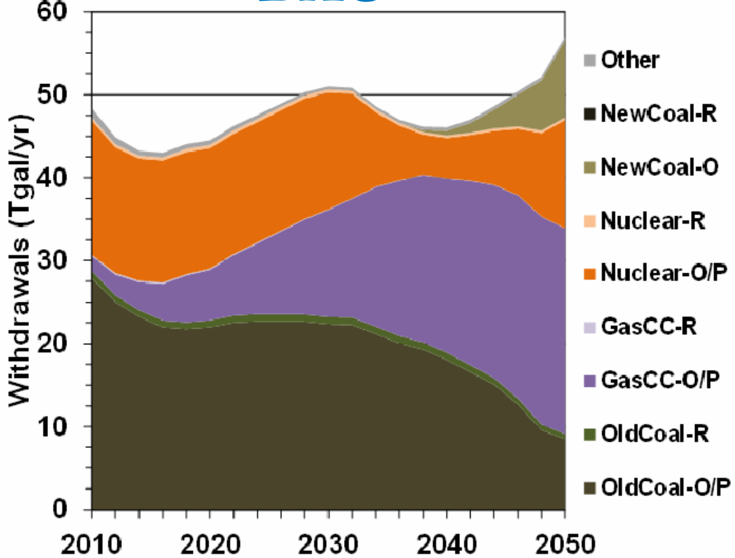


- Under BAU, more NGCC are built in in California, Texas, and the Southeast
- Under LR-NO, more NGCC are built in other parts of Southwest and in the North

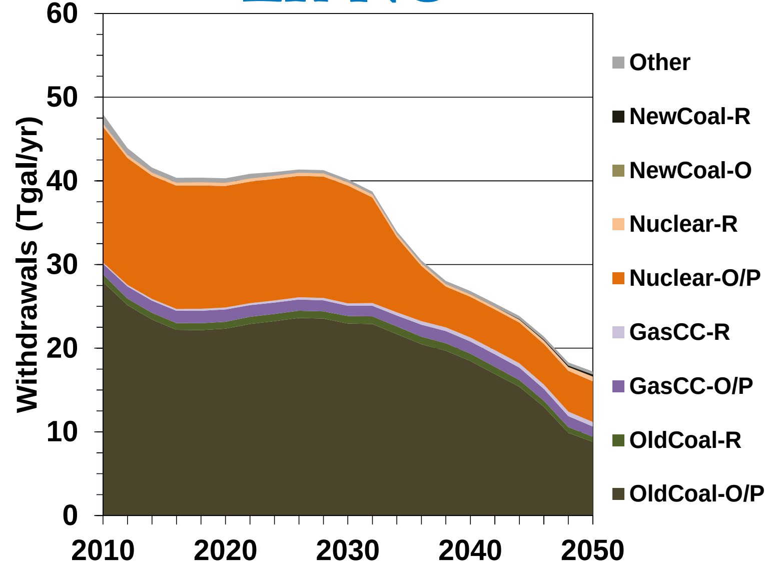
Blue areas indicate where more NGCC is built in BAU, when water is not considered as a constraint

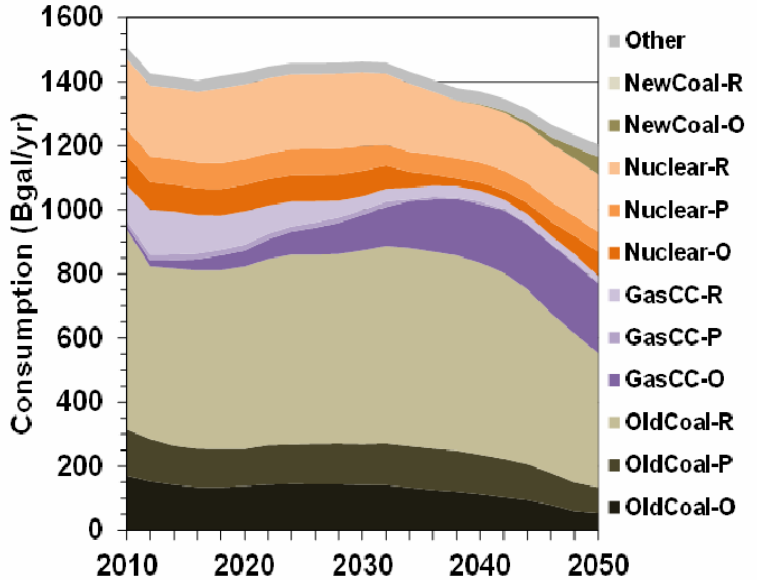
Water withdrawal and consumption trends vary greatly depending on water availability and cooling system decisions

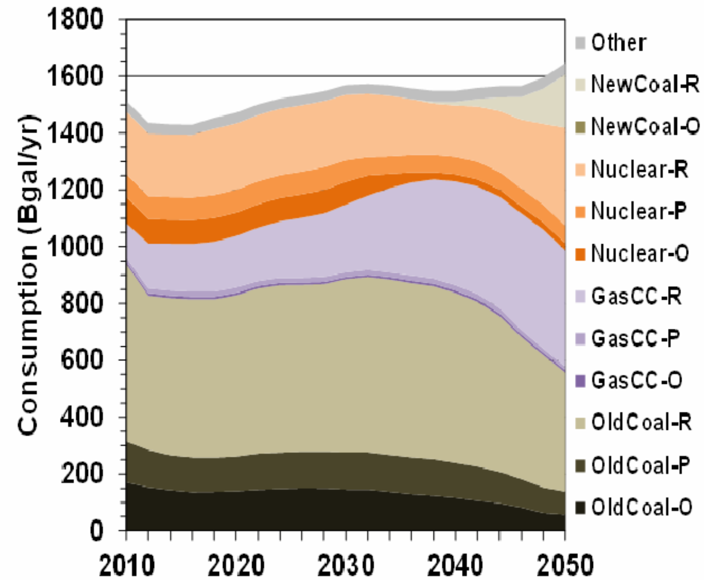
BAU



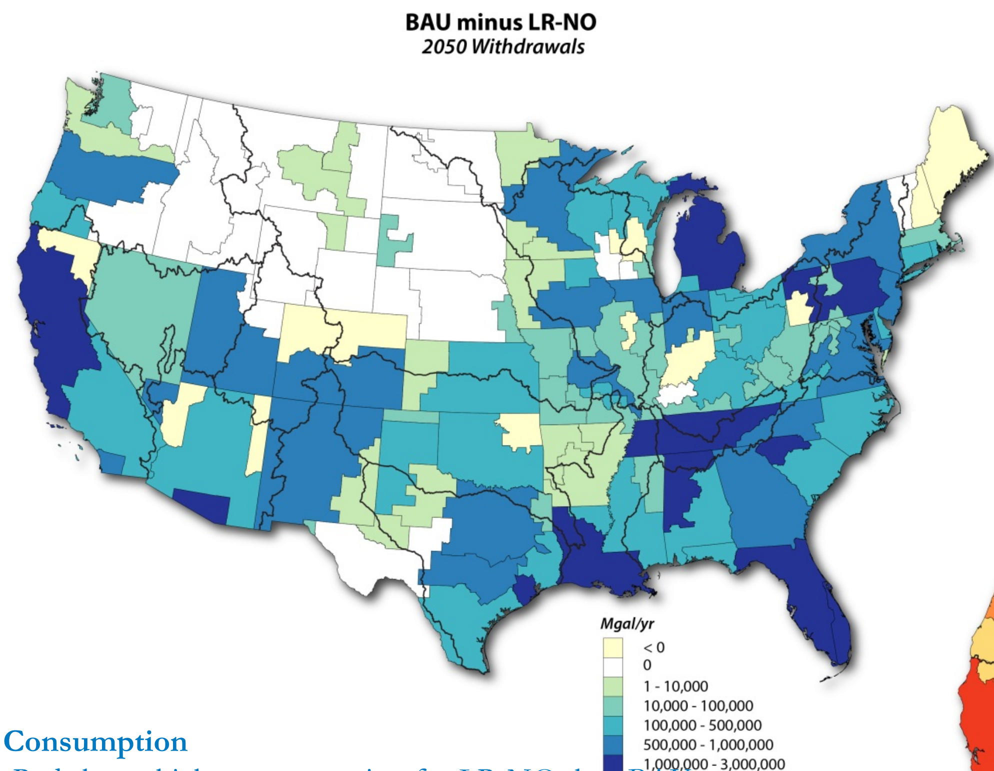
LR-NO







Regional withdrawal and consumption trends vary greatly, and are inversely related

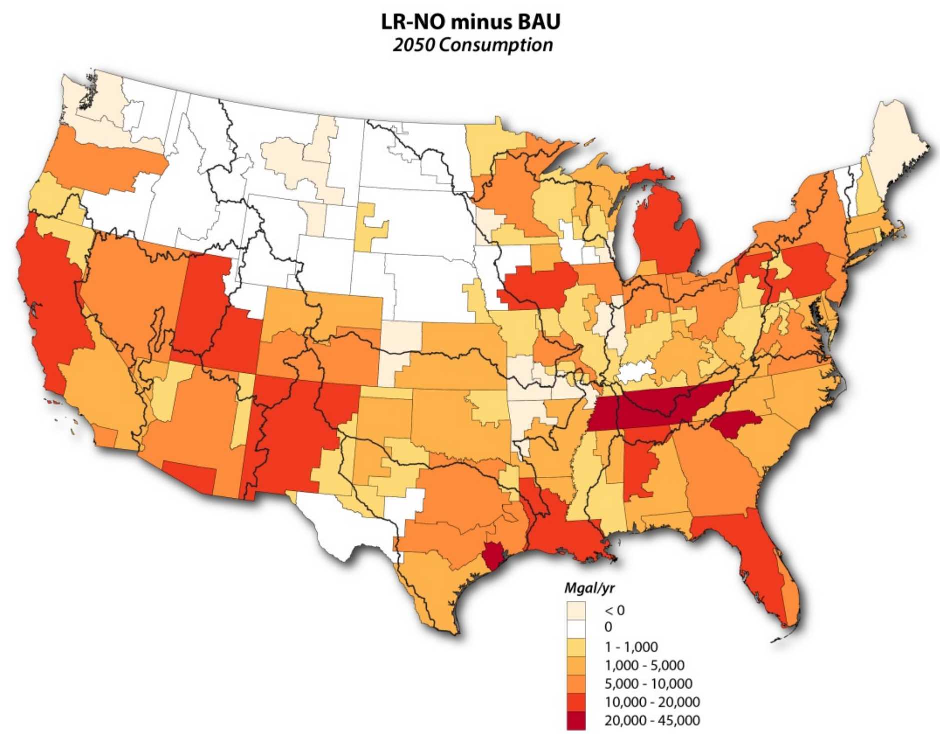


Withdrawals

-Blue indicates higher withdrawals for BAU than LR-NO
-BAU shows higher withdrawals than LR-NO for most regions
-Differences are highest in CA, TX, SE, and Great Lakes

Consumption

-Red shows higher consumption for LR-NO than BAU
-LR-NO shows higher consumption than BAU for most regions
-Differences mirror withdrawal trends
-As withdrawals increase, consumption decreases

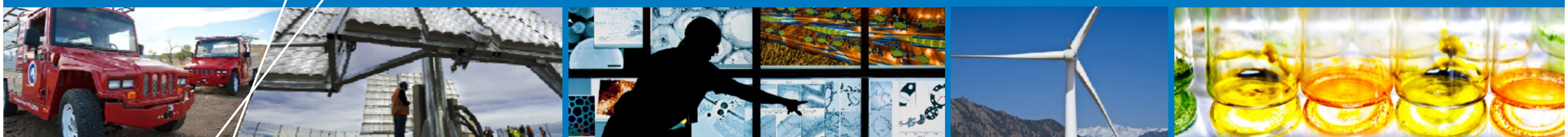


Key Initial Takeaways

- Water availability has affected electricity operations and siting decisions in the past
- Water availability will likely continue to influence the location and technology choices in the future
- Cooling system and location are more likely to change than fuel type when water is a constraint
- Certain regions (Southwest, Texas, Southeast, Great Lakes) see more water constraint-driven changes
- Water constraint-driven changes are less pronounced in scenarios with high natural gas penetration
- Cooling system regulations can greatly affect national trends in water withdrawal and consumption amounts
- Consumption and Withdrawal trends are often inversely related

Future areas of research

- **Future scenario analysis**
  - Water availability as affected by climate change
  - Cooling system policy analysis
  - Energy scenario analysis
- **Exploration of new capabilities**
  - Seasonal assessments
  - Temperature inclusion
  - Greater spatial resolution analyses
  - Case studies on specific areas
  - Additional refinement of model



Thank you

Jordan.Macknick@NREL.gov

Panelist 3

Ms Kelly T. Sanders

University of Texas at Austin

kellytwomeysanders@utexas.edu

Strategies of using the energy-water nexus to achieve cross-cutting efficiency gains

Kelly T. Sanders

University of Texas at Austin; USC

Energy and Water: Essential, Interdependent Commodities and Strategies

July 25, 2013

There Are Several Themes to Keep in Mind

1. **Energy and water are interrelated**
    - **we use energy for water and water for energy**

2. **The energy and water relationship is already under strain**
    - **constraints in one resource introduce constraints in the other**

3. **Trends imply these strains will be exacerbated**
    - **Population growth increases total demand**
    - **Economic growth increases per capita demand**
    - **Global climate change intensifies the hydrological cycle**
    - **Policy shifts towards increasing water-intensity of energy and energy-intensity of water**

4. **Technical and Policy Solutions Exist**

Energy and Water are Interrelated

Water for Energy

- Water is required for:
  - Mining Fuels
  - Hydroelectric Power
  - Cooling Power Plants
- Water Quality vs. Water Quantity

Energy for Water

- Energy is required for:
  - Water Treatment
  - Water Pumping
  - Water Heating
  - Creating Steam for Industrial Processes

Energy Production Has Water Quantity and Water Quality Consequences

- **We use water for primary fuel extraction**
  - **Growing biofuels**
  - **Extracting oil and gas**
  - **Mining coal and uranium**

- **We use water for transporting fuels**
  - **Oil is transported across oceans**
  - **Coal is moved across the Mississippi via barges**

- **We use water for the power sector**
  - **Driving hydroelectric turbines**
  - **Driving steam turbines**
  - **Cooling power plants**

Energy Production, Distribution and Use Can Impact Water Quality

Deepwater Horizon Spill;
Source: Wikipedia

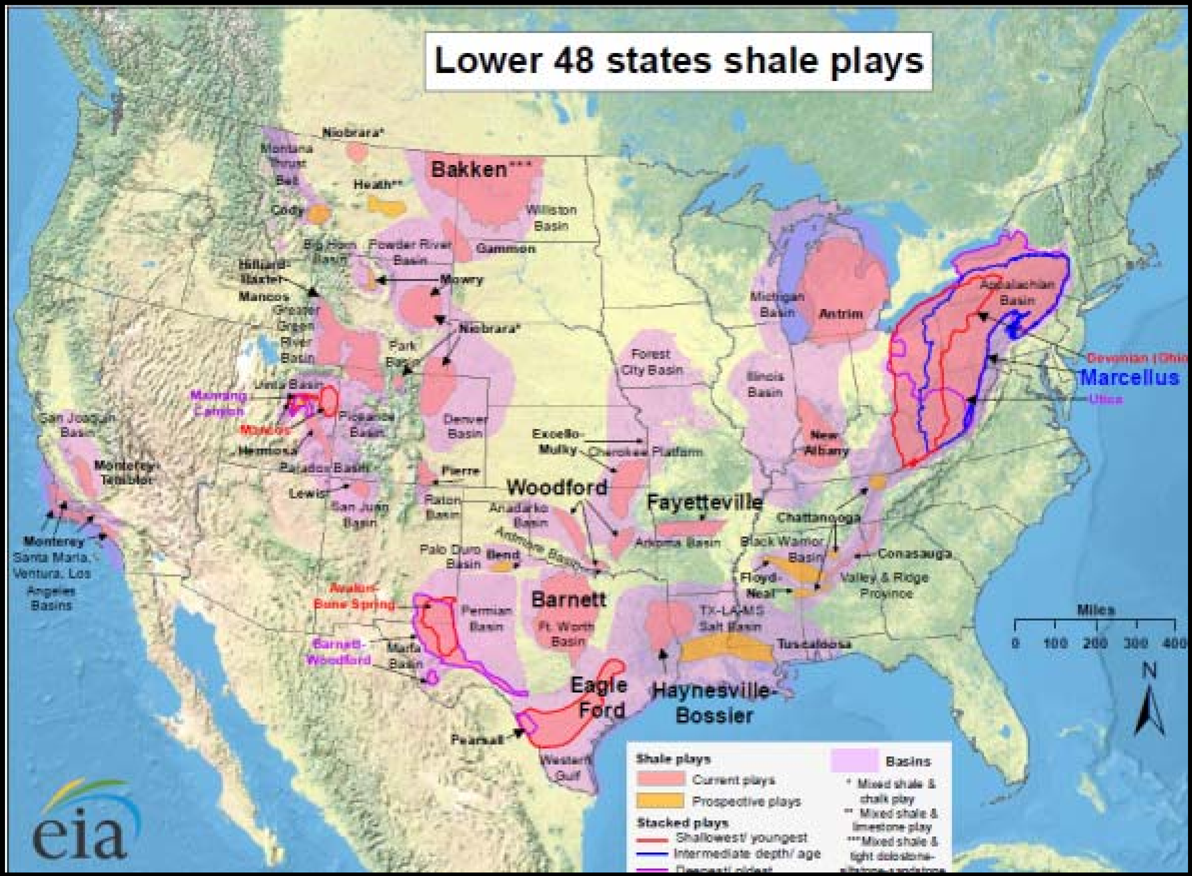
2008 Coal Ash Spill in TN;
Source: NYT

Bay of Campeche Spill, Mexico;
Source: Popular Mechanics

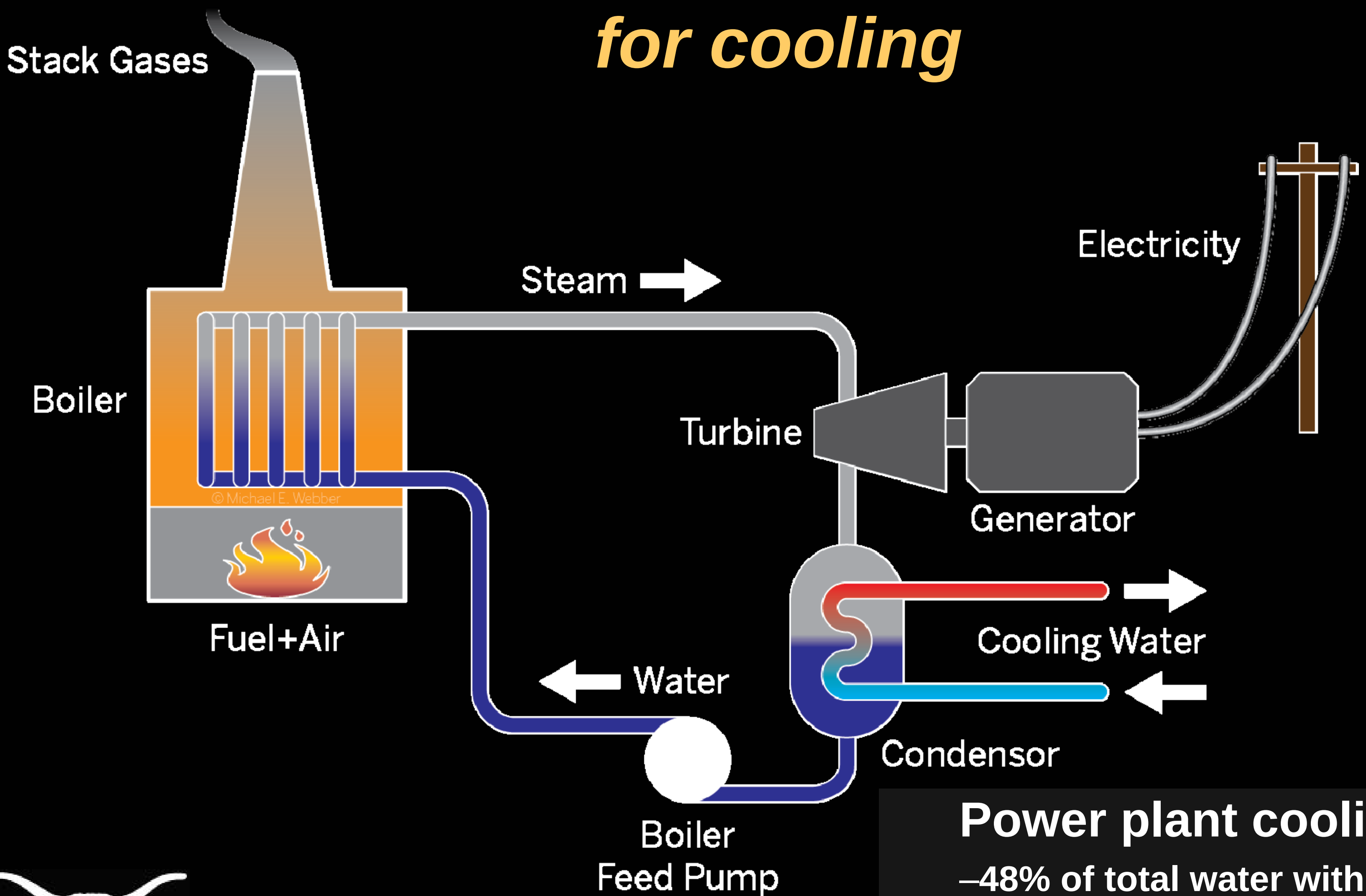
Hydropower;
Source: Howstuffworks.com

Hydraulic Fracturing Raises Water-quantity and Water-quality Issues

- **How much water is needed?**
- **Will adjacent water tables be contaminated?**
- **What should be done with the residual wastewater?**



