Water Implications of Energy Choices

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Northern Chapter (NCRES)

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Understanding the Energy-Water-Land Nexus

Energy production requires water and land:
- Thermoelectric cooling
- Hydropower
- Extraction and mining
- Fuel Production (H₂, ethanol, biofuels)
- Emission controls

Water production and distribution require energy and land:
- Pumping
- Treatment
- Transportation
- Heating

Land-use activities (e.g., agriculture) require energy and water:
- Irrigation
- Processing
- Transportation

Introduction to the Nexus

Source: DOE report to Congress, 2006
Energy and Water are interconnected

**Energy production requires water**
- Thermoelectric cooling
- Hydropower
- Extraction and mining
- Fuel Production
- Emission controls

**Water production, distribution, and treatment require energy**
- Pumping
- Treatment
- Transportation
- Heating (End use)

### 2011 U.S. interconnected water and energy flows

*Source: The Water-Energy Nexus: Challenges and Opportunities, DOE, July, 2014*
Locations of existing power plants that have shut down or curtailed generation due to water temperature or water availability constraints (2006-2013).

Source: Union of Concerned Scientists, 2014
Two primary types of power plant cooling systems utilize water differently:

- **Low Withdrawal**
  - High Consumption
  - Recirculating cooling

- **High Withdrawal**
  - Low Consumption
  - Once-through cooling

Source: Union of Concerned Scientists
Operational water withdrawal rates (gal/MWh)

Operational water consumption rates (gal/MWh)

Operational water consumption rates (gal/MWh)

Water use by power plant in Colorado

### Annual Water Consumption

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Acre Feet Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craig</td>
<td>16,400</td>
</tr>
<tr>
<td>Comanche</td>
<td>8,200</td>
</tr>
<tr>
<td>Cherokee</td>
<td>6,300</td>
</tr>
<tr>
<td>Hayden</td>
<td>5,900</td>
</tr>
<tr>
<td>Pawnee</td>
<td>5,700</td>
</tr>
<tr>
<td>Rawhide</td>
<td>3,700</td>
</tr>
<tr>
<td>Fort St Vrain</td>
<td>3,000</td>
</tr>
<tr>
<td>Rocky Mountain Energy</td>
<td>2,900</td>
</tr>
<tr>
<td>Ray D Nixon</td>
<td>2,800</td>
</tr>
<tr>
<td>Martin Drake</td>
<td>2,700</td>
</tr>
<tr>
<td>Valmont</td>
<td>1,900</td>
</tr>
<tr>
<td>Front Range Power Plant</td>
<td>1,300</td>
</tr>
<tr>
<td>Arapahoe</td>
<td>1,000</td>
</tr>
<tr>
<td>Nucla</td>
<td>800</td>
</tr>
<tr>
<td>W N Clark</td>
<td>400</td>
</tr>
<tr>
<td>Colorado Energy Nations</td>
<td>300</td>
</tr>
<tr>
<td>Lamar Plant</td>
<td>200</td>
</tr>
<tr>
<td>TCP 272</td>
<td>200</td>
</tr>
<tr>
<td>Williams Ignacio</td>
<td>100</td>
</tr>
<tr>
<td>Arapahoe Combustion</td>
<td>100</td>
</tr>
<tr>
<td>Brush Generation Facility</td>
<td>100</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>64,200</strong></td>
</tr>
</tbody>
</table>

Source: CFWE, 2013
In Colorado, agriculture is the dominant water user.

Water Withdrawals in Colorado

- 86% Agriculture
- 8% Municipal
- 2.5% Recreation & Fisheries
- 1.5% Industrial/Commercial
- 1% Augmentation
- 1% Recharge
- 0.80% Large Industry
- 0.45% Thermoelectric Power Generation
- 0.07% Commercial
- 0.04% Hydraulic Fracturing
- 0.03% Solar, Coal, Natural Gas & Uranium Development
- 0.03% Snowmaking

Source: Colorado Division of Water Resources Cumulative Yearly Statistics 1996-2008

Source: CFWE, 2013
Life cycle water consumption across life cycle stages for representative electricity generating technologies

Source: Meldrum et al., 2013
Irrigated crops can use more water per acre than renewable energy technologies.

Source: DOE, 2012
Regional water impacts of different low-carbon electricity pathways
Multiple Clean Electricity Scenarios

- **Scenario 1: Business As Usual (BAU)**
  - Existing state and federal policies

- **Scenario 2: Carbon Budget (RPS)**
  - Carbon Budget: 83% reduction in 2005 CO₂ levels by 2050
  - No technology targets

- **Scenario 3: Carbon Capture and Nuclear (CCS/Nuke)**
  - Carbon Budget
  - Technology targets
    - Nuclear: 36% by 2050
    - Coal with CCS: 35% by 2050

- **Scenario 4: Energy Efficiency and Renewable Energies (EERS)**
  - Carbon Budget
  - Technology targets
    - 80% renewable by 2050
    - 35% reduction in electricity by 2050
How do our electricity sector choices affect potential energy-water impacts?

