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

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   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
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
Growing Limitations on Fresh Surface and Ground Water Availability

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

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

(Shannon 2007)
Most State Water Managers Expect Some Shortages by 2013 Under Average Conditions

Source: GAO 2003
Climate Change will Impact Precipitation, Evapotranspiration, and Runoff

Mid-latitude population belt will be strongly affected
Southwest U.S. Precipitation Patterns Based on Tree Ring Data

Avg. Precipitation (inches)

Year

-150 50 250 450 650 850 1050 1250 1450 1650 1850 2050

20 18 16 14 12 10
"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

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

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

* 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

- 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

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

Dry Cooling Performance
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

Can now use 200,000 ppm TDS water for fracturing
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

![Projected Water Use of Non-traditional Water](image)
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

*Thermoelectric water requirements (USGS):
  - Withdrawal: ~ 540 Mm³/day (41%)
  - Consumption: ~ 15 Mm³/day (3%)

Sources: ¹USGS, Estimated Use of Water in the United States in 2005, USGS Circular 1344, 2009
  *1995 is the most recent consumption data collected by the USGS
Multiple examples of current or emerging impacts at the energy-water nexus

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

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

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

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

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

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

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

• Regional Energy Deployment System (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

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
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

Operational Water Withdrawal

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**
  
<table>
<thead>
<tr>
<th></th>
<th>Once</th>
<th>Recirc</th>
<th>Dry</th>
<th>Pond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas-CC</td>
<td>1.004</td>
<td>1.000</td>
<td>0.983</td>
<td>1.004</td>
</tr>
<tr>
<td>Coal</td>
<td>1.017</td>
<td>1.000</td>
<td>0.930</td>
<td>1.017</td>
</tr>
<tr>
<td>Nuclear</td>
<td>1.017</td>
<td>1.000</td>
<td>n/a</td>
<td>1.017</td>
</tr>
</tbody>
</table>

Model considers freshwater availability and costs

Source: Tidwell et al., forthcoming 2013.
Model considers alternative water resource availability and costs

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

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Water Rights constraint Active?</th>
<th>Water Rights Available</th>
<th>Cooling Technology Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>No</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td>AR-O</td>
<td>Yes</td>
<td>All</td>
<td>None</td>
</tr>
<tr>
<td>AR-NO</td>
<td>Yes</td>
<td>All</td>
<td>No once-through cooling</td>
</tr>
<tr>
<td>LR-O</td>
<td>Yes</td>
<td>Limited</td>
<td>None</td>
</tr>
<tr>
<td>LR-NO</td>
<td>Yes</td>
<td>Limited</td>
<td>No once-through cooling</td>
</tr>
</tbody>
</table>

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 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.
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
  o Water availability as affected by climate change
  o Cooling system policy analysis
  o Energy scenario analysis

• Exploration of new capabilities
  o Seasonal assessments
  o Temperature inclusion
  o Greater spatial resolution analyses
  o Case studies on specific areas
  o Additional refinement of model
Thank you

Jordan.Macknick@NREL.gov
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;  

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

Water “Consumption”: Water does not return to reservoir (Evaporation)

Water “Withdrawal”: Water used and released to original basin
ERCOT consumes more natural gas and less coal than the average US electricity mix

ERCOT 2012 Power Generation:
324 Billion kWh

- Natural Gas: 45%
- Nuclear: 12%
- Coal: 34%
- Wind: 9%
- Other: 1%

ERCOT consumes more natural gas and less coal than the average US electricity mix.
ERCOT dispatches power plants in the order of least marginal cost:

- Power plants dispatched so that supply = demand
- Marginal Cost = VOM + HR FC

- VOM = Variable Operations and Maintenance Costs ($/MWh)
- HR = Heat Rate (MMBTU/MWh)
- FC = Fuel Cost ($/MMBTU)

Example: If demand is 50,000 MW, all power plants to the left of the line are dispatched.
Competitive retail electricity markets dispatch power according to least marginal cost – Are there alternative strategies?
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]
Nuclear is cheap but withdraws a lot of water
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.

