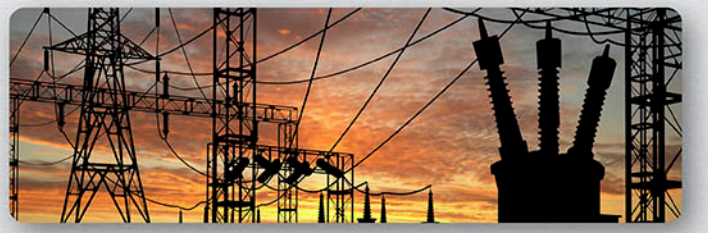

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Potential Game Changing Cooling Technology Development for Power Plant Water Conservation

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Presentation for 15th IAHR International Cooling Tower and Air-Cooled Heat Exchanger Conference, Beijing, China

Oct. 25, 2011

Outline

- EPRI Overview
- Program Overview
- Technology Scanning Approach
- Proposal Stats and Selection Criteria
- Four Technologies to be Developed
- Summery and 2012 Funding Plan

EPRI is Member Funded & Non-Profit Organization.

- 38 year history
- 450+ funders in more than 40 countries
- About $370 m funding in 2011
- More than 90% of the electricity in the United States generated by EPRI members
- More than 15% of EPRI funding from international members

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TI Water Conservation Program Overview and Objective

- Initiated in early 2011
- Funded by EPRI Office of Technology Innovation
- Collaborated by all EPRI Sectors (Nuclear, Generation, and Environment)
- Broadly distributed Request for Information (RFI) to solicit top technologies for development in Feb., 2011

Objective

Seek and develop "out of the box", game changing, early stage, and high risk cooling ideas and technologies with high potential for water conservation, performance, and financial improvements to members.

EPRI Technology Innovation (TI) Strategic Issues

Smart Grid

Energy Efficiency

Long-Term Operations

Renewable Resources and Integration

Near Zero Emissions

Water Conservation

Water Conservation Ranked Top Priority.

Received More Than 70 RFI Responses

Organization Type	Number of Proposals
Universities	35
National Labs	7
Company	29
International	3

Technology Type	Number of Proposals
Cooling/Thermal Technologies	35
Green Chillers	4
Thermal-Electric Cooling	1
Evaluation	3
Water Treatment	19
Membrane	7
Scrubber Water	9

- **Many respondents never worked with power industry.**
- **Second round of RFI will start early next year.**