Over 75% of US electricity is generated in thermoelectric power plants that require water for cooling

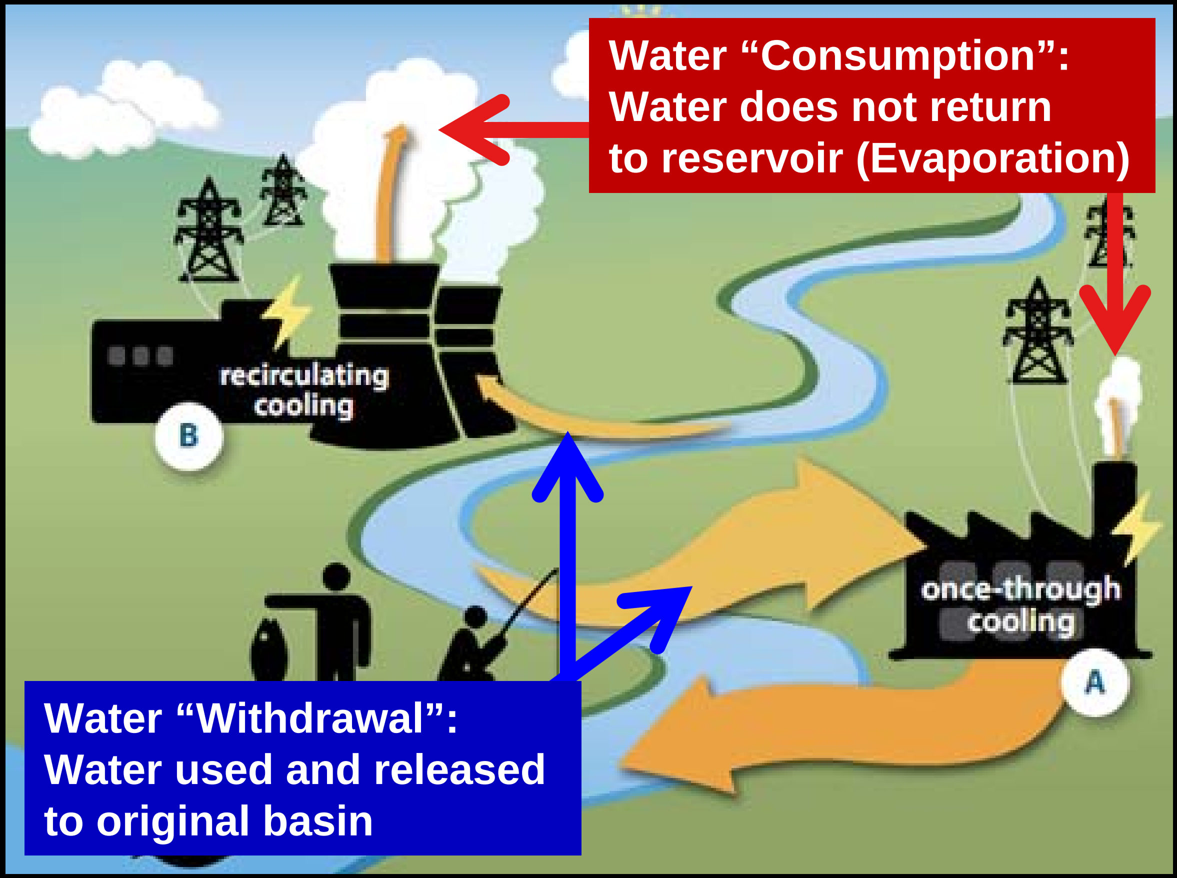


Power plant cooling:

- –48% of total water withdrawals
- –39% of freshwater withdrawals

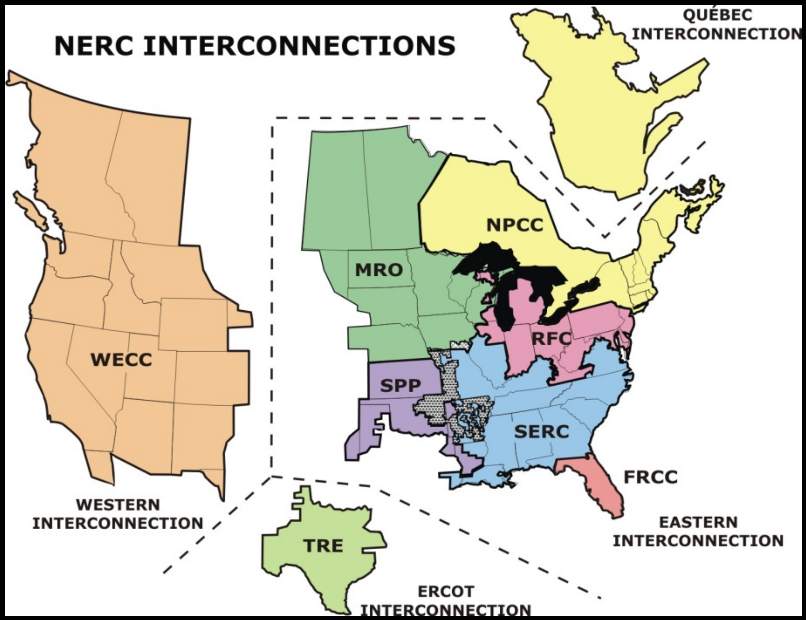
Water Use At the Power Plant Depends on Fuel, Power Cycle & Cooling Technology

- **Recirculating cooling:**
  - **Small withdrawals**
  - **Large consumption**
- **Once-through cooling:**
  - **Large withdrawals**
  - **Small consumption**
  - **Being phased out in California**

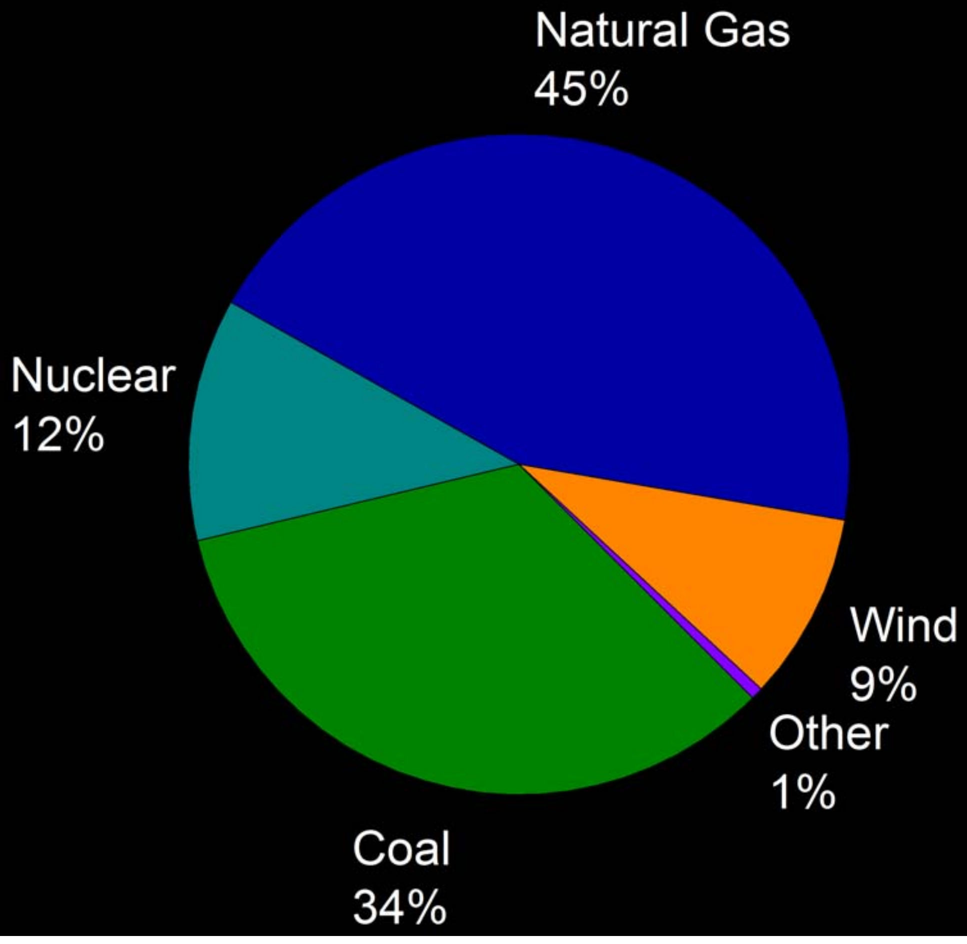


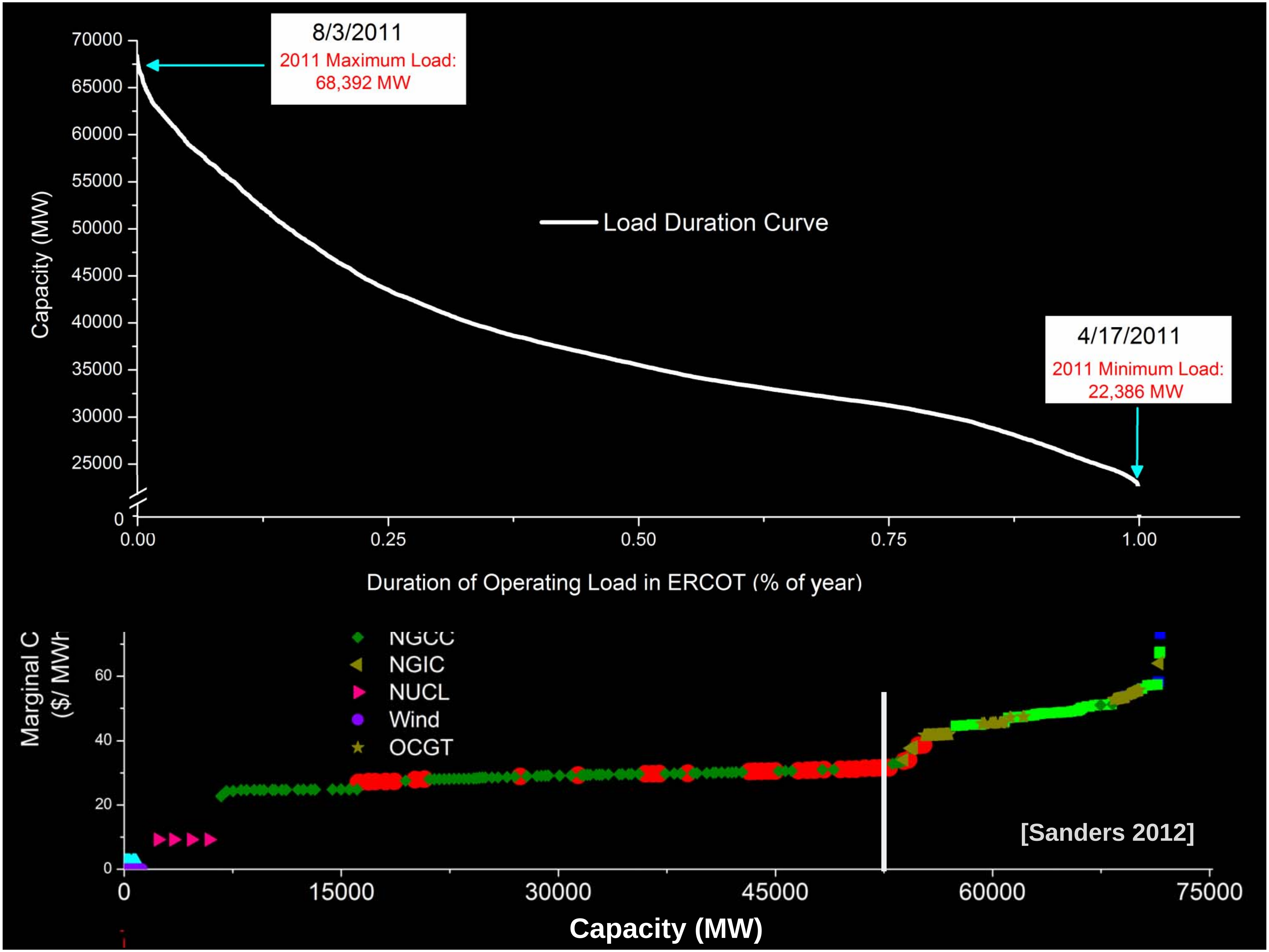
[Image source: Union of Concerned Scientists]

ERCOT consumes more natural gas and less coal than the average US electricity mix

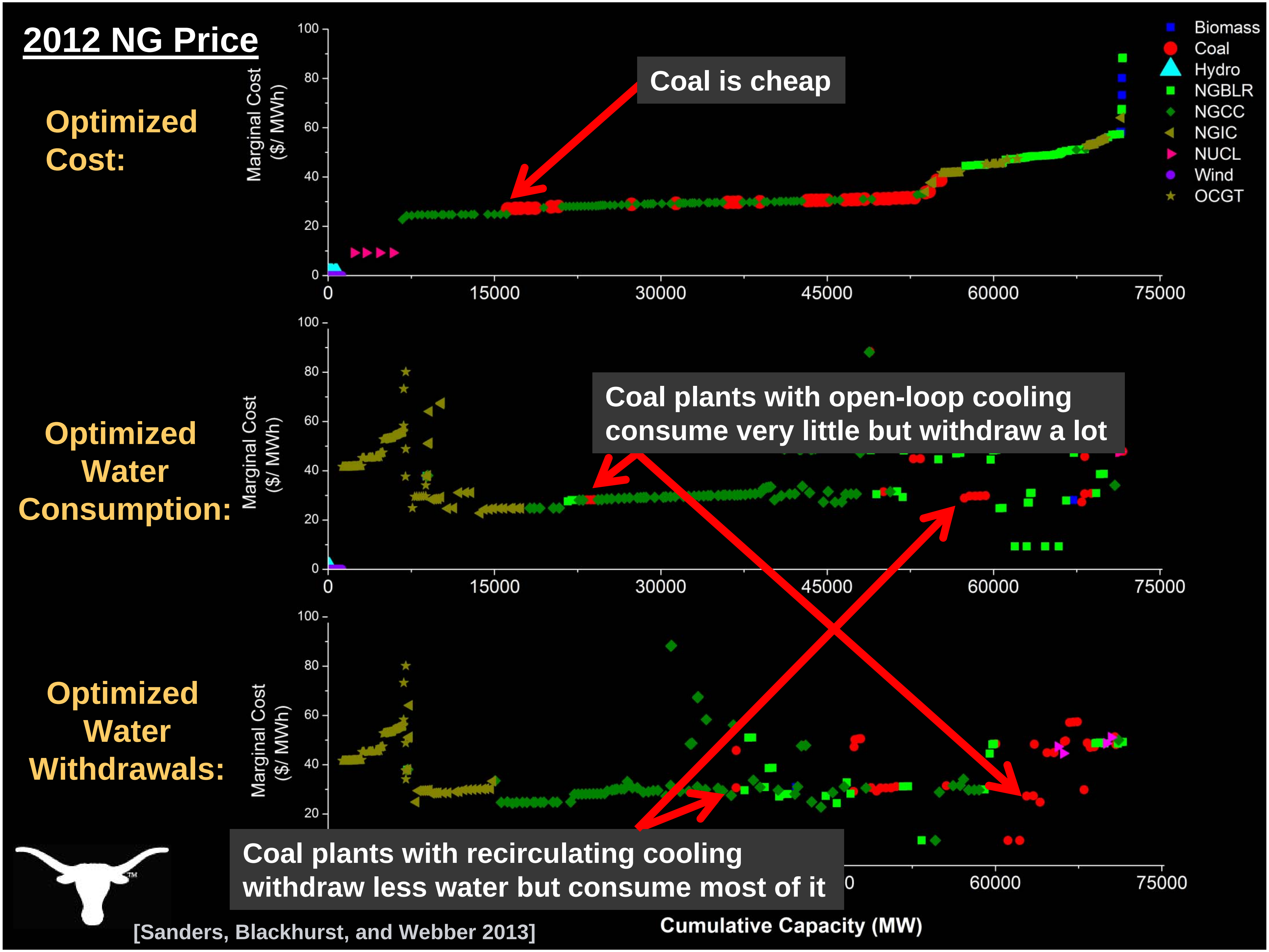


ERCOT 2012 Power Generation:
324 Billion kWh




8/3/2011
2011 Maximum Load:
68,392 MW
Load Duration Curve
4/17/2011
2011 Minimum Load:
22,386 MW
Capacity (MW)
70000
65000
60000
55000
50000
45000
40000
35000
30000
25000
0
0.00
0.25
0.50
0.75
1.00
Duration of Operating Load in ERCOT (% of year)
NGCC
NGIC
NUCL
Wind
OCGT
Marginal C
($/ MWh
60
40
20
0
0
15000
30000
45000
60000
75000
Capacity (MW)
[Sanders 2012]

Competitive retail electricity markets dispatch power according to least marginal cost – Are there alternative strategies?