[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

Water Consumption in ERCOT (BGal per yr)

[Sanders, Blackhurst, and Webber 2013] Coal
Natural Gas and Coal Prices Affect Water Withdrawals for Power Production

Water Withdrawals in ERCOT (BGal per yr)

[Sanders, Blackhurst, and Webber 2013] Coal
Fuel prices affect water withdrawals for power in a least marginal cost dispatch regime.
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

- Water Source
- Supply and conveyance
- Water Treatment
- Water Distribution
- Recycled Water Treatment
- Recycled Water Distribution
- Discharge
- Wastewater Treatment
- Wastewater Collection
- Residential, Commercial, Industrial, Or Public End-use

(Adapted from CEC2005)
~13% of US Energy Consumption (12.3 quads) is for Direct Water and Direct Steam Services

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

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

Heat Waves

Droughts

Freezes

Floods
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


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”

- “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

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 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

2nd Day of Power Failures Cripples Wide Swath of India

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
Drought Hurts the Ability to Ship Energy By Inland Waterways

The New York Times

After Drought, Reducing Water Flow Could Hurt Mississippi River Transport

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

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
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
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• 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
Essential, Interdependent Commodities and Strategies

Institute of Electrical and Electronic Engineers
Power & Energy Society General Meeting
Vancouver, BC
21-25 July 2013
Getting Beyond “BAU” …

• 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

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.)


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.
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…

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Challenges</th>
<th>Opportunities</th>
<th>Key Stakeholders</th>
</tr>
</thead>
</table>
| **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  
*Note: challenges & opportunities different for IOUs vs. POU* |
| **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 |
“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
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*

Where should we invest for the long-haul??

Annual

Capital

World energy use

© Richard Perez, et al.

*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear “use-them, lose-them” resources. World energy use is annual.
DOE-EIA: **2005** estimated US annual energy:
~ 100 quads = 100 TWh

Estimated Future U.S. Energy Requirements - 96.8 Quads

- Hydro: 0.94
- Bio/Geo: 3.81
- Wind: 0.06
- Solar: 0
- Nuclear: 7.48
- Coal: 20.83
- Gas: 24.73
- Oil: 38.96

Electricity Generation: 33.91

H2 Production: 0

Residential: 11.89
Commercial: 8.96
Industrial: 26.36
Automotive: 16.18
Freight: 9.19
Airlines: 2.9

Useful Energy: 44.76
Rejected Energy: 52.06

Projection Year 2005
From Year 2005
Efficiency Year 2005
Energy Distribution Year 2005
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
Solar Hydrogen Energy System

- Sunlight from local star
- Electricity
- Electrolyzer
- H₂
- O₂
- Fuel Cell
- Electricity
- Work
Hydrogen Energy Storage

1,000 miles Hydrogen Gas
Pipeline 36" diameter, 1,500 - 500 psi

Electrolyzers

Wind Generators

Storage

Generators ICE, CT, FC

AC grid Wholesale

Storage

Endusers Retail

Storage

Cars, Buses, Trucks, Trains

Liquefy

Aircraft Fuel

Storage

Geologic Storage?
• 860,000 m\(^3\) 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

Domal Salt Storage Caverns
Texas
“Clemens Terminal” Conoco Phillips 20 years
Praxair ‘07
PB ESS
Anhydrous Ammonia $\text{NH}_3$

N Nitrogen

H Hydrogen

Molecular weight = ~ 17

18% H by weight: “other hydrogen”

$\text{NH}_3 + \text{O}_2 = \text{N}_2 + \text{H}_2\text{O}$
Solid State Ammonia Synthesis (SSAS)

- Wind Generators
- Electricity
- Air
- Air Separation Unit (ASU)
- N₂
- SSAS reactor
- Liquid Ammonia Transmission Pipeline
- H₂O
- Liquid Ammonia Tank Energy Storage
- Generators ICE, CT, FC
- AC grid Wholesale
- End users Retail
- Cars, Buses, Trucks, Trains
- Aircraft Fuel
Liquid Anhydrous Ammonia (NH₃)
-33 C, 1 atmosphere
“Atmospheric” Liquid Ammonia Storage Tank (corn belt)

- 30,000 Tons
- 190 GWh
- $15M turnkey
- $80 / MWh
- $0.08 / kWh

-33 C
1 Atm

'09 ARPA-E “Grids” Goal: $100 / kWh
Valero LP Operations

Liquid ammonia pipeline

Valero LP Operations
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: $\text{H}_2\text{O}$, $\text{N}_2$
“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} \text{ J}**

- 17,000 billion liters
  - “Withdrawn”
  - “Consumed”
  - Include all NG + oil “fracking” ?

- If all via GH2 + NH3 feedstock:
  - Dissociated, disintegrated: \( \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{O}_2 \)
  - 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: $\text{H}_2\text{O} \rightarrow \text{H}_2 + \text{O}_2$
- 7,000 billion liters fresh $\text{H}_2\text{O}$
- 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