Scenario 1: High Natural Gas No carbon cap

Scenario 2: Carbon cap High Renewable

Scenario 3: Carbon cap High Nuclear and Coal with CCS

Scenario 4: Carbon cap 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


States based on different electricity pathways through 2050. Environmental Research Letters. 7 (045803).
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 2: High Renewable

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

Scenario 3: High coal with carbon capture and nuclear

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

Scenario 4: High Energy Efficiency and Renewable Energy

Water as a constraint for future electricity sector development
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*.

- NREL has implemented water resource availability as a constraint into the ReEDS model.
NREL’s ReEDS (Regional Energy Deployment System) Model
- a premier tool for U.S. electricity system capacity expansion modeling

Generation technologies:
- Coal (pulverized, IGCC, & IGCC-CCS)
- Nuclear
- Natural Gas (combustion turbine(NGCT), combined cycle(NGCC), & CC-CCS)
- Biomass (dedicated, cofired with coal, landfill-gas/MSW)
- Geothermal (hydrothermal & EGS)
- Hydropower, Marine Hydrokinetic
- Solar (concentrating solar power & PV)
- Wind (onshore & offshore)

Storage: pumped hydropower storage, CAES, batteries

Demand-side technologies: plug-in hybrid/electric vehicles (PHEVs), thermal energy storage in buildings, interruptible load

• Projects electric sector growth to 2050 under different economic, technology, and policy assumptions
• Spatially resolved into 356 wind/solar regions, 134 balancing areas (BAs) for demand and other renewables
• Serves load, meets planning and operating reserves requirements, and obeys physical constraints

Freshwater availability and cost have recently been defined at the national level.

Climate Scenarios: Moderately Hot, Hot-Dry

- Each scenario reflects 5 CMIP5* model runs
  ✓ Hydrology generated (Wood and Mizukami 2014) from downscaled (Reclamation 2013) climate projections for each of 97 model runs
  ✓ Model runs selected from combined Summer-Fall projected changes in temperature and runoff for seven Southwestern US HUC2 basins

- Monthly average temperature used to approximate Heating Degree Days (HDD) and Cooling Degree Days (CDD)

- Water constraints: unallocated water rights (by season) = 50% x (seasonal runoff - seasonal water demands)

<table>
<thead>
<tr>
<th>Model Name</th>
<th>CMIP5 Scenario*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS1.0</td>
<td>RCP 8.5</td>
</tr>
<tr>
<td>CCSM4</td>
<td>RCP 6.0</td>
</tr>
<tr>
<td>HadGEM2-AO</td>
<td>RCP 8.5</td>
</tr>
<tr>
<td>HadGEM2-ES</td>
<td>RCP 8.5</td>
</tr>
<tr>
<td>MIROC-ESM-CHEM</td>
<td>RCP 4.5</td>
</tr>
<tr>
<td>BCC_CSM1.1</td>
<td>RCP 8.5</td>
</tr>
<tr>
<td>CESM1(CAM5)</td>
<td>RCP 8.5</td>
</tr>
<tr>
<td>FGOALS-G2</td>
<td>RCP 4.5</td>
</tr>
<tr>
<td>INM-CM4</td>
<td>RCP 8.5</td>
</tr>
<tr>
<td>MPI-ESM-LR</td>
<td>RCP 4.5</td>
</tr>
<tr>
<td>*All use r1i1p1 experiment</td>
<td></td>
</tr>
</tbody>
</table>

*Coupled Model Intercomparison Project 5
Changes in unappropriated water availability (2010-2050) under scenarios of climate change

**Moderately Hot** Climate Scenario: increases in annual unappropriated water availability in many parts of the West, with decreases in the Southeast

**Hot and Dry** Climate Scenario: widespread reductions in annual unappropriated water availability, with increases in the Northeast

Unappropriated water availability in the Southwest remains zero as there are many over Appropriated basins.

The Southeast is projected to have lower water availability under both climate scenarios.

New England is projected to have higher water availability under both climate scenarios.

*Blue indicates more unappropriated water available under climate scenario.*

*Red indicates less unappropriated water available under climate scenario.*
Highest demand growth in summer requires greater peaking generation

- Increased demand is primarily met by GasCC-R, wind, and PV
- Higher summer peak requires additional GasCT capacity
- Operational water constraints under climate change reduce generation from once-through cooled coal and nuclear capacity

\( O = \text{once-through} \)
\( P = \text{cooling pond} \)
\( R = \text{recirculating} \)
\( D = \text{dry} \)

\( \text{NoCon} = \text{No constraints} \)
\( \text{Con-NoCC} = \text{water constrained, no climate change} \)
\( \text{Con-HotDry} = \text{water constrained, hot/dry climate} \)
Regional differences in capacity builds under scenarios of climate change for PV, Wind, NGCC, and Coal: *climate-induced changes in water*

**Preliminary results**

**2050: Hot-Dry climate - no Constraints**

- **PV**: More PV is built in the SE.
- **Wind**: Wind is built throughout the U.S.
- **NGCC**: NGCC is built throughout the U.S.
- **Coal**: Coal is retired in the South and West.