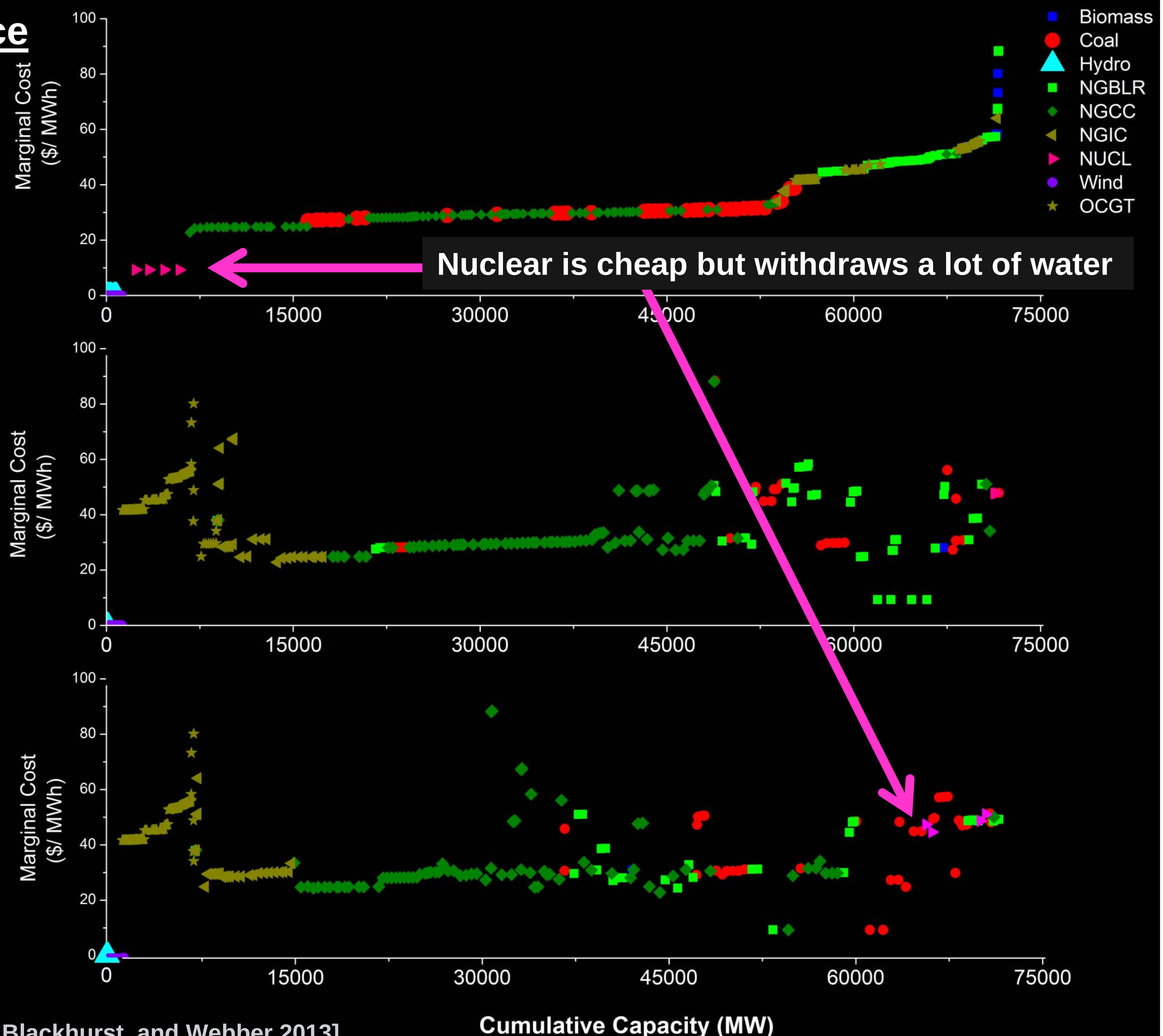

2012 NG Price
Optimized Cost:
Optimized Water Consumption:
Optimized Water Withdrawals:
Marginal Cost ($/ MWh)
Cumulative Capacity (MW)
Biomass
Coal
Hydro
NGBLR
NGCC
NGIC
NUCL
Wind
OCGT
Coal is cheap
Coal plants with open-loop cooling consume very little but withdraw a lot
Coal plants with recirculating cooling withdraw less water but consume most of it
[Sanders, Blackhurst, and Webber 2013]

2012 NG Price

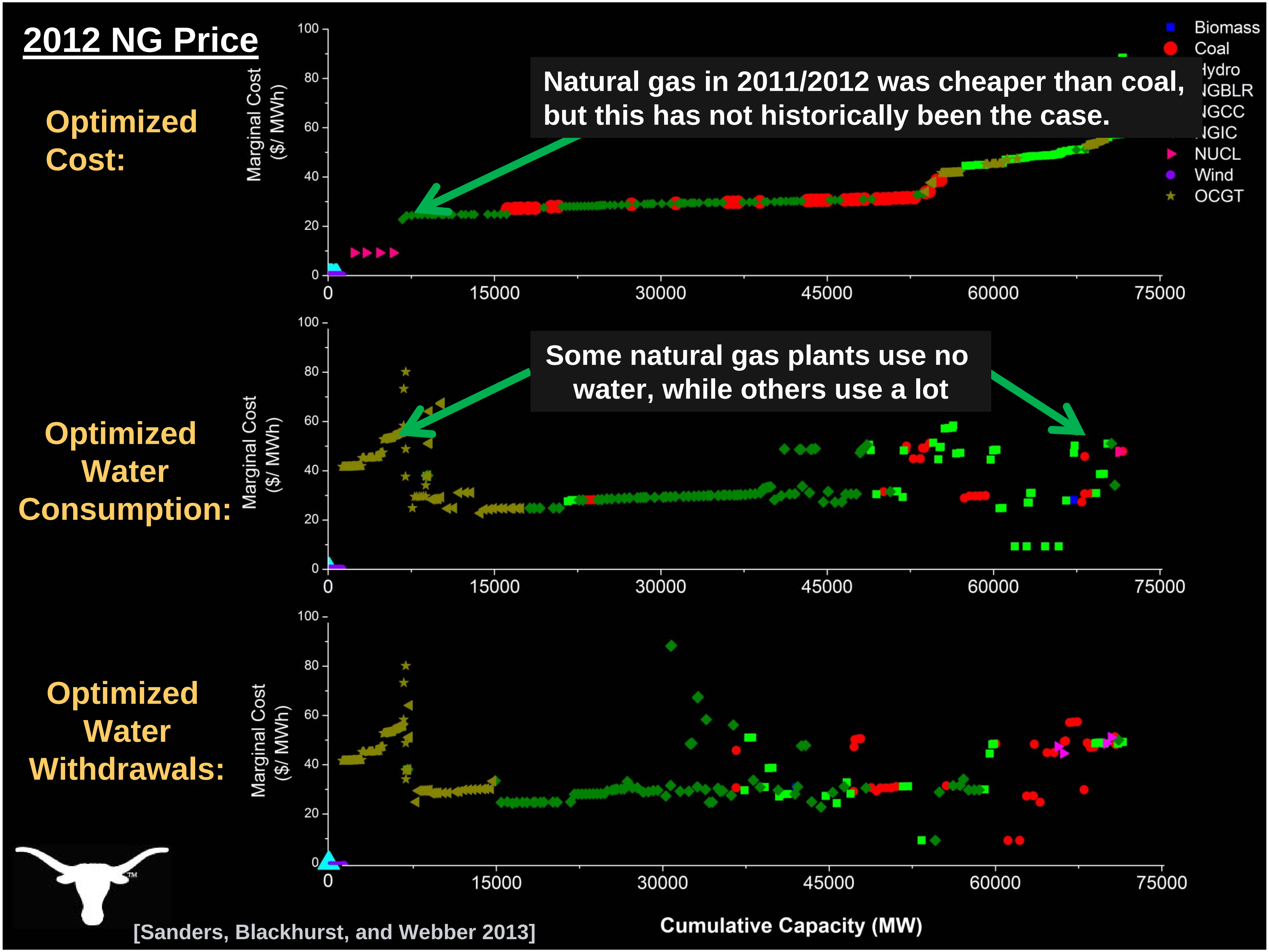
Optimized Cost:

Optimized Water Consumption:

Optimized Water Withdrawals:

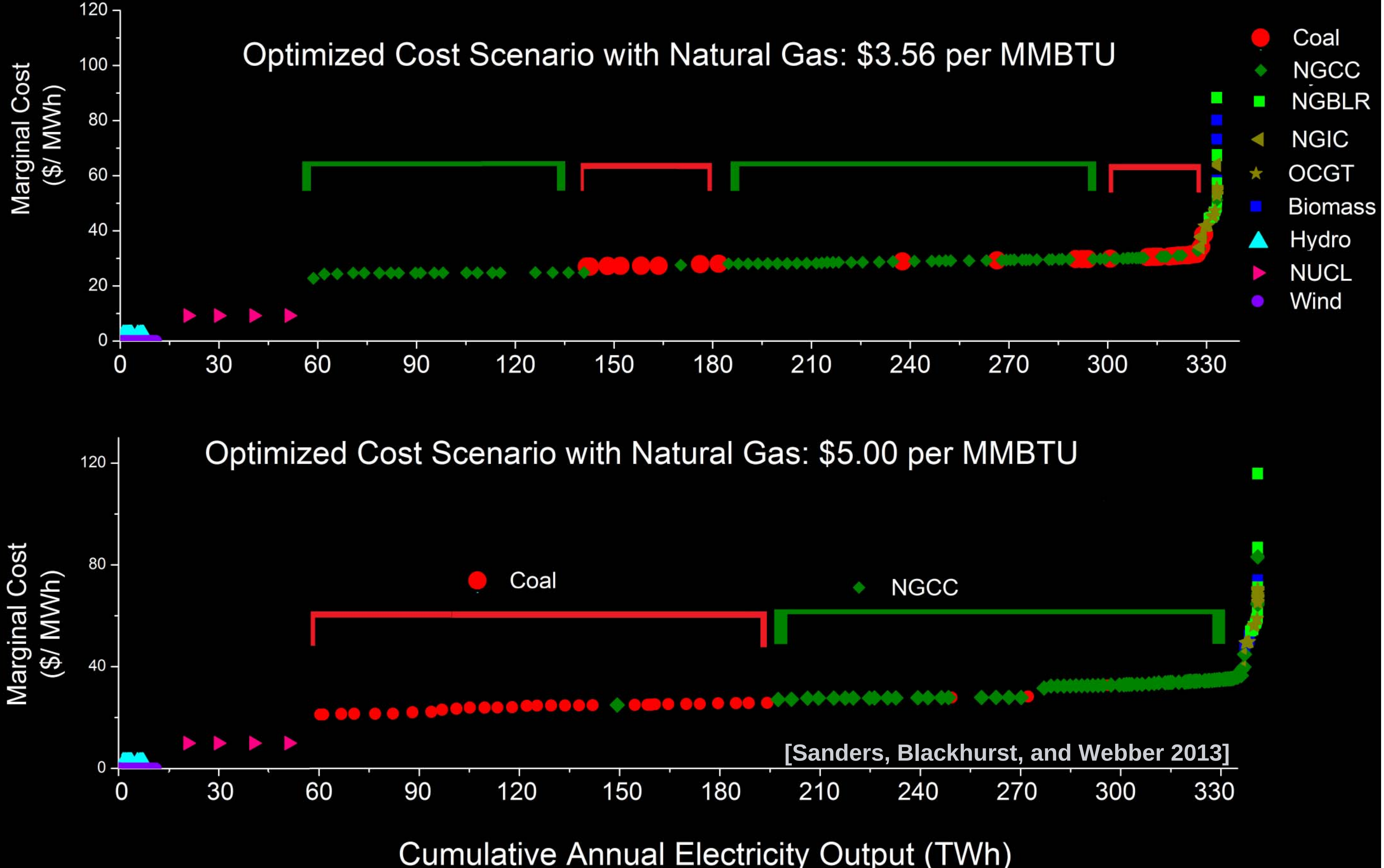


[Sanders, Blackhurst, and Webber 2013]

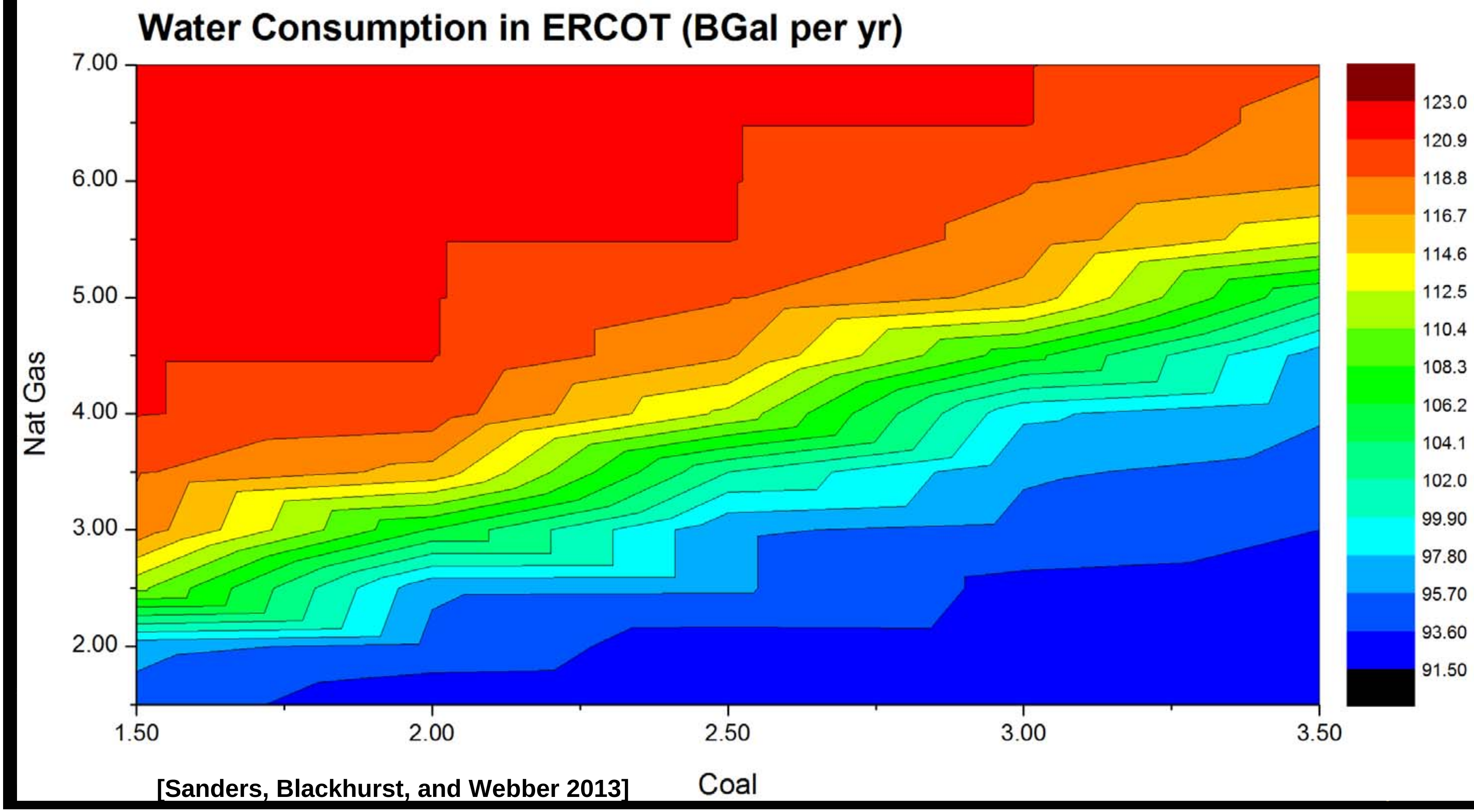


2012 NG Price
Optimized Cost:
Optimized Water Consumption:
Optimized Water Withdrawals:
Natural gas in 2011/2012 was cheaper than coal, but this has not historically been the case.
Some natural gas plants use no water, while others use a lot
Marginal Cost ($/ MWh)
Cumulative Capacity (MW)
Biomass
Coal
NUCL
Wind
OCGT
0
20
40
60
80
100
15000
30000
45000
60000
75000
[Sanders, Blackhurst, and Webber 2013]

Downward shifts in natural gas prices have decarbonized and dewatered ERCOT

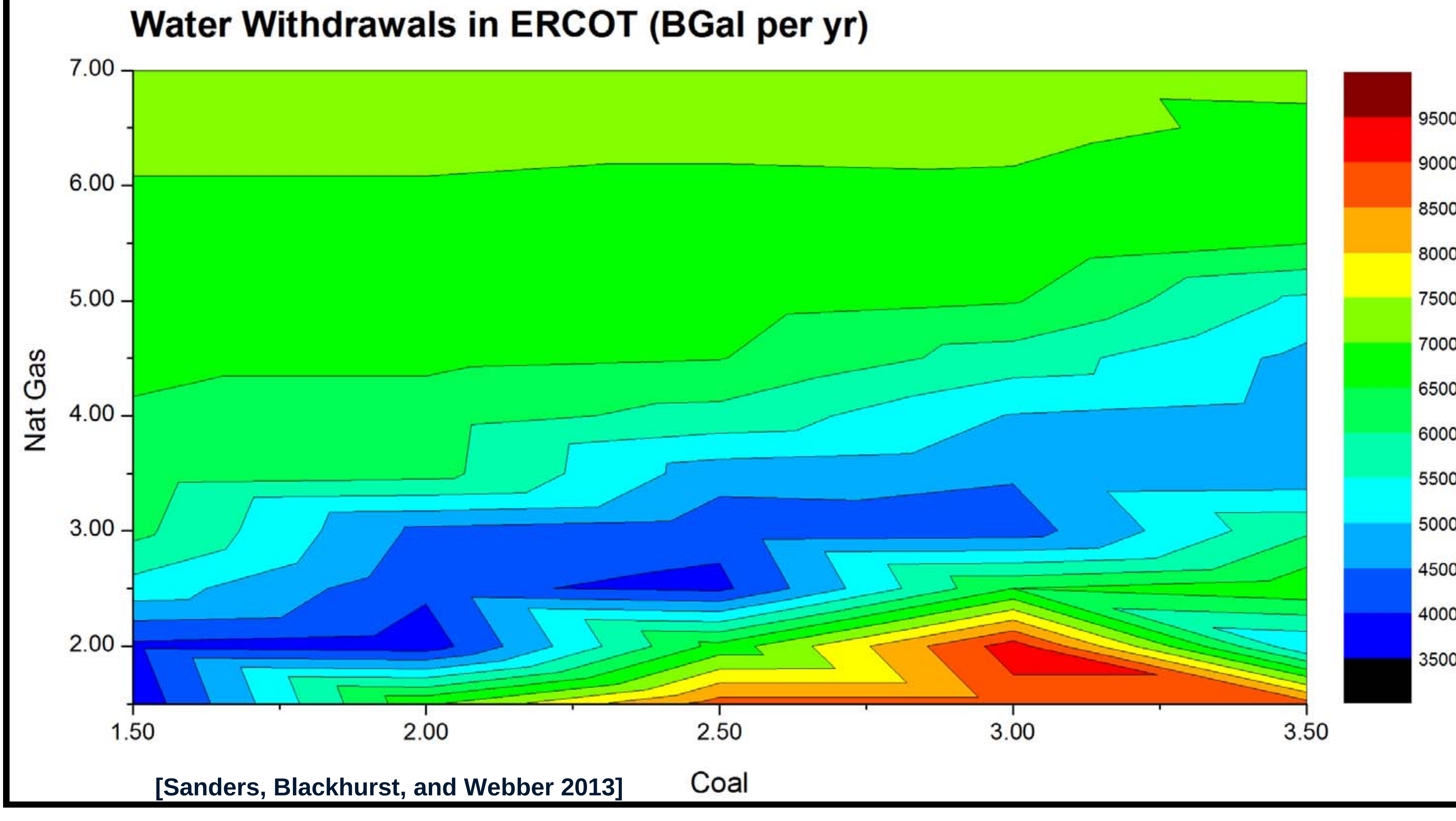


Natural Gas and Coal Prices Affect Water Consumption for Power Production



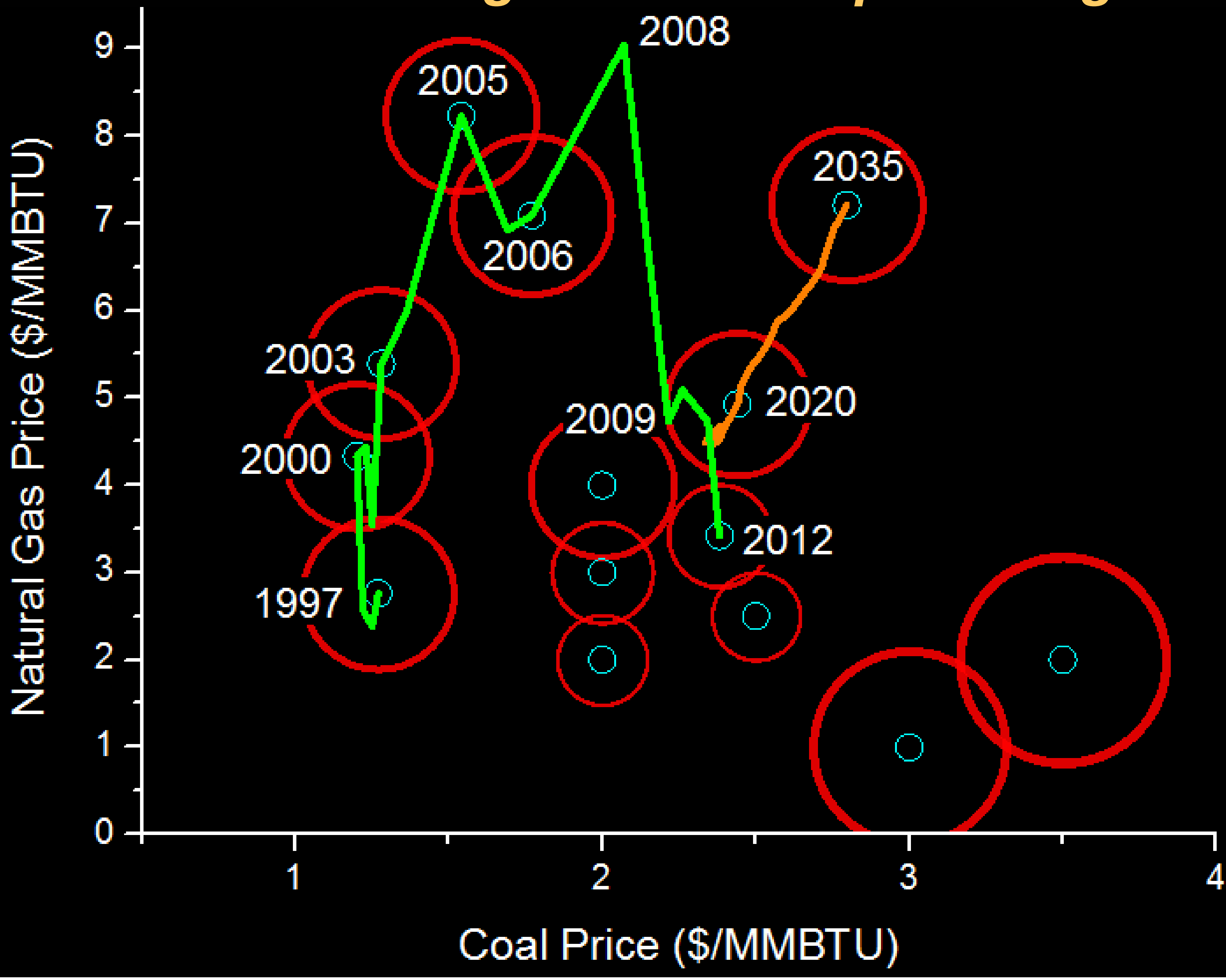
[Sanders, Blackhurst, and Webber 2013]

Natural Gas and Coal Prices Affect Water Withdrawals for Power Production



[Sanders, Blackhurst, and Webber 2013]

Fuel prices affect water withdrawals for power in a least marginal cost dispatch regime



Kelly T, Sanders
IEEE 2013 64
July 25, 2013

Energy and Water are Interrelated

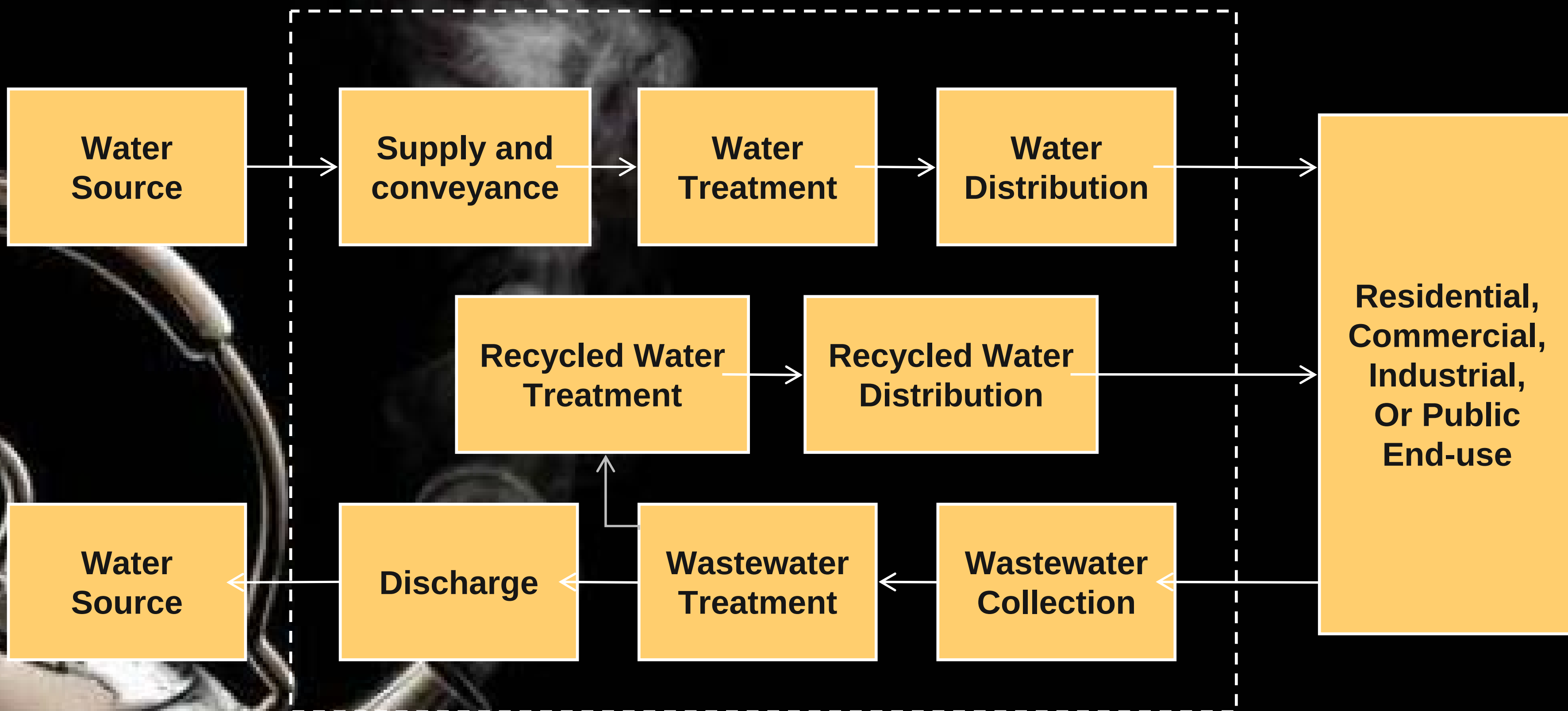
Water for Energy

- Water is required for:
  - Mining Fuels
  - Hydroelectric Power
  - Cooling Power Plants
- Water Quality vs. Water Quantity

Energy for Water

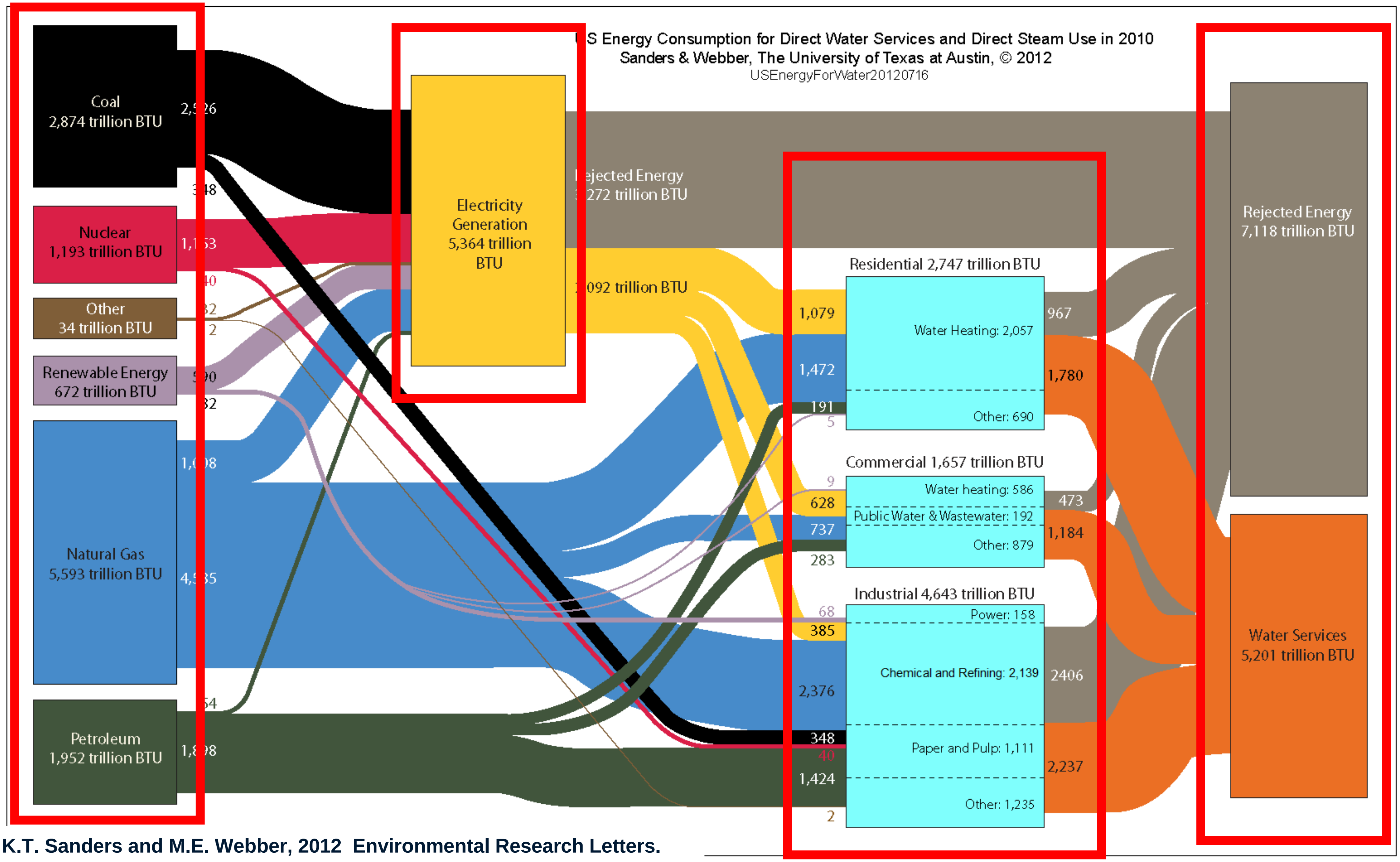
- Energy is required for:
  - Water Treatment
  - Water Pumping
  - Water Heating
  - Creating Steam for Industrial Processes

Water systems are composed of several stages with varying energy intensities



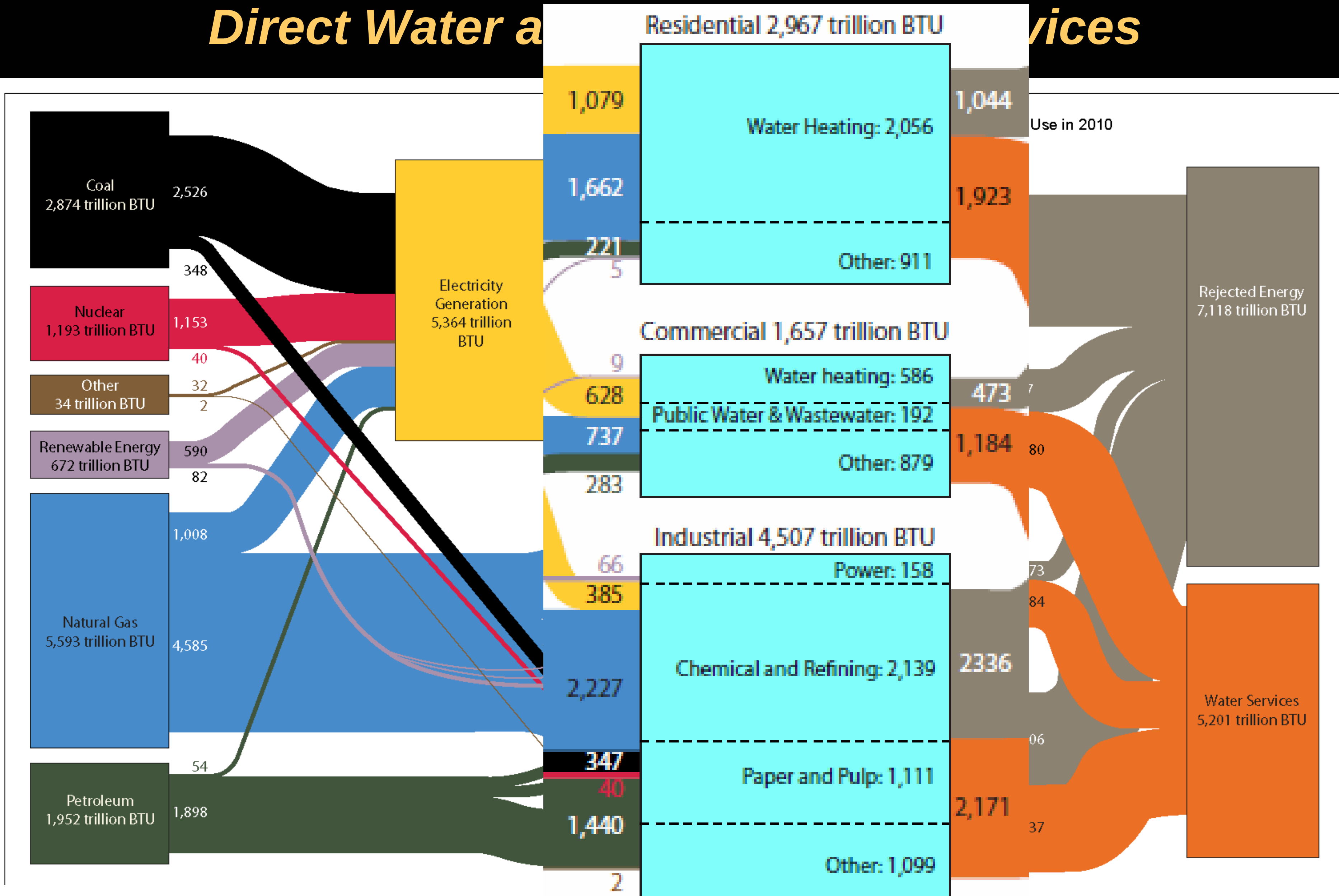
(Adapted from CEC2005)

~13% of US Energy Consumption (12.3 quads) is for Direct Water and Direct Steam Services



K.T. Sanders and M.E. Webber, 2012 Environmental Research Letters.

~13% of US Energy Consumption (12.3 quads) is for Direct Water a vices



K.T. Sanders and M.E. Webber, 2012 Environmental Resear

What do these numbers mean?

All US Water-related Energy

- 12.3 quads (12.6%)
  - ~40 million Americans
- 611 billion kWh (16.6%)
  - ~25% more electricity than for residential and commercial lighting

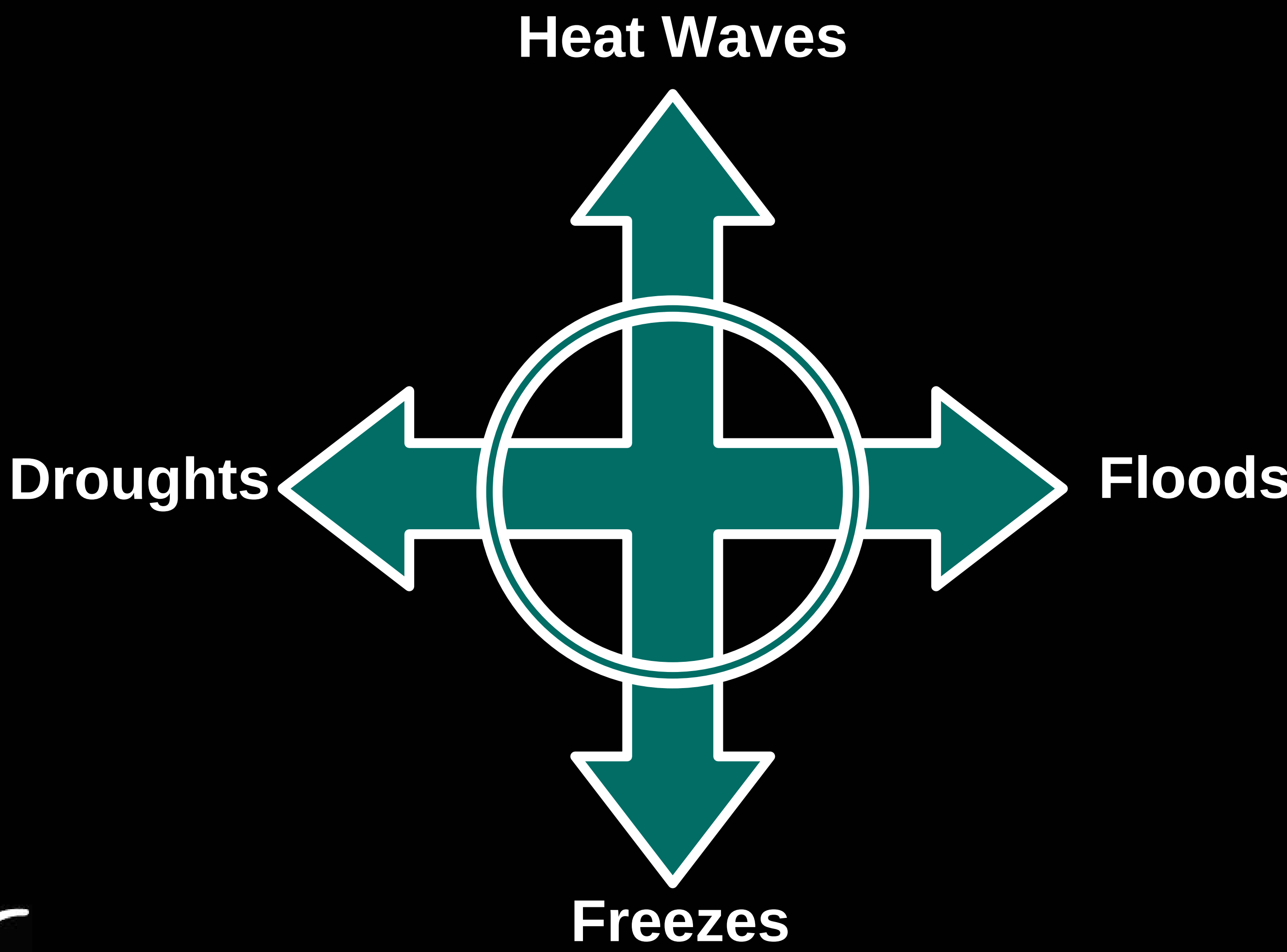
Energy for the Public Water Supply

- 4.4 quads (4.7%)
  - ~13 million Americans
- 228 billion kWh (6.2%)
  - ~ electricity for residential lighting

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

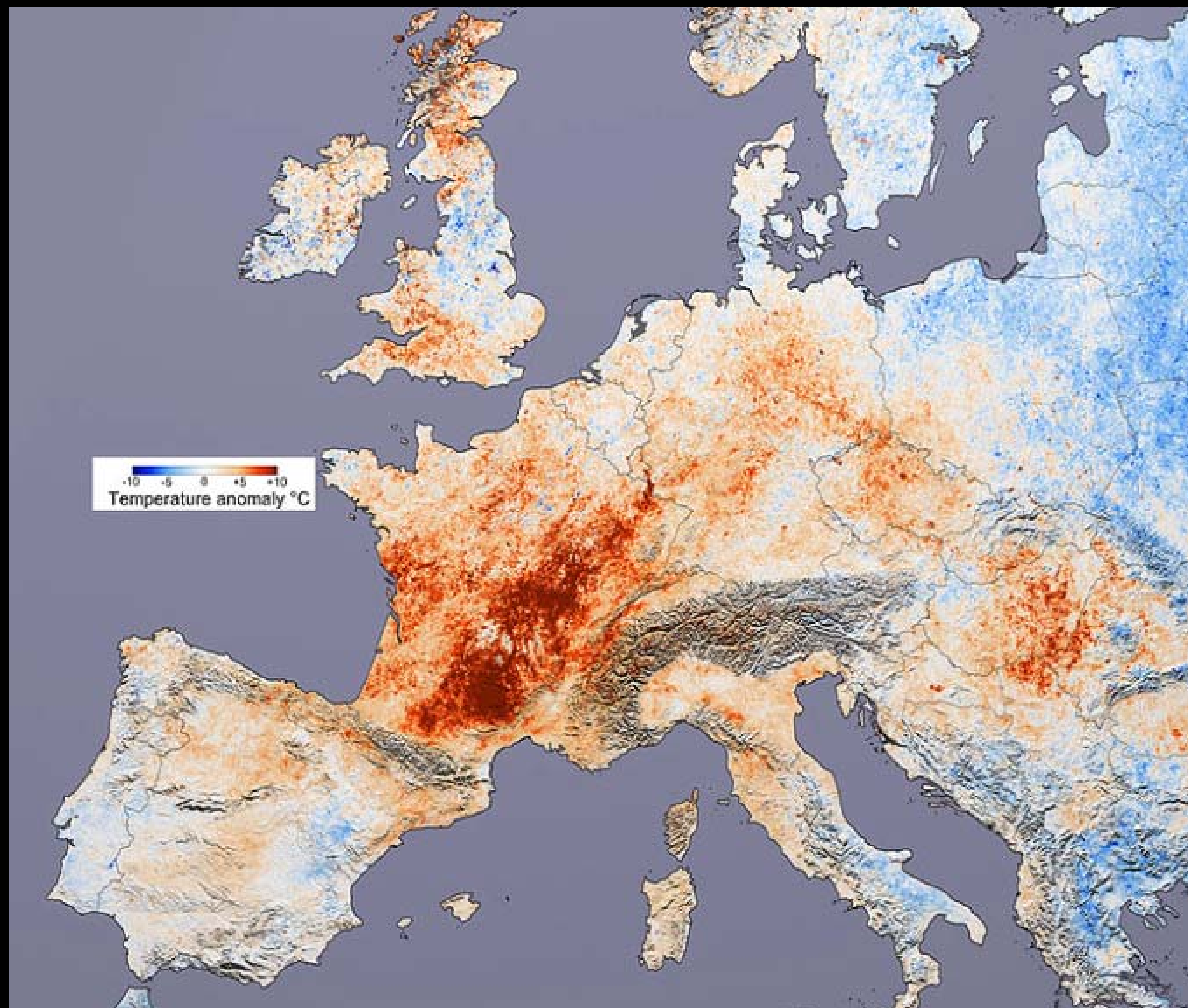
EPA rules govern power plant cooling

- **Clean Water Act §316(a)**
  - **Limits thermal pollution from discharge of heated cooling water**
  - **Aims to maintain a balanced aquatic ecosystem**
- **Clean Water Act §316(b)**
  - **Requires best technology available for intake structures**
  - **Aims to minimize environmental impact**

The 2003 European Heat Wave Caused Power Generators to Dial Back

Source: NASA (2003)

Snapshot of the European heat wave in 2003
-hottest summer on record in Europe since at least 1540
-Tens of thousands died



“Las Vegas Running Out of Water Means Dimming Los Angeles Lights”

Worst 10-year drought in recorded history

Hoover Dam provides electricity to 750,000 people in LA

Bloomberg.com, 2/26/09

A white "bathtub ring" on canyon walls at Lake Mead National Recreation Area in July shows mineral deposits left by higher levels of water near the Arizona Intake Towers at the Hoover Dam. (Ethan Miller, Getty Images)

- **“The surface of Lake Mead has dropped 100 feet in six years. If it drops 50 feet lower, Las Vegas could lose an intake that supplies 40 percent of its water. Simultaneously, "Hoover Dam stops generating electricity”**
  - ***Denver Post*, 1/29/2008**

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

Kelly T, Sanders
IEEE 2013 76
July 25, 2013

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

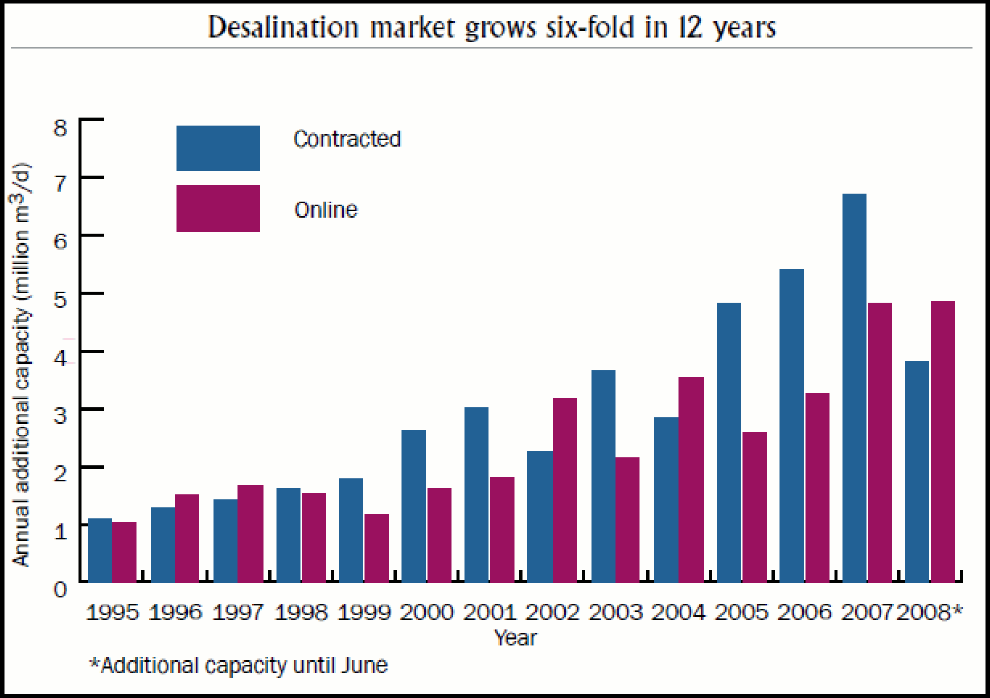
Trends Imply That Strain in the Energy-Water Relationship Will Be Exacerbated

Trends Imply That Strain in the Energy-Water Relationship Will Be Exacerbated

- **Population growth**
  - **drives up total demand for energy & water**
- **Economic growth**
  - **drives up per capita demand for energy & water**
    - **might be counteracted by efficiency**
- **Climate change: distorted rainfall, snowmelt, etc.**
- **Policy choices**
  - **movement towards energy-intensive water and water-intensive energy**

We Are Moving Towards More Energy-Intensive Water

- Stricter water/wastewater treatment standards
- Deep aquifer production
- Desalination
  - Worldwide capacity double by 2025
  - Middle East, London, San Diego, TX
- Long-haul pipelines and inter-basin transfer
  - China, India, Texas
- Desalination plus long-haul transfer



Global Water Intelligence, Vol 9, Issue 8 (August 2008)

The Future of Water for Energy is Not Clear

- **Some trends indicate more water-intensive energy**
  - **Nuclear power, Concentrating Solar Power (CSP), Carbon Capture and Sequestration (CCS), Hydraulic Fracturing**
  - **Future transportation fuels are especially thirsty**
    - **Electricity (2-3x worse)**
    - **Unconventional fossil fuels (2-4x worse)**
    - **Hydrogen (1-500x worse)**
    - **Biofuels (1-1000x worse)**

- **Some trends indicate more water-efficient energy**
  - **Wind, Solar PV, Natural Gas, Dry Cooling, etc.**

The Future of the Water-Energy Nexus is Not Clear

- Some trends indicate more **water-intensive** energy
  - Nuclear power, Concentrating Solar Power (CSP), Carbon Capture and Sequestration (CCS), Hydraulic Fracturing
  - Future transportation fuels are especially thirsty
    - Electricity (2-3x worse)
    - Unconventional fossil fuels (2-4x worse)
    - Hydrogen (1-500x worse)
    - Biofuels (1-1000x worse)

- Some trends indicate more **water-efficient** energy
  - Wind, Solar PV, Natural Gas, Dry Cooling, etc.

Section 316(b) of the Clean Water Act affects the cooling water intake structures at power plants

- **Requires that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact**

- **"No later than November 4, 2013, the EPA Administrator shall sign for publication in the Federal Register a notice of its final action pertaining to issuance of the requirements for implementing 316(b) of the CWA at existing facilities." EPA, 6/27/2013**

Environmental Objectives Often Conflict

- **Nuclear, CSP, CCS, and Geothermal:**
  - **low emissions**
  - **high water use**

- **PV and Wind:**
  - **low emissions and low water systems**
  - **trade-offs in reliability**

- **Open-loop cooled power plants:**
  - **low water consumption**
  - **high water withdrawals; raise environmental concerns**

- **Dry-cooling systems:**
  - **low water use**
  - **reduced plant efficiency (i.e. higher energy and emissions)**

Take-away: Energy production and water production require multi-faceted modes of evaluation

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

Kelly T. Sanders

NSF Research Fellow
The University of Texas at Austin
Department of Civil, Architectural, and Environmental Engineering

Assistant Professor (Starting January 2014)
Sonny Astani Department of Civil and Environmental Engineering
University of Southern California

ktsanders@usc.edu

Panelist 4

Ms Lorraine White

In Absentia

(Mike Hightower, presenting)

Handout available

Water-Energy Program Manager
GEI Consultants, Inc.
2868 Prospect Park, Suite 400
Rancho Cordova, CA 95670
(916) 631-4540 - office (916) 990-2410 - cell

lwhite@geiconsultants.com

Presented By:

Lorraine White

Water and Energy

Essential, Interdependent Commodities and Strategies

Institute of Electrical and Electronic Engineers

Power & Energy Society General Meeting

Vancouver, BC

21-25 July 2013

GEI Consultants

Getting Beyond “BAU” …

GEI Consultants

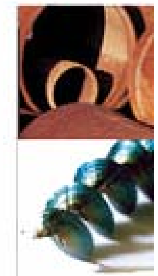
- New policy frameworks
  - Systems and Integrated Approaches to Resource Management
- New metrics & tools for efficiency programs
  - Water-Energy-Carbon Calculators that help optimize decisions
- Creating pathways to the Utilities of the Future
  - Distributed resources & infrastructure
- New technologies
  - That save both water and energy
  - Address key environmental constraints
- Cost-effective Retrofits & Upgrades
  - Much of our existing infrastructure is in Crisis

Water-Energy Policies

- 2003 IEPR - Power Generation
  - Non-fresh Supplies or Alternatives
  - ZLD
- 2005 IEPR – System and End Use Conservation and Efficiency
  - Saving Water Saves Energy
  - Reduce Peak Demand
  - Renewable and Self-Generation
- 2007 IEPR – Tools and Implementation
  - EM&V

Alliance for Water Efficiency & ACEEE's Successful Engagement

WATER-ENERGY RESEARCH WORK GROUP



Water-Energy Research Work Group

- More than 70 Individuals
- All Sides of the Water-Energy Nexus:
  - Water & power utilities;
  - Public works and county agencies;
  - Universities and academics
  - Private and public research groups;
  - Local, state, federal, and international agencies;
  - Climate and resource advocate groups;
  - Industry and consulting firms.

W-E Research Roadmap & Work Group

- *Water-Energy Nexus Research:*
  - *Recommendations for Future Opportunities*
- W-E Nexus Research Database
- Active Exchange of Information, Results and Ideas

http://www.allianceforwaterefficiency.org/Water-Energy-Research-Group.aspx

W-E Nexus Research Recommendations

1. Develop comprehensive studies and associated guidelines to conduct a detailed audit of embedded energy demands for an entire local, regional or national water/wastewater system for the purposes of determining system optimization.

2. Assess technical and economic energy efficiency and demand response potential in water and wastewater systems and develop industry accepted guidelines for such studies on individual systems.

3. Identify and eliminate regulatory barriers to co-implementation of efficiency programs in the water and energy sectors.

Recommendations (cont.)

4. Develop water AND energy industry accepted Evaluation, Measurement and Verification (EM&V) protocols for use in efficiency programs.

5. Develop industry standards, protocols and successful business models for advanced biogas development programs and net zero facilities at wastewater treatment plants.

6. Conduct landscape irrigation equipment efficiency potential studies that can support establishment of efficiency standards.

7. Identify rate structures, price constructs, and financing mechanisms that eliminate the financial disincentives of efficiency programs and alternative water supply use in the water sector.

Recommendations (cont.)

8. Evaluate technologies and practices that can reduce the energy demand of desalination and lower its costs.

9. Continue investigations into the water energy trade-offs of differing resource development and management choices that can better inform multi-sectorial integrated resource planning.

10. Develop technologies and protocols that can increase water use efficiency and reuse, support water supply switching, and reduce water quality impacts of power generation facilities and other energy fuels development.

Recommendations (cont.)

11. Assess potential impacts to water supplies and quality of energy resource development, such as fracturing for natural gas and biofuels development; identify methods, practices and technologies that reduce or eliminate these impacts.

12. Supply chain and product embedded water-energy evaluations that can inform consumers of the energy and water intensity of the products or services they buy.

Recommendations (cont.)

13. Identify effective methods, forums, practices and other mechanisms for communication and engagement by the research and policy communities with practitioners and adopters to ensure commercialization and adoption of preferred research results and technological developments that maximize acceptance and application in the marketplace and public service industry.

A Role for Everyone…

Barriers	Challenges	Opportunities	Key Stakeholders
Institutional	•Single resource & entity perspective; decades of thinking to be un-done: •Jurisdictional & regulatory "buckets" inhibit cross-cutting programs	New policies, programs & practices that enable cross-cutting programs and measures; e.g.: •Optimize water & energy efficiency together •Strive for sustainable water & energy resources with zero net energy and carbon •Allow cross-subsidization where beneficial to achieve incremental benefits •Provide regulatory pathways to the utilities of the future	•Policymakers, regulators, legislators •Water & wastewater agencies •Energy Utilities •Water & energy customers •Environmental & sustainability advocates [<u>Note:</u> *challenges & opportunities different for IOUs vs. POUs*]
Data, Tools & Methods	•Insufficient data of the types & forms needed to effectively evaluate tradeoffs •Tools & methods not sufficient	Data & analytical methods, models & tools that enable optimizing multiple resource, economic and environmental goals on a fully integrated basis	•Regulators •Water & energy sectors •Academia •Researchers •Developers of data systems & solutions (SCADA & other)
Economic	•Significant disparity between prices of water vs. energy •Regional & agency specific tradeoffs vary significantly	•Elevate public purpose goals (e.g., evaluate "marginal supplies" on a more macro basis) •Decouple revenues from earnings (much harder for publicly owned utilities) •Special purpose investment funds (e.g., "public benefit")	•Water & wastewater agencies •Energy utilities •Their regulators & constituents
Technology	•Water & energy need each other, both in production and in use; but technology development efforts often not synchronized	•Prioritize RD&D investments that yield multiple value streams •Multi-sector investments & incentives	•Federal & state agencies and industry associations that establish standards •Technology developers, equipment manufacturers, venture capitalists •Regulators, water agencies, utilities (that incentivize efficiency)
Information	•Awareness is key to change, but building & communication of knowledge has been slow	•More collaboration across multiple sectors •More sharing of information & insights •More education & awareness: policymakers & regulators, market participants, consumers & constituents	•All of the above

GEI Consultants

GEI Consultants

"Anyone who can solve the problems of water will be worthy of two Nobel Prizes – one for peace and one for science."

John F. Kennedy

To continue the dialogue, contact:

Lorraine White
Water-Energy Program Manager
916.631.4540 cell: 916.990-2410
lwhite@geiconsultants.com

GEI Consultants, Inc.
2868 Prospect Park, Ste. 400
Rancho Cordova, CA 95670
916.631.4500 fax: 916.631.4501
www.geiconsultants.com

Panelist 5

Ron Faibish

In absentia: personal opinion

(Bill Leighty, presenting)

- Principal Chemical and Nuclear Engineer, Argonne National Laboratory
- Science Fellow, U.S. Senate Committee on Energy and Natural Resources

The Energy-Water Nexus: Federal Interests

Ron Faibish, Ph.D.
Science Fellow
U.S. Senate Energy & Natural Resources Committee
July 25, 2013

Senate ENR Committee Growing Interest

- Visibly growing interest by Congress and specifically the Senate Energy and Natural Resources (ENR) Committee in this topic
- Senate is planning potential legislation
- Addressing the energy-water nexus along six key areas:
  1. Water in power production;
  2. Energy for water treatment and transport;
  3. Water and fuels;
  4. Modeling and simulation;
  5. Data sharing and needs,
  6. Availability

•

What can Congress potentially do?

Provide federal leadership in creating (via legislation) a national platform for info exchange

- Establish a "clearing house" or some type of an energy-water nexus center
- Specific goals:
  - Information exchange on a national and international level
  - Identification of best practices and possible incentives to employ these
  - Identification of R&D gaps and possible demonstration projects
  - Encourage and facilitate constructive collaboration across agency boundaries between federal, state and local agencies.
  - Facilitate optimal interaction between public and private sectors: ALL STAKEHOLDERS NEED TO BE INCLUDED: government, industry, utilities, academia, trade organizations.
  - Identify funding gaps and potential funding sources (preferably existing funds) to enable a meaningful progress in this area

Actions to Date

- Two roundtables on energy-water nexus in July ‘13
  - o NGO roundtable: trade organizations, industry, academia, National Academies, national labs
  - o Gov’t roundtable: federal, state , local agencies and public utilities
- All agree that this must be addressed as a high priority item
- All agree that actions can be taken by Congress to facilitate better and more constructive interaction between all stakeholders
- The links between energy, water and land/food were highlighted
- Agencies not traditionally thought of as part of the energy-water were recognized (e.g., USDA)
- Additional actions are expected throughout the year leading up to possible legislation
- A real push and will to do this !

Panelist 5

Ron Faibish

Ron_Faibish@energy.senate.gov
(202) 224-5523

- Principal Chemical and Nuclear Engineer, Argonne National Laboratory
- Science Fellow, U.S. Senate Committee on Energy and Natural Resources

Panelist 6

Bill Leighty

Director, The Leighty Foundation

Juneau, AK

wleighty@earthlink.net

www.leightyfoundation.org/php

Mendenhall Glacier, Juneau, AK

June '71

Mendenhall Glacier, Juneau, AK
10 October 10

Mendenhall Glacier, Juneau, AK
10 October 10

Rapid climate change

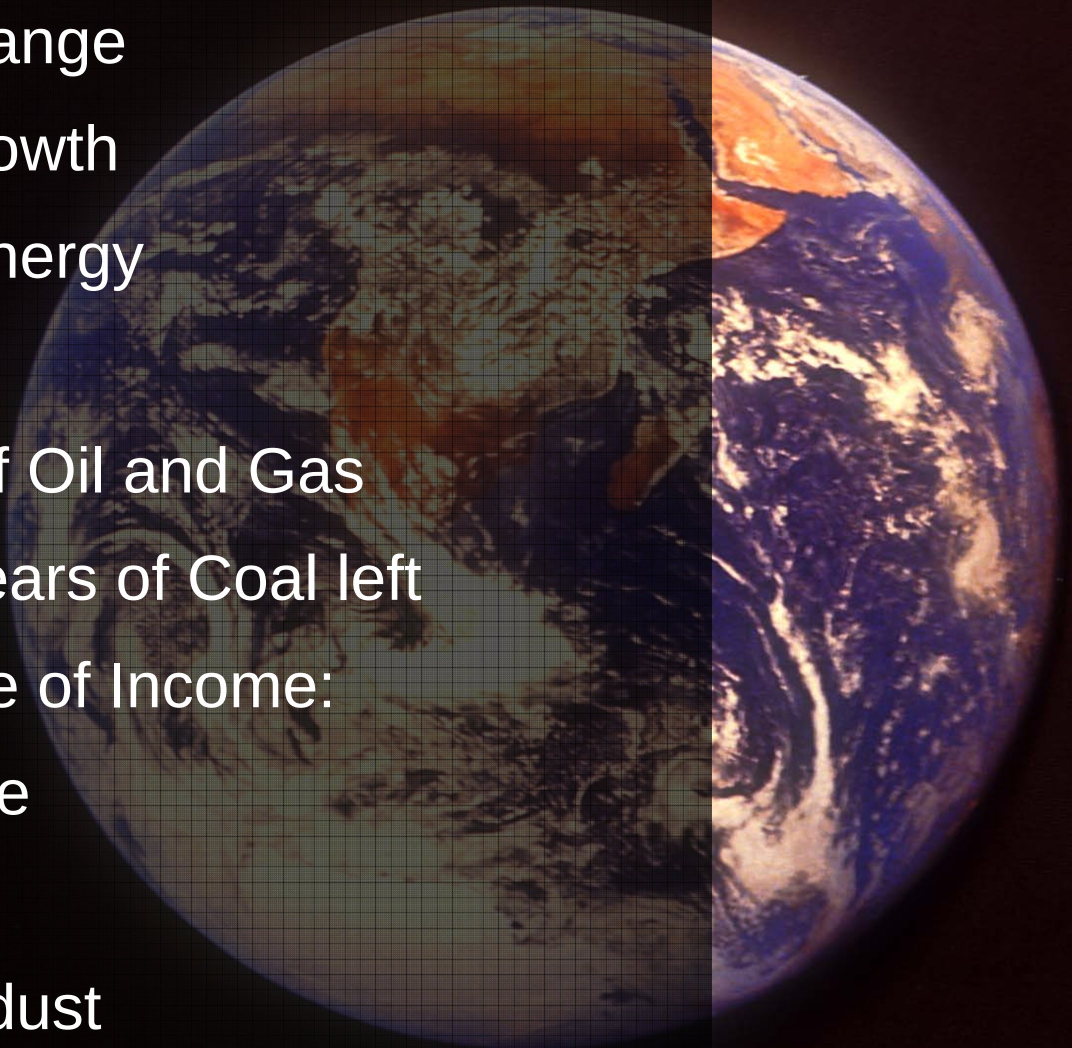
Spruce bark beetle kill, Alaska

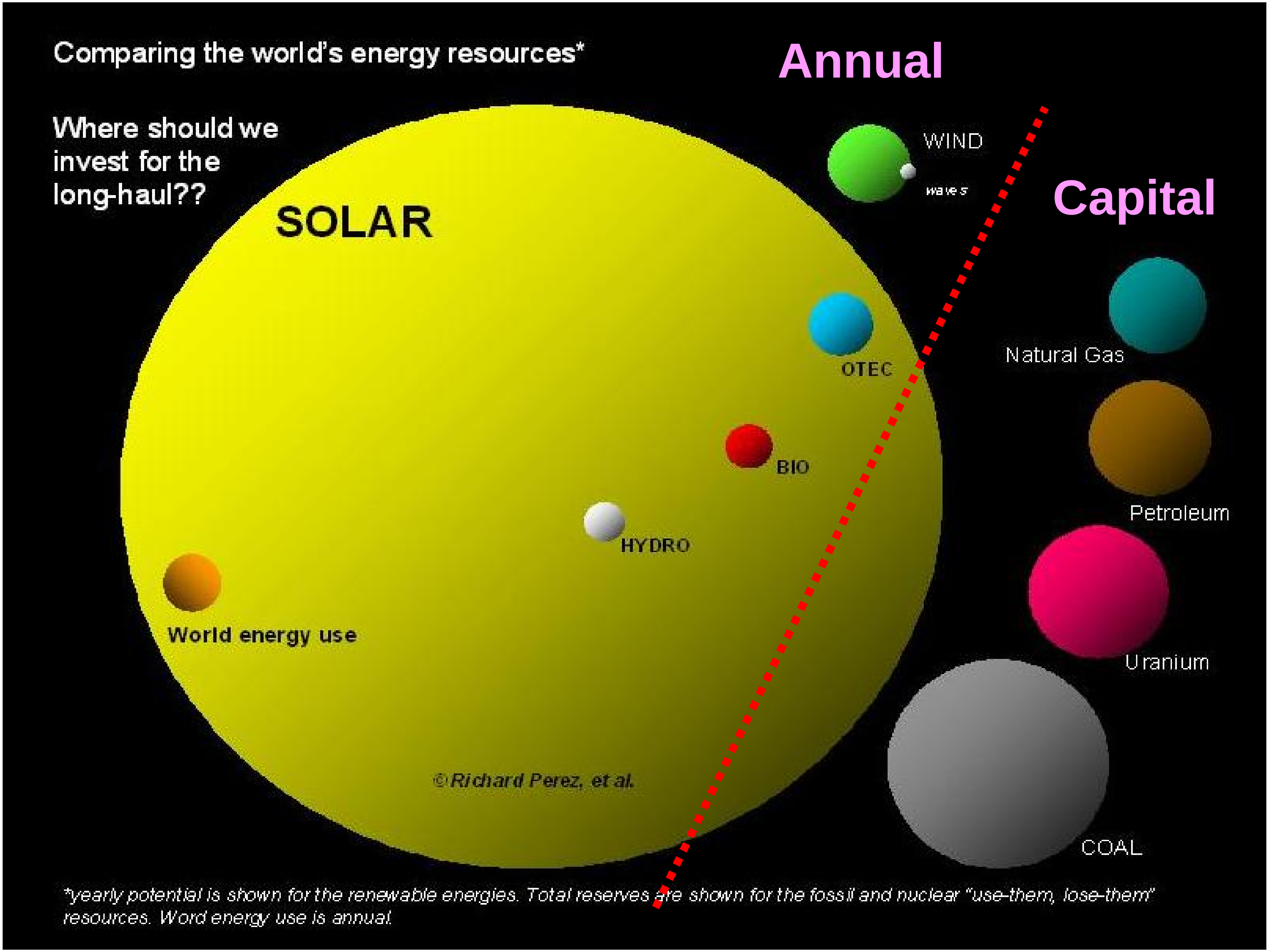
Shishmaref, Alaska

Winter storms coastal erosion

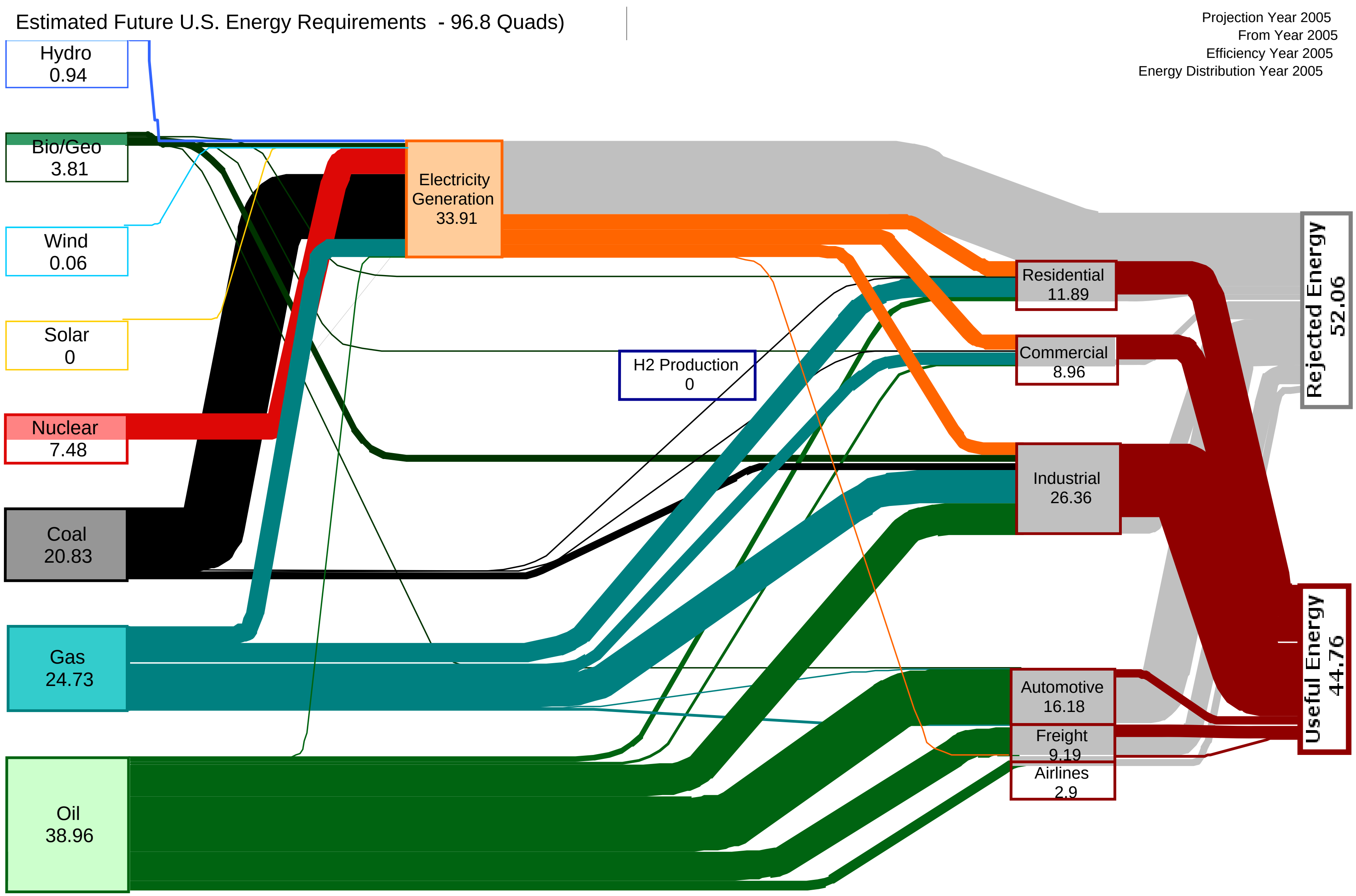
MUST Run the World on Renewables – plus Nuclear ?

- Climate Change
- Demand growth
- Water for energy
- War
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
    - Sunshine
    - Tides
    - Meteor dust
- Spend our capital ?

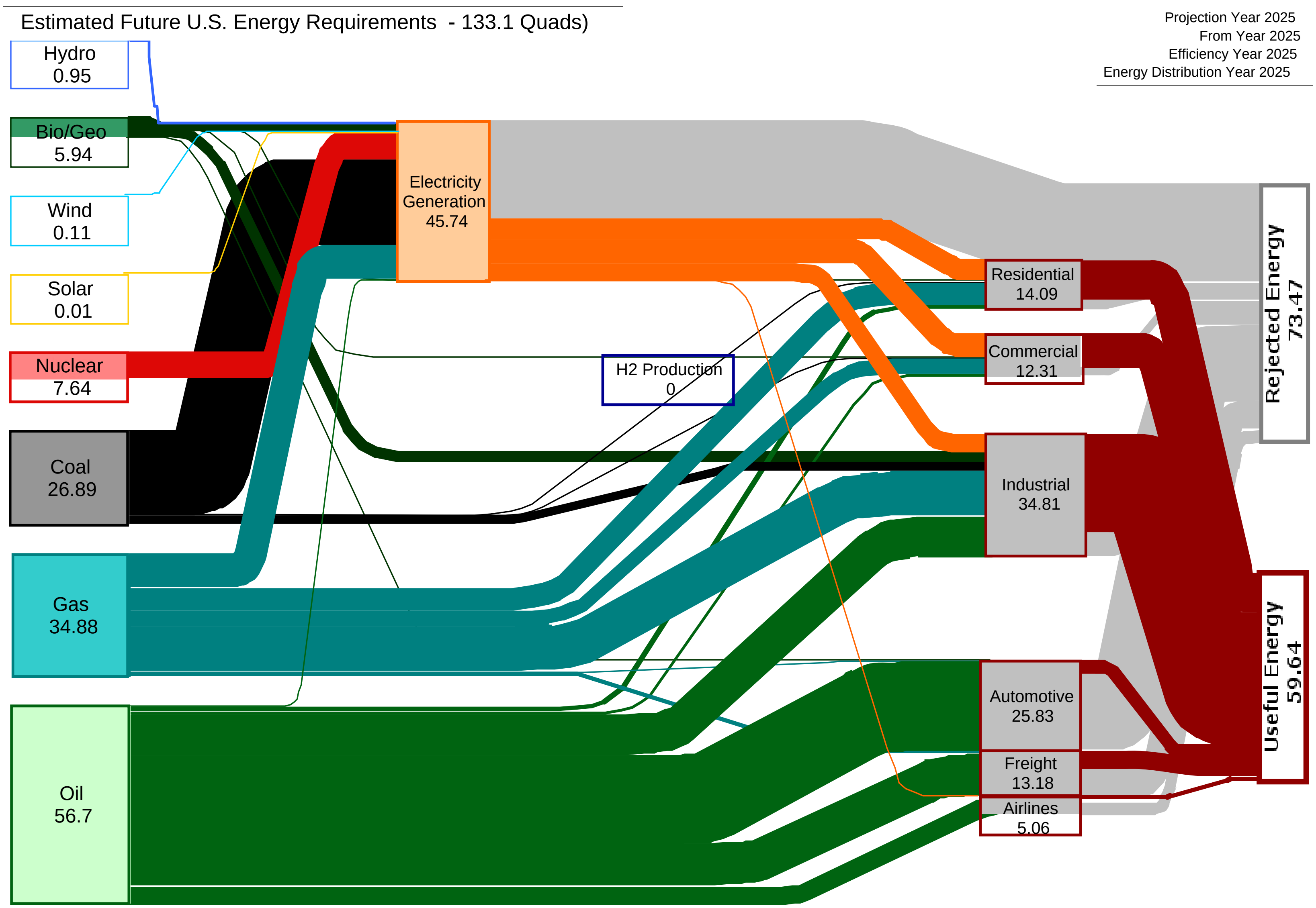


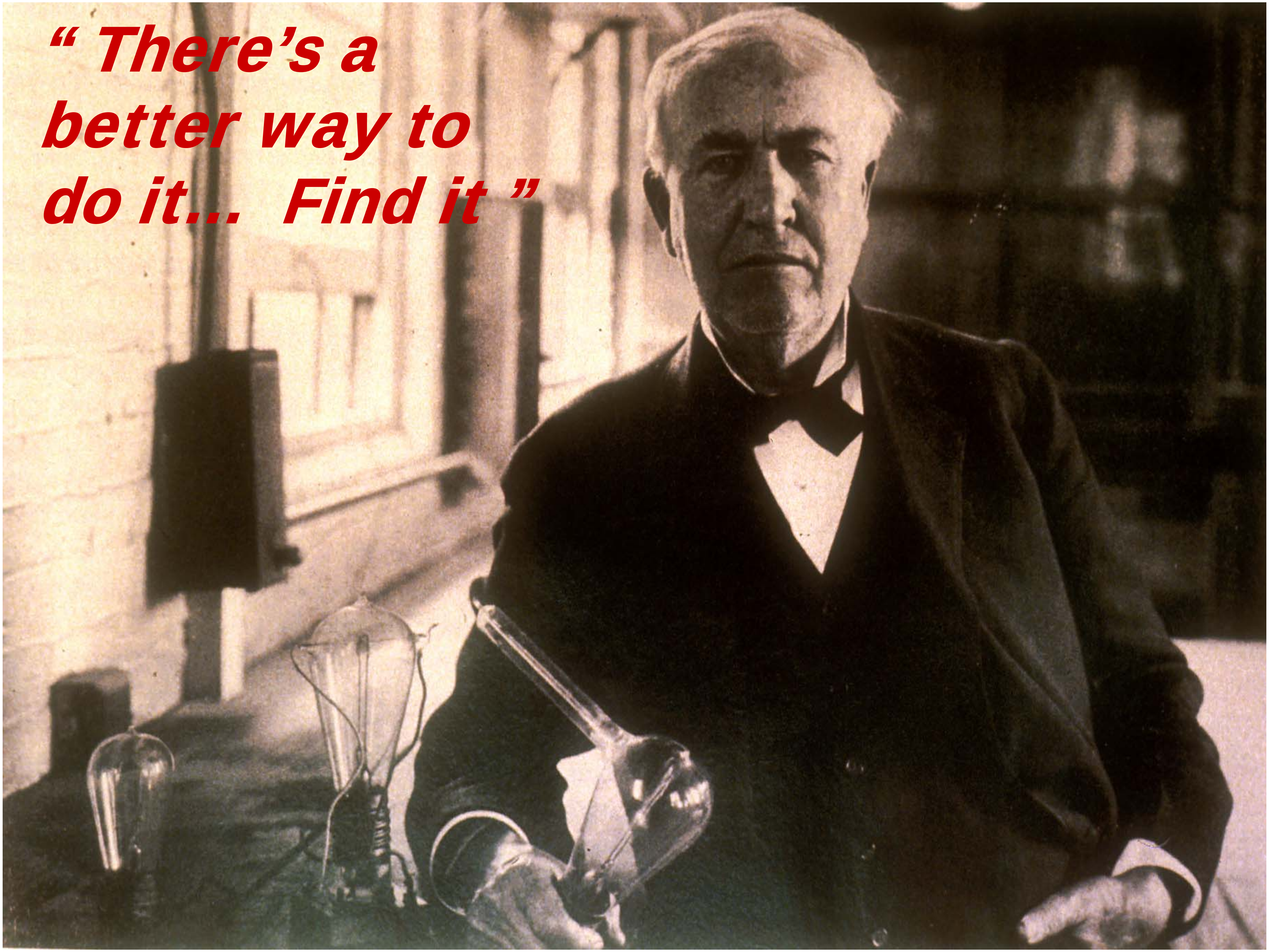

Comparing the world's energy resources*
Annual
Where should we invest for the long-haul??
SOLAR
WIND
waves
Capital
Natural Gas
OTEC
BIO
Petroleum
HYDRO
World energy use
Uranium
© Richard Perez, et al.
COAL
*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them" resources. Word energy use is annual.

DOE-EIA: 2005 estimated US annual energy:
~ 100 quads = 100 TWh



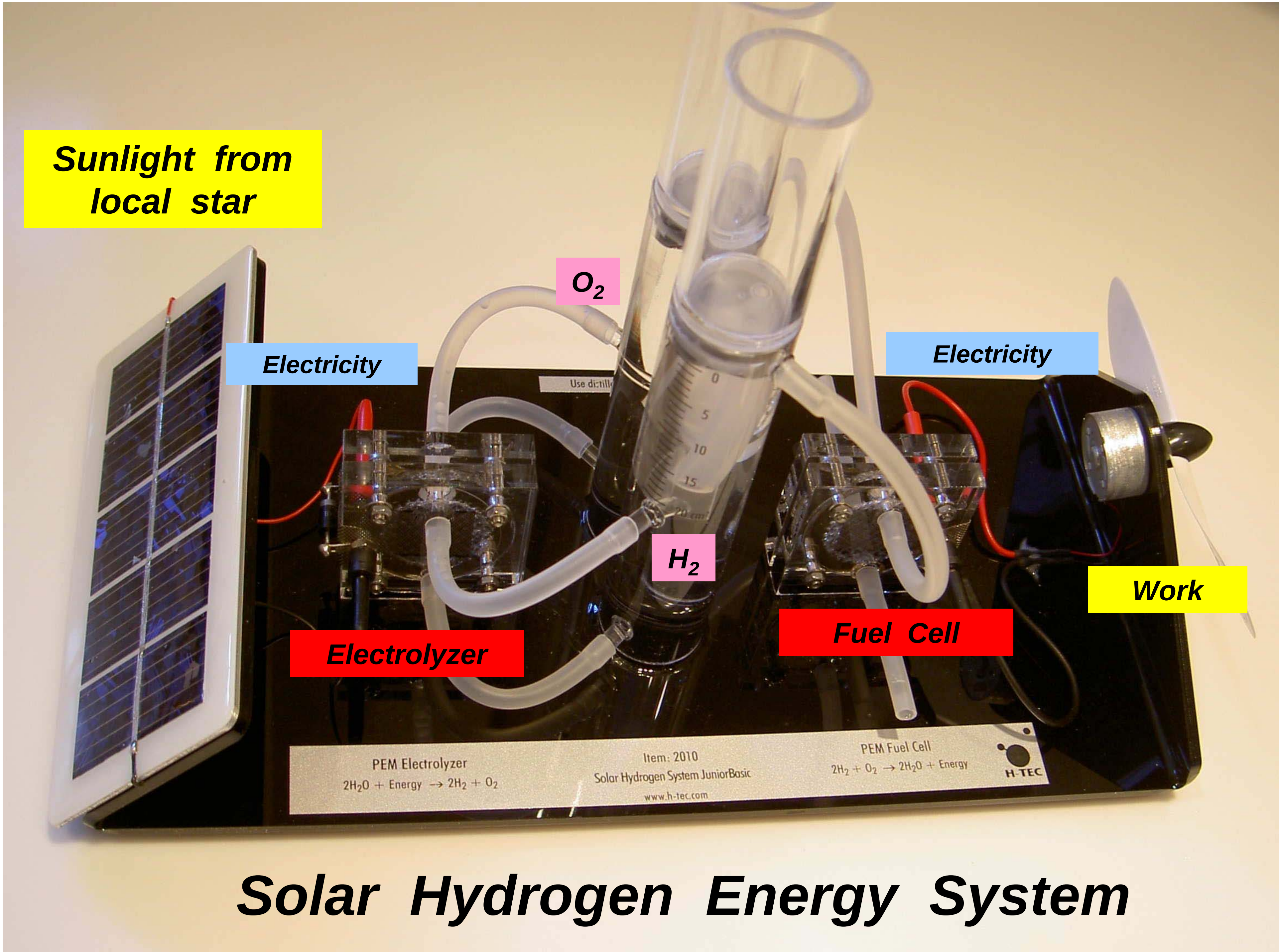
EIA estimated 2025 annual energy:
~ 130 quads = 130 TWh

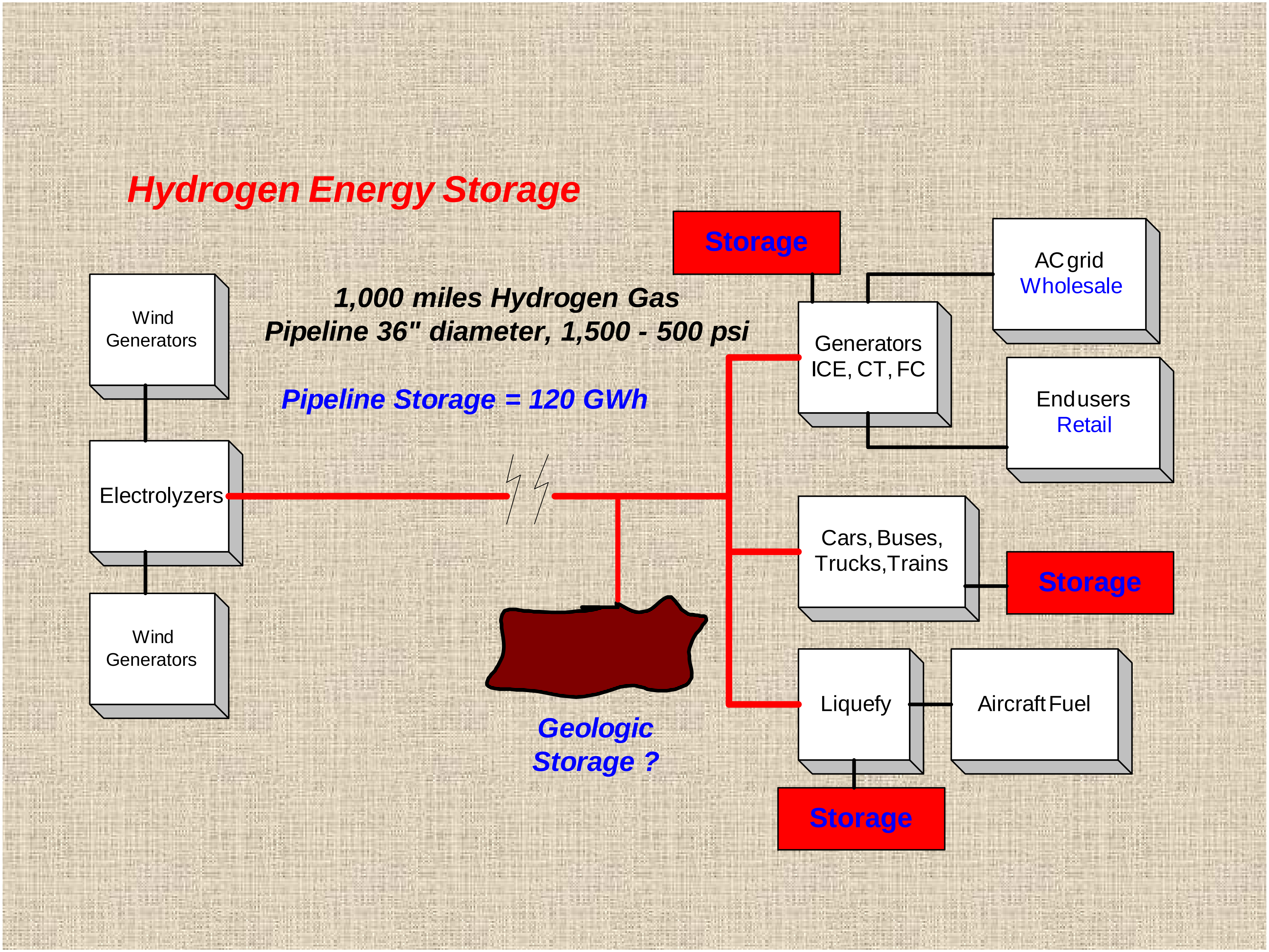



“ There’s a better way to do it… Find it ”

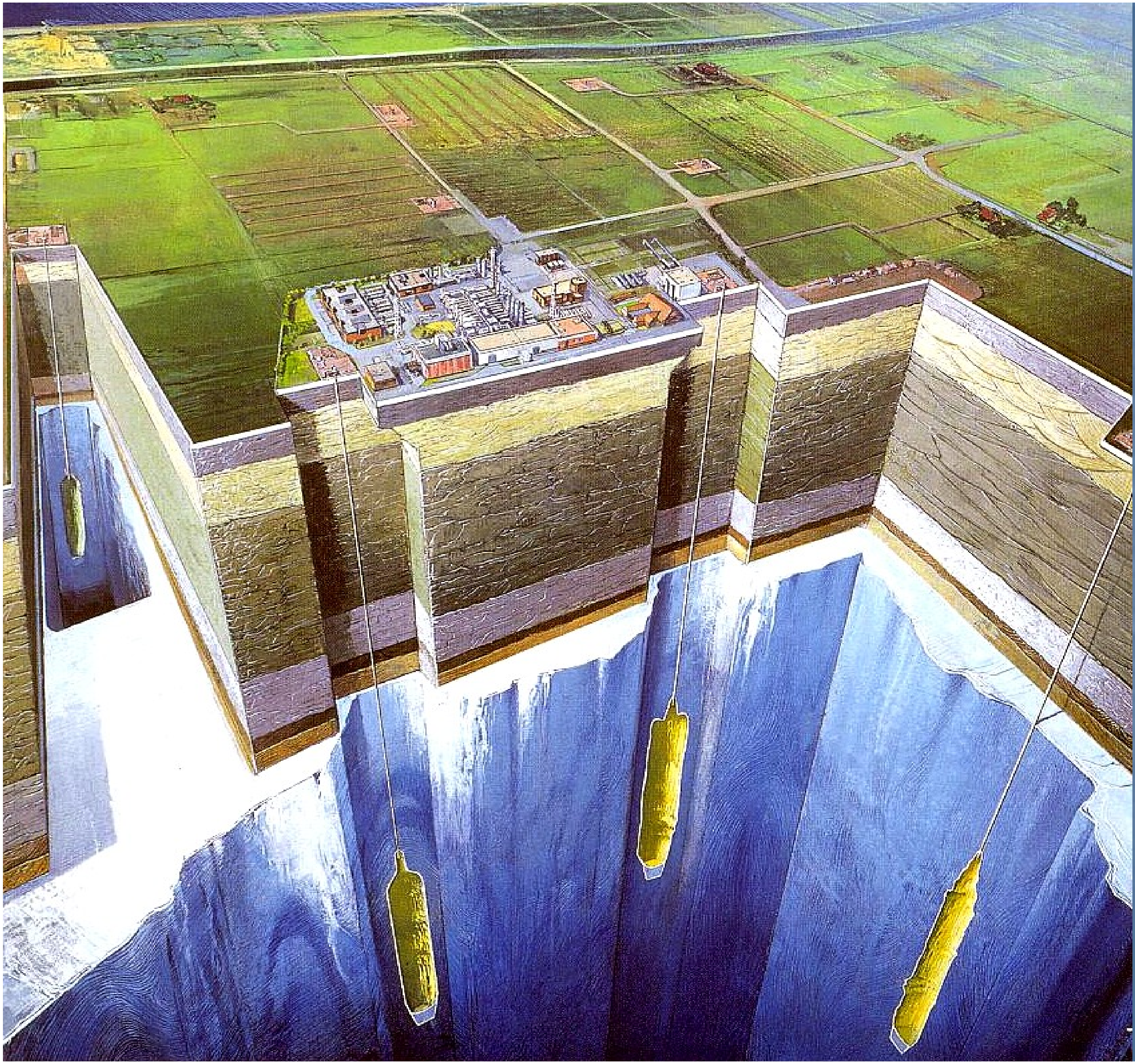
Beyond "Smart Grid"

- **Primarily DSM**
- **More vulnerable to cyberattack ?**
- **Adds no physical:**
  - **Transmission, gathering, distribution**
  - **Storage**
- **Next big thing; panacea**
- **Running the world on renewables ?**
- **Must think:**
  - **Beyond electricity**
  - **Complete renewable energy systems**
  - **ALL energy: Hermann Scheer, Bundestag**


Sunlight from local star
Electricity
O_2
H_2
Electricity
Work
Electrolyzer
Fuel Cell
PEM Electrolyzer
$2H_2O$ + Energy → $2H_2 + O_2$
Item: 2010
Solar Hydrogen System JuniorBasic
www.h-tec.com
PEM Fuel Cell
$2H_2 + O_2$ → $2H_2O$ + Energy
H-TEC
Solar Hydrogen Energy System



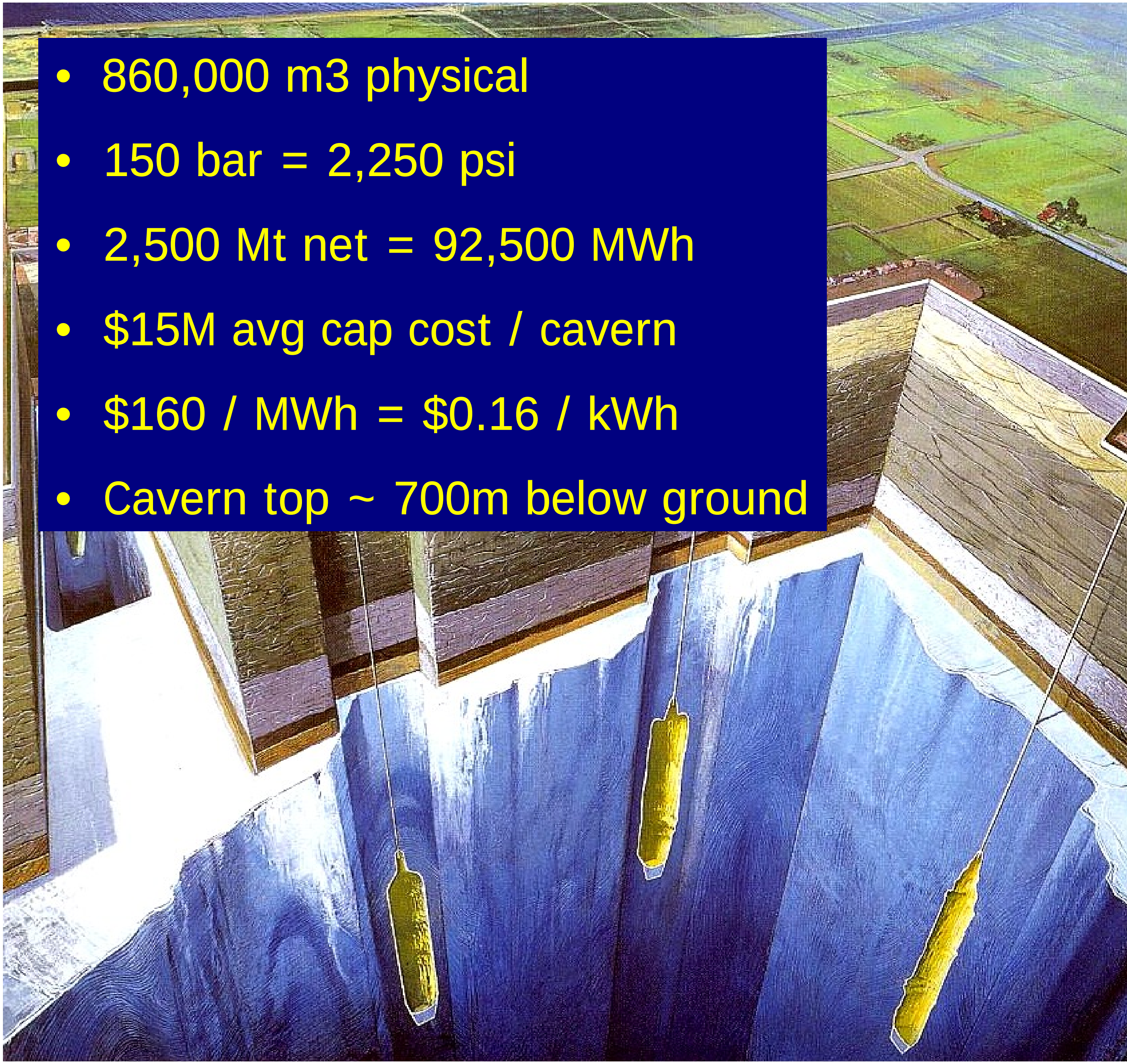
Hydrogen Energy Storage
Wind Generators
Electrolyzers
Wind Generators
1,000 miles Hydrogen Gas
Pipeline 36" diameter, 1,500 - 500 psi
Pipeline Storage = 120 GWh
Geologic Storage ?
Storage
Generators ICE, CT, FC
AC grid Wholesale
Endusers Retail
Cars, Buses, Trucks, Trains
Storage
Liquefy
Aircraft Fuel
Storage



Domal Salt Storage Caverns

PB ESS

Domal Salt Storage Caverns

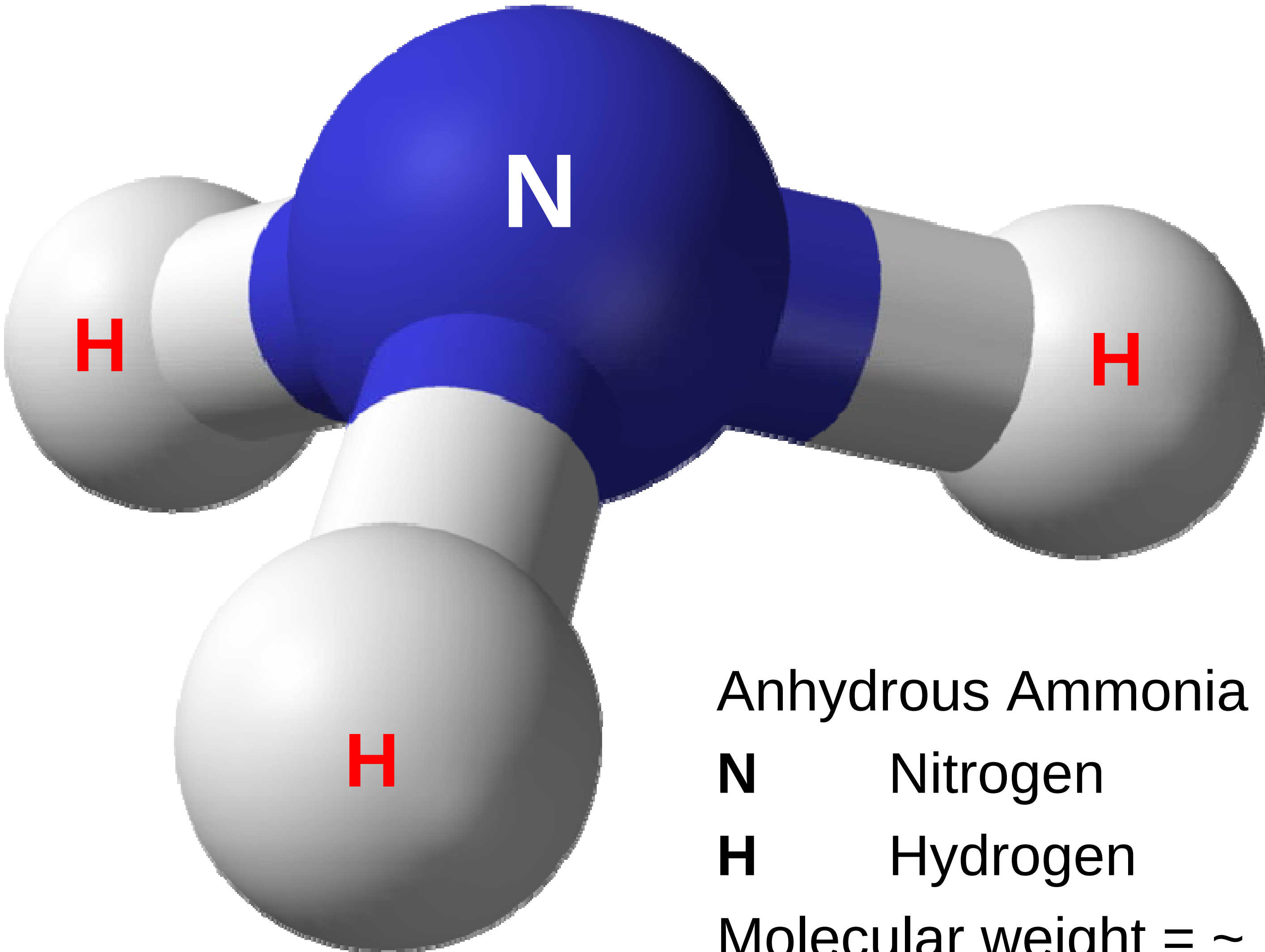


- 860,000 m3 physical
- 150 bar = 2,250 psi
- 2,500 Mt net = 92,500 MWh
- $15M avg cap cost / cavern
- $160 / MWh = $0.16 / kWh
- Cavern top ~ 700m below ground

Texas

"Clemens Terminal" Conoco Phillips 20 years

Praxair '07



Anhydrous Ammonia **NH_3**

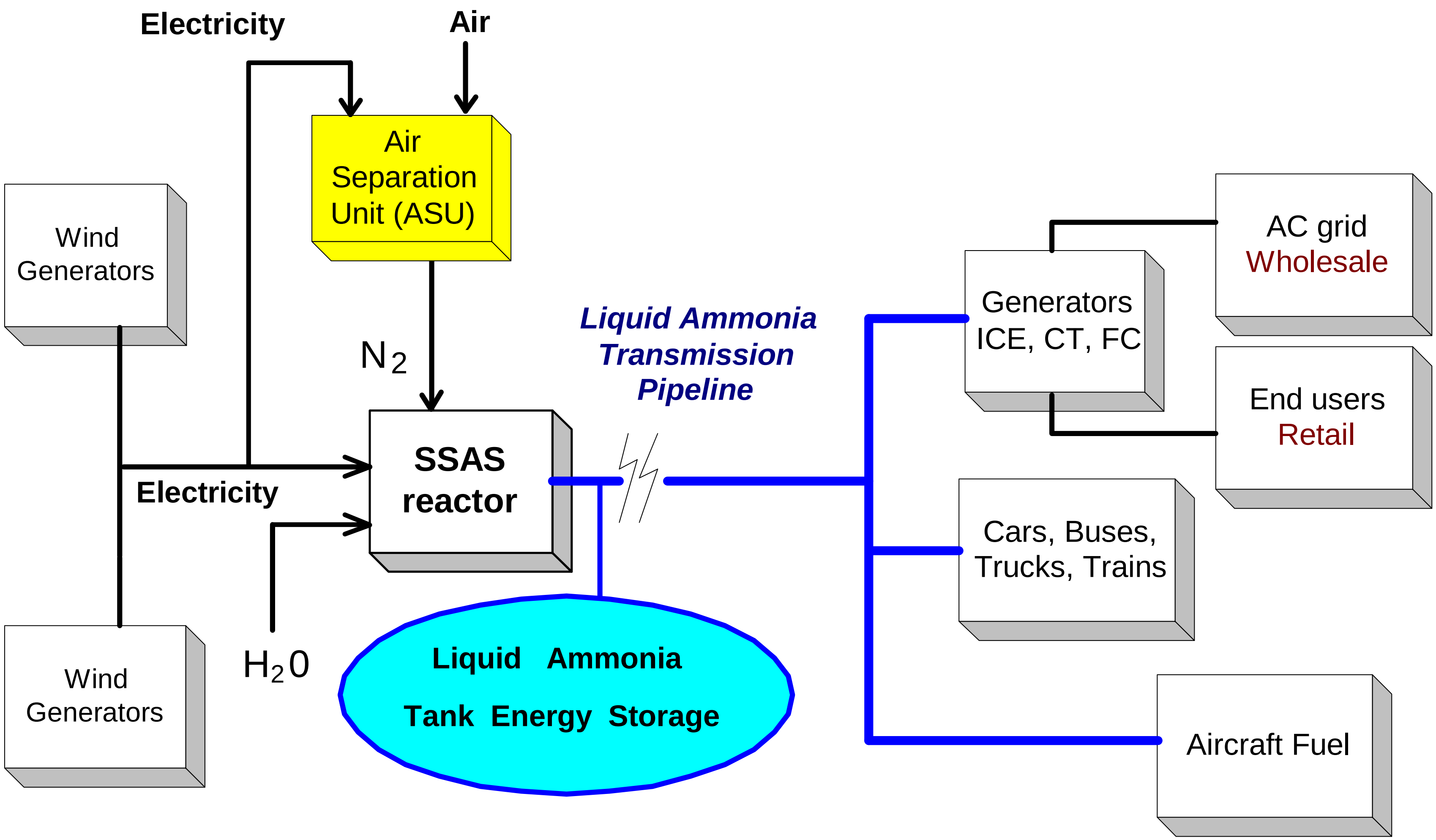
N Nitrogen

H Hydrogen

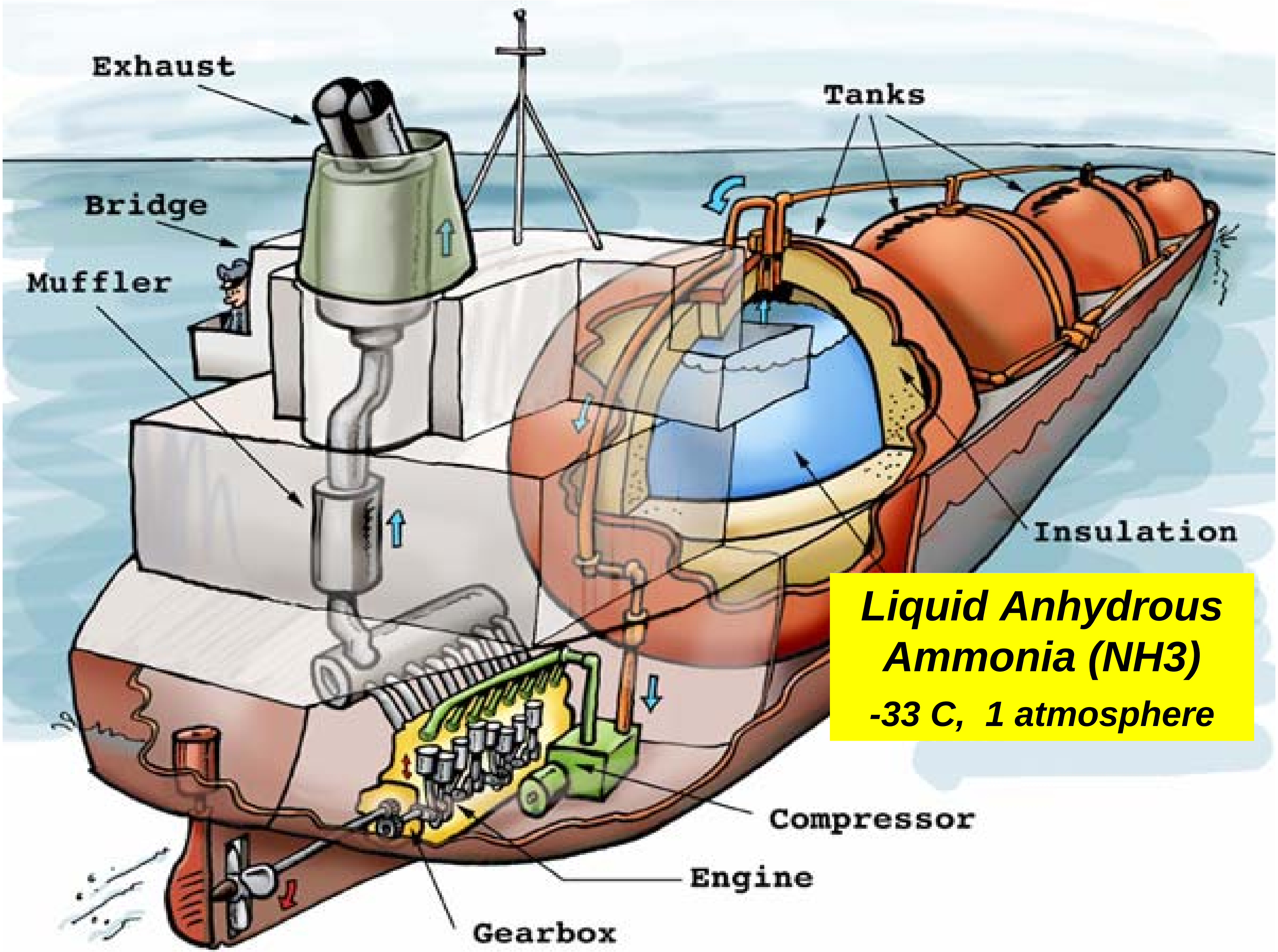
Molecular weight = ~ 17

18% **H** by weight: "other hydrogen"

$NH_3 + O_2 = N_2 + H_2O$

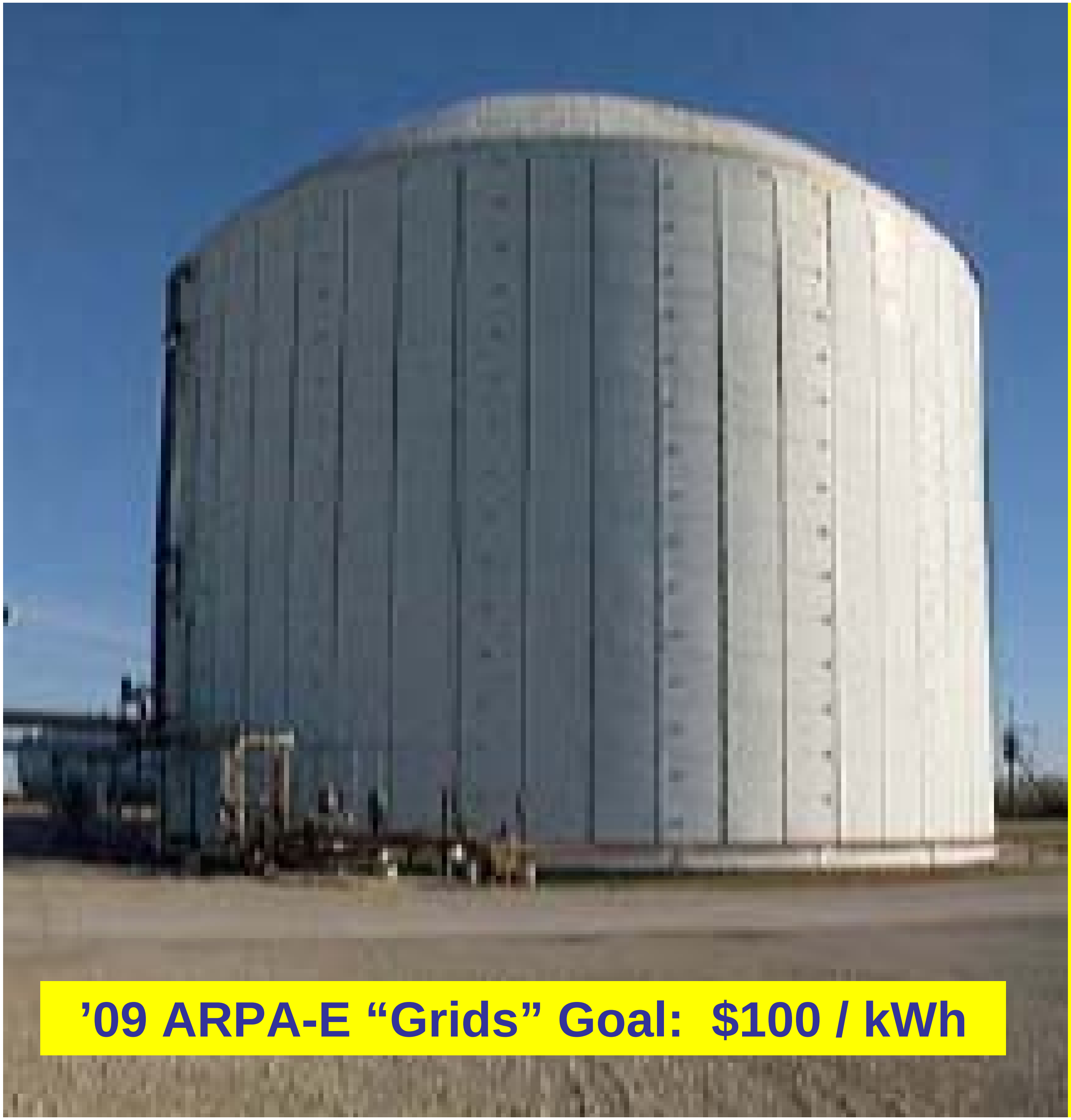


Solid State Ammonia Synthesis (SSAS)



Liquid Anhydrous Ammonia (NH_3)

-33 C, 1 atmosphere



'09 ARPA-E "Grids" Goal: $100 / kWh

"Atmospheric" Liquid Ammonia Storage Tank (corn belt)

30,000 Tons

190 GWh

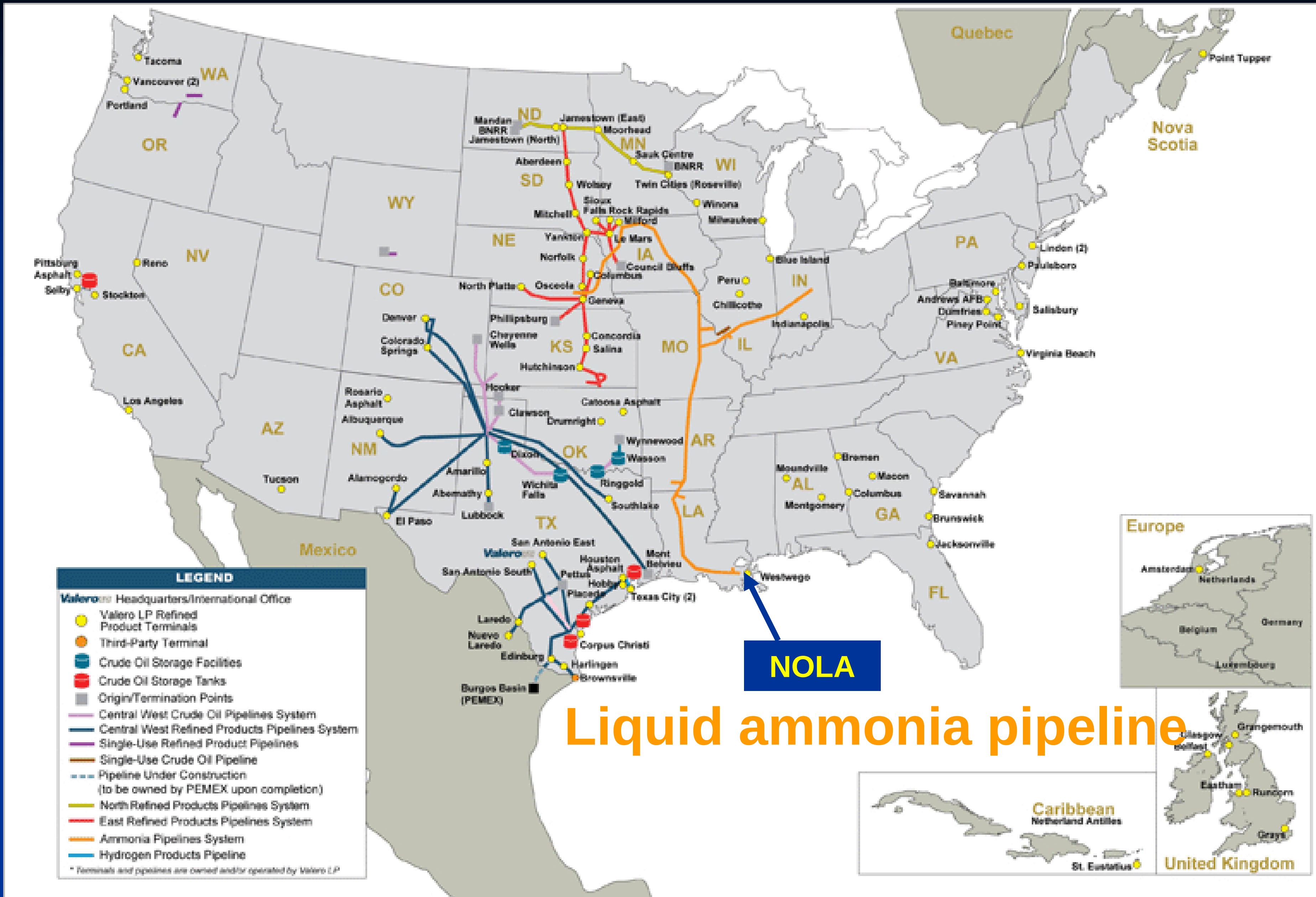
$ 15M turnkey

$ 80 / MWh

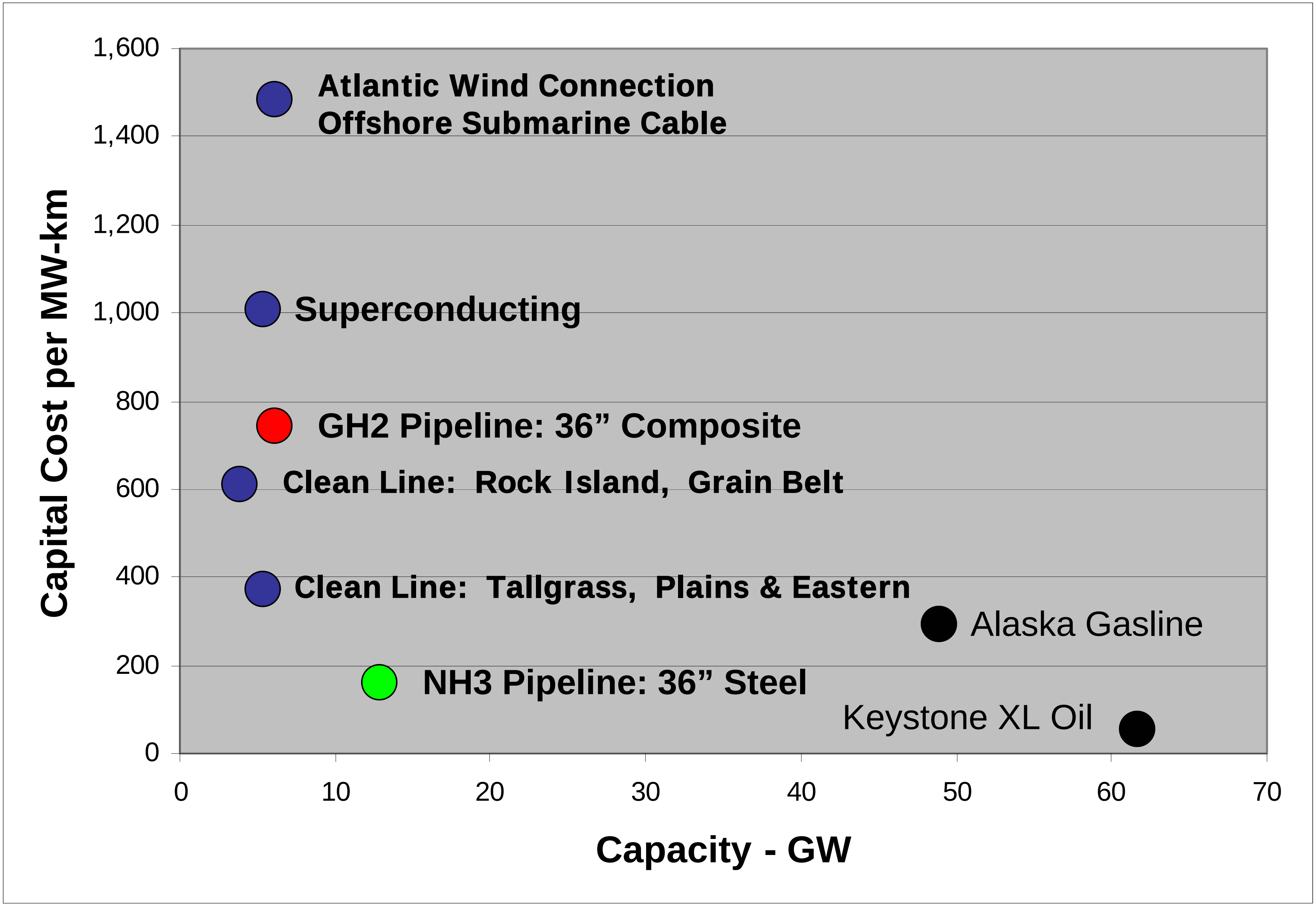
$ 0.08 / kWh

-33 C

1 Atm



Valero LP Operations



Capital Cost per MW-km
1,600
1,400
1,200
1,000
800
600
400
200
0
Atlantic Wind Connection
Offshore Submarine Cable
Superconducting
GH2 Pipeline: 36” Composite
Clean Line: Rock Island, Grain Belt
Clean Line: Tallgrass, Plains & Eastern
Alaska Gasline
NH3 Pipeline: 36” Steel
Keystone XL Oil
0
10
20
30
40
50
60
70
Capacity - GW

Hydrogen and Ammonia Fuels

- **Solve RE's Big Three problems:**
  - **Transmission**
  - **Firming storage**
  - **Grid integration: time-varying output**
- **Carbon-free**
- **Underground pipelines**
- **Low-cost storage: < $ 1.00 / kWh capital**
  - **Pipelines**
  - **GH2 salt caverns**
  - **NH3 tanks**

Hydrogen and Ammonia Fuels

- **Delivering fuels: distribution**
- **ICE, CT, Fuel cell**
- **CHP on-site**
- **Utility substation wholesale**
- **Transportation**
  - **Rail**
  - **Truck**
  - **Personal**
- **Emissions: H_2O, N_2**

“Running the World on Renewables”

- ***USA today***
- ***All energy = 100 Quads = 10^20 J***

- **All generated as CO2-free renewable-source electricity**
- **All transmission as pipelined C-free fuels:**
  - **Gaseous hydrogen (GH2)**
  - **Anhydrous ammonia (NH3)**
  - **Low-cost storage: pipelines, caverns, tanks**
- **Distributed for:**
  - **Combined heat and power (CHP)**
  - **Transportation fuel**
  - **Other**

Annual Fresh Water for Energy

- ***USA today***
- ***All energy = 100 Quads = 10^20 J***

- **17,000 billion liters**
  - **"Withdrawn"**
  - **"Consumed"**
  - **Include all NG + oil "fracking" ?**
- **If all via GH2 + NH3 feedstock:**
  - **Dissociated, disintegrated: $H_2O \rightarrow H_2 + O_2$**
  - **7,000 billion liters H2O**
  - **System efficiency vis-à-vis today's ?**

Annual Fresh Water for Energy

- ***USA today***
- ***All energy = 100 Quads = 10^20 J***

If all via GH2 + NH3, feedstock water:

- **Dissociated, disintegrated: $H_2O \rightarrow H_2 + O_2$**
- **7,000 billion liters fresh H_2O**
- **Gal / MWh = 63**
- **Liters / kWh = 0.24**
- **System efficiency vis-à-vis today's ?**

Handout: GM 2014 panel

“ Americans can be counted on to always do the right thing –

but only after they have tried everything else ”

Winston Churchill

The dog caught the car.

Dan Reicher

Panel Discussion until 1200

Mike Hightower
Sandia National Laboratories,
Energy Systems Analysis Department, Albuquerque, NM

Ms Kelly T. Sanders
University of Texas at Austin

Jordan Macknick
Energy and Environmental Analyst, NREL

Bill Leighty, Chair
Director, The Leighty Foundation