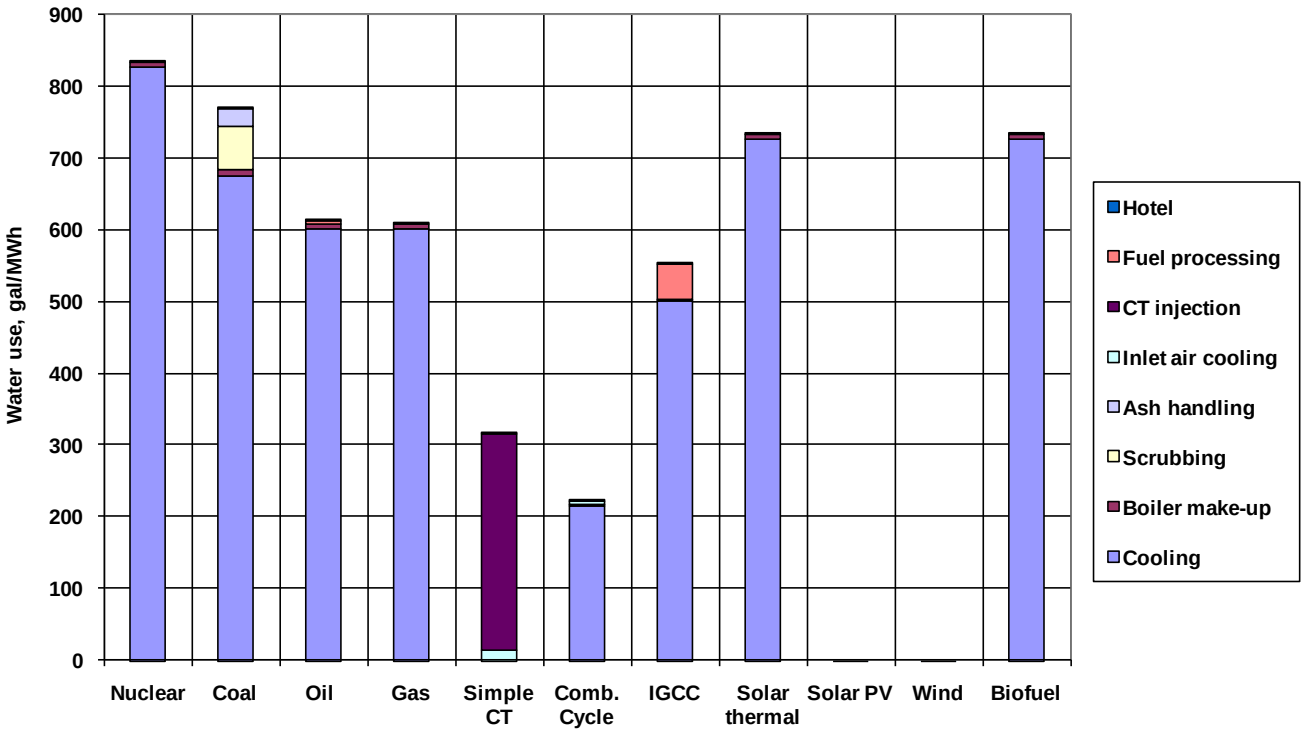
Selection Criteria for TI Funded Projects

- Innovation (“out of the box”, game changer, cutting edge)
- Potential Impacts
  - Significant reduction of water (especially fresh water) consumption and/or withdrawals
  - Improved thermal efficiency
  - Economic potential in terms of water and energy consumption, cost, and space
  - Other
- Respondent’s capabilities and related experience
- Realism of the proposed plan and cost estimates

More than 35 proposals kept for funding considerations

Target All Types of Thermal Power Plants

- Coal
- Oil
- Natural Gas
- Combined Cycle
- Renewable
  - Solar Thermal (Many built in hot desert.)
  - Geothermal (Low steam temperature)
  - Bio-fuel
  - Others



Source: EPRI Report , “Water Use for Electric Power generation”, No. 1014026, 2008

- **Most thermoelectric power plants use a lot fresh water.**
- **About 90% of thermoelectric power plant fresh water use is for cooling.**

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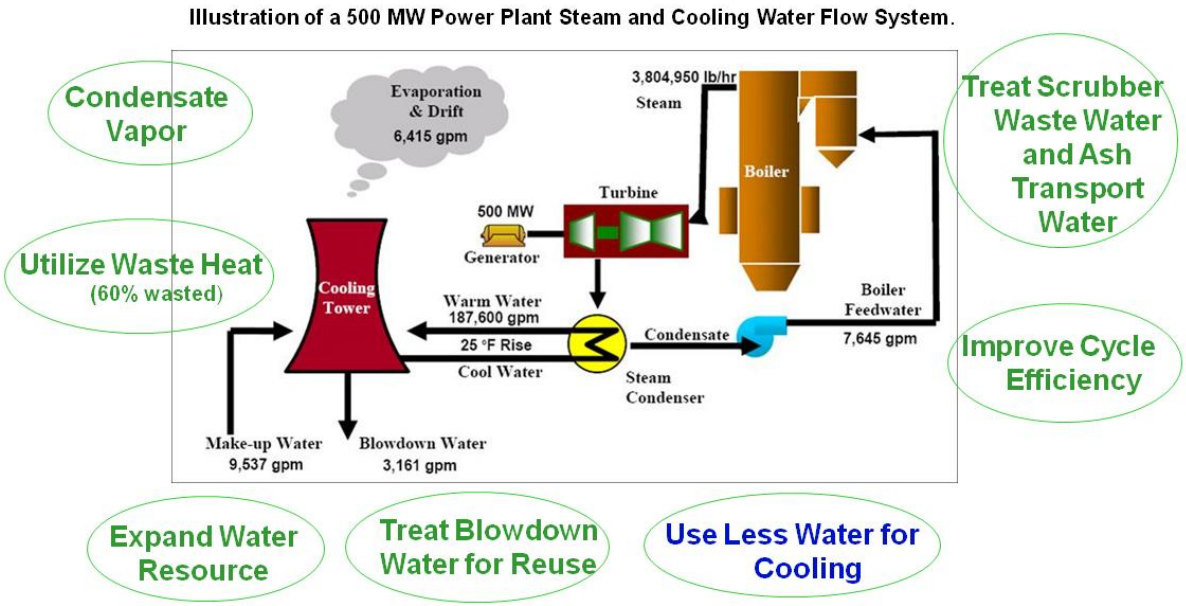
First Round of Funding Dedicated to Cooling Technology Advancement

Drivers

- Majority of freshwater use (~90%) in plants for cooling
- Current water-conserving technologies, such as air-cooled condensers and hybrid cooling with significant capital outlays, lower efficiency, and operational and maintenance issues.

Water Use Reduction Opportunities Identified for Power Plants



Top Priority in 2011

Develop Water Conserving Cooling Technologies

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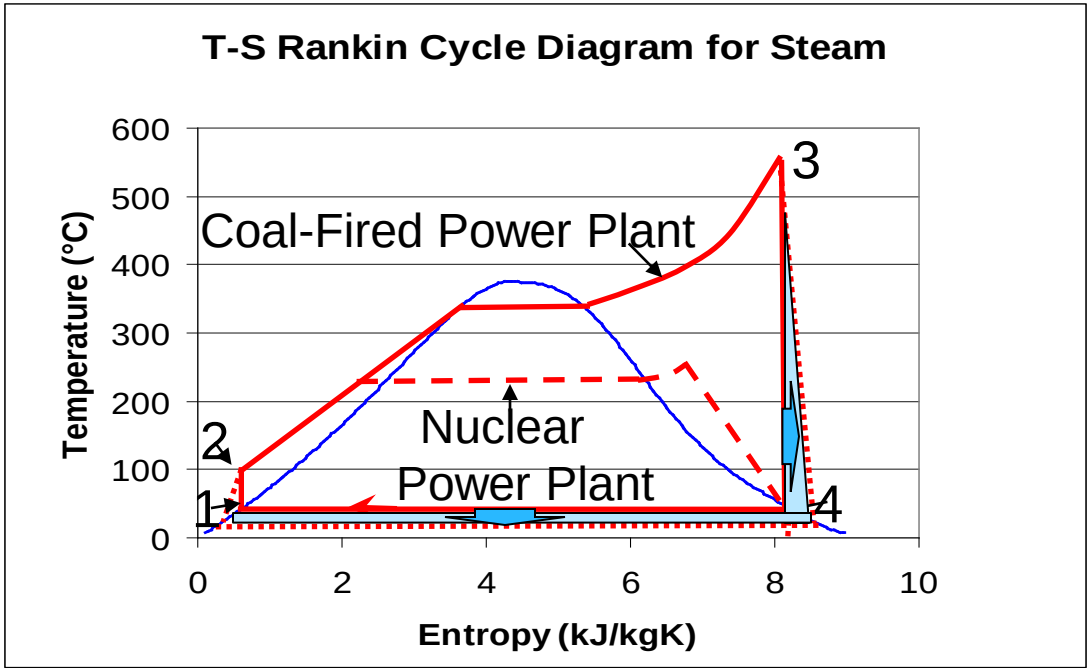
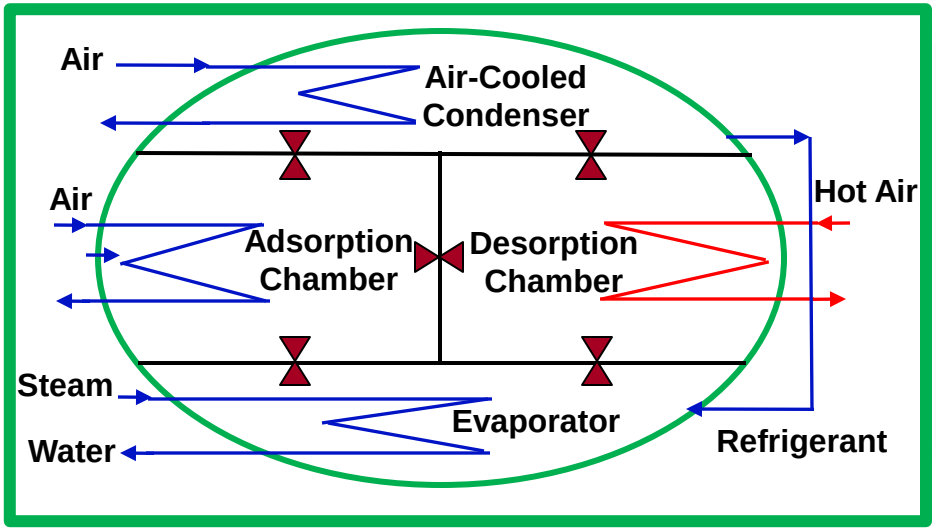
Effect of Reducing Condensing Temperature on Steam Turbine Rankine Cycle Efficiency



Potential for 10% (1st Order Estimate) more power production or $37 m more annual income ($0.085/kWh) for a 500 MW power plant due to reduced steam condensing temperature from 50 °C to10 °C.

Project 1 (EPRI Patent Pending):
Development of Green Adsorption Chillers to Replace Cooling Towers and Water Cooled Steam Condensers by Allcomp

Schematic Illustration of a Typical Adsorption Chiller



Key Potential Benefits

- Evaporative cooling
  - Significantly higher heat removal rate than convective water cooling
- Closed loop cooling system
  - **Near Zero** water use and consumption
- Reduced condensation temperature
  - As low as **10 °C**
  - Potential for increased power production by 10%
- Waste Heat Utilization

Project Scope

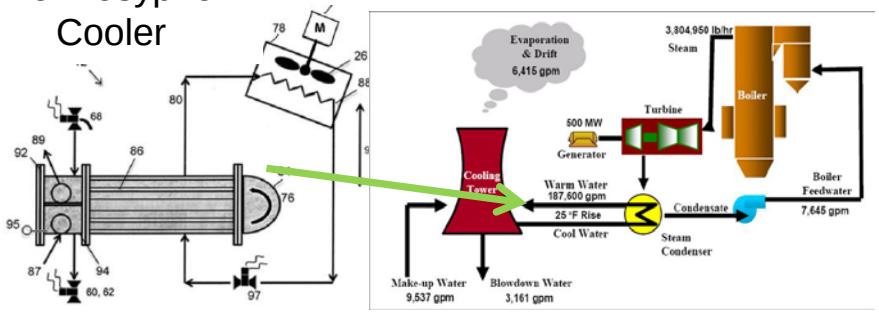
- Explore best power plant system level approaches to utilize waste heat for desorption
- Perform system integration energy and mass flow balance analysis for a 500 MW coal-fired power plant
- Develop and build a 5 kW Green Adsorption Chiller Prototype
- Perform prototype testing
- Perform technical and economic feasibility study

Potential Project 2 for 2011 Start

Feasibility Study of Using Thermosyphon Coolers to Reduce Cooling Tower Water Consumption by Johnson Controls Inc.

As ambient conditions permit, the thermosyphon cooler pre-cools the condenser water leaving the steam surface condenser reducing the evaporative load on the cooling tower

Thermosyphon Cooler

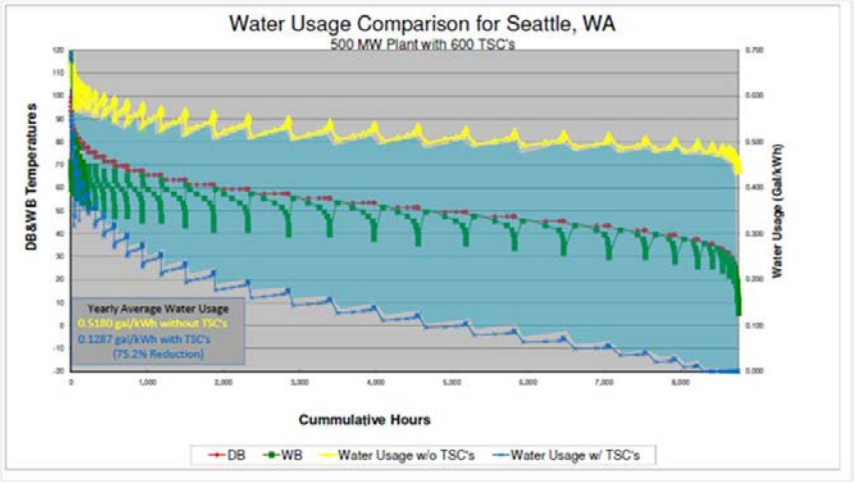


Project Scope

- Perform a thorough feasibility evaluation of a hybrid, wet/dry heat rejection system comprising recently developed, patent pending, thermosyphon coolers (TSC).
- Make comparisons in multiple climatic locations, to standard cooling tower systems, all dry systems using ACC's, hybrid systems using parallel ACC's, and air coolers replacing the thermosyphon coolers.
- Determine the most effective means to configure and apply the thermosyphon coolers .

Key Potential Benefits

- Potential for annual savings > 50% in cooling tower evaporation, make-up, chemical use, and blowdown
- Full plant output is available on the hottest days when the demand for electricity is the greatest
- Ease of retrofitting
  - Taps into existing condenser water cooling loop
  - Increased layout flexibility – just run water piping
  - Can be added incrementally in stages
- No increase in surface area exposed to primary steam
- Reduces operating concerns in sub freezing weather
- Broad application (hybrid, new, and existing cooling systems)



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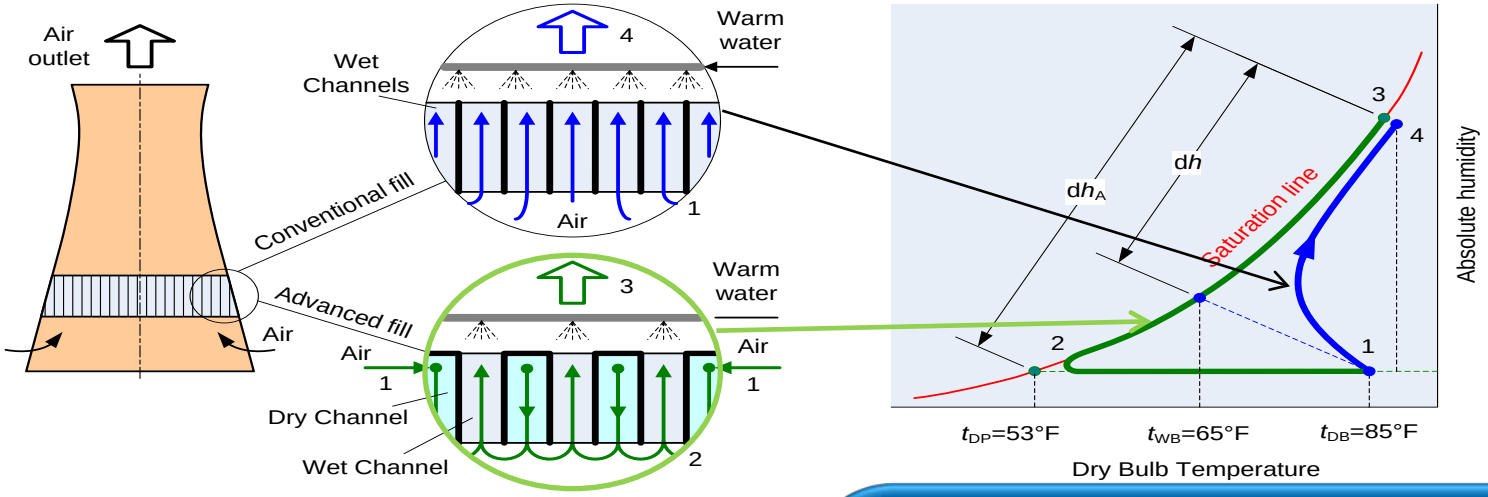
Potential Project 3 for 2011 Start

Development of Advanced Cooling Tower Fill to Enable Cooling Near Dew Point Temperature Through Maisotsenko Cycle by Gas Technology Institute



Project Scope

- Develop an advanced fill
- Perform CFD and other types of energy, mass, and momentum balance modeling
- Evaluate performance and annual water savings for several typical climates using simulation models
- Perform prototype testing in scaled down cooling towers
- Perform technical and economic feasibility evaluation

Key Potential Benefits

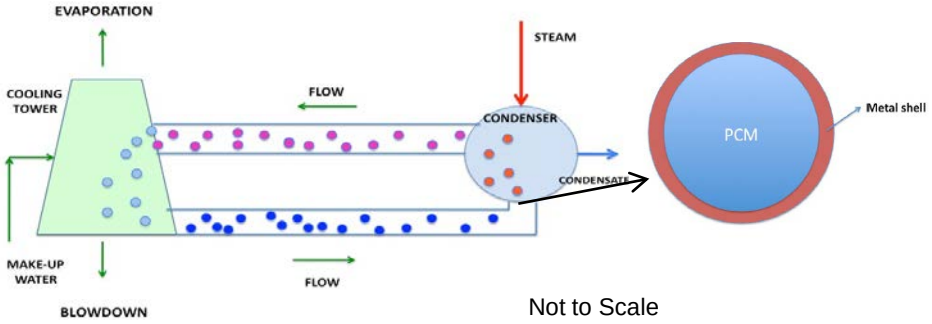
- Potential for less cooling water consumption by 18%
- Colder water exiting cooling tower
  - 43 °C to 13 °C (slightly higher than DP)
  - Lower steam condensation temperature potential
  - More power production potential
- Ease of retrofitting
- Potential to further enhance hybrid systems

Potential Project 4 for 2012 Start:
Multi-functional Nanoparticles for Reducing Cooling Tower Evaporative Loss By Argonne National Lab

Project Scope

- Develop multi-functional nanoparticles with ceramic/metal shells and phase change material cores
- Measure nano-fluid thermo-physical properties
- Perform prototype testing in scaled down water cooled condenser and cooling tower systems
- Assess potential environmental impacts due to nanoparticle loss to ambient air and water source.
- Perform technical and economic feasibility evaluation

Phase Change Material (PCM) Core/Ceramic or Metal Shell Nano-particles added into the coolant.



Not to Scale

Key Potential Benefits

- Cooling Water Consumption:
  - 20% less evaporative loss potential
  - Less drift loss
  - 20% annual makeup water use reduction potential
- Nanoparticles
  - Enhanced thermo-physical properties of coolant
  - Heat of vaporization shown to increase by 20-25% with addition of ceramic nanoparticles
  - Reduced flow rates by 15% for same heat removal due to increased heat transfer coefficient & heat capacitance
  - Inexpensive
- Reduced pumping requirements & Ease of retrofitting
- Broad application (hybrid/new/existing cooling systems)

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Summary and Future Plan

2011 Progress

- Initiated cooling technology development program to conserve water.
- Received more than 70 responses from Request for Information.
- Funded one project.
- Working on funding four more projects (One More on Thermoelectric Technology with Purdue Univ.).

2012 Plan

- Expand technology scouting activity.
- Start second round of Request for Information.
- Fund more technologies in cooling and other types of water conservation. technologies.
- Explore co-funding opportunities with other funders.
- Publish three Phase I reports.

Thank You!

Any Questions?

Please feel free to contact me at:

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or

Katie Vroom, Technical Assistant