*Green = more, Red = less*
Takeaways from Regional Impact Assessment

• Energy efficiency measures lead to greatest reduction in water impacts
• High renewable penetration generally leads to lower water impacts, with regional variations
• Scenarios with high penetration of:
  o 1) natural gas
  o 2) coal with carbon capture and nuclear

see regional increases in water consumption in the southwest, southeast and Texas

*Water constraints (from policy or climate change) can greatly affect regional electricity deployment and water use trends*
Thank you

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NREL Activities in the Energy-Water Nexus
NREL’s EWN activities fall into 4 primary categories:

1. Energy Sector Modeling and Analysis
2. Energy Systems Integration
3. Technologies
4. Energy-Water System Solutions

Partnerships are a key component of each area
Overview: NREL’s Energy Sector Modeling and Analysis activities analyze the interactions and dependencies of water with the dynamics of the power sector and the transportation sector. A variety of models and tools are utilized to consider water as a critical resource for power sector development and operations as well as transportation fuels.

Notable Projects: Renewable Electricity Futures Study, Life Cycle Harmonization Project, Western Wind and Solar Integration Study, Natural Gas and the Transformation of the Electricity Sector

Core Capabilities: ReEDS capacity expansion model with water resource constraints, PLEXOS production cost model, REPRA capacity value model, Bioenergy Water Footprinting Tool

Partnerships: CU-Boulder, CUNY, NCAR, Union of Concerned Scientists, Sandia National Laboratories, Industry

Key Activities

- **Power Sector**
  - Electricity Capacity Expansion Modeling (ReEDS)
  - Production Cost Modeling and Valuation (PLEXOS/REPRA)
  - Life Cycle Assessment
  - Unconventional Oil/Gas Development
  - Resources/Climate Impacts

- **Transportation Sector**
  - Biomass feedstock analysis
  - Biomass to biofuel conversion analysis
  - Transportation fleet/system analysis
Energy Systems Integration

Overview: NREL is exploring a unique system-of-systems concept to energy systems integration. This approach considers the relationships among electricity, thermal, and fuel systems and data and information networks to ensure optimal integration and interoperability across the entire energy system spectrum. NREL’s Smart Power Laboratory focuses on the development and integration of smart technologies including the integration of distributed and renewable energy resources through power electronics and smart energy management for building operations.

Notable Projects: Distributed energy systems integration, large-scale renewable energy integration, residential and commercial-scale integration, campus/city/community-scale integration, regional and national integration

Core Capabilities: Smart Power Laboratory, Energy Systems Integration Facility

Partnerships: Advanced Energy, Asetek, CSIRO, Solectria, Toyota, Wyle

Key Activities
- Systems modeling and systems engineering
- Demand Response/Smart Grid/ Energy Efficiency
- Modeling end-use and generation
- Smart Power Laboratory in the Energy Systems Integration Facility
Technologies

Overview: NREL has extensive experience and expertise related to energy-water technology research all along the supply chain. NREL has designed alternative cooling systems to reduce water needs on-site, developed anti-soiling coatings to reduce wash water needs for solar technologies, explored desalination opportunities utilizing renewable energy technologies, investigated marine hydrokinetic technology opportunities and characteristics, and evaluated manufacturing systems for various technologies.


Core Capabilities: Thermal Test Facility, National Center for Photovoltaics, Buildings and Thermal Systems Center, Field Test Laboratory Building

Partnerships: U.S. General Services Administration, Mountain Energy Partnership, Partnership for Resource Conservation

Key Activities
- Low-water cooling system designs
- Anti-soiling coatings for PV and CSP solar collectors to reduce water needs
- Desalination with renewable energy technologies
- Marine Hydrokinetic research
- Manufacturing
- Biofuels
Energy-Water System Solutions

Overview: NREL has been a pioneer in the development of energy-water system solutions that explicitly address and optimize energy-water tradeoffs. NREL has evaluated energy-water system solutions for Department of Defense bases, islands, communities recovering from disasters, individual buildings and campuses, and large-scale water treatment and transport facilities.


Core Capabilities: Site analysis, campus-level optimization solutions, Clean Energy Solutions Center,

Partnerships: Department of Defense, Department of Interior, U.S. Virgin Islands

Key Activities
- Department of Defense Forward Operating Base (FOB) analysis
- Emergency Response/Disaster Recovery and Island rebuilding
- Building/Campus-scale energy-water analysis and optimization
- Water management with renewable energy technologies
- Energy-Water Synergies
- International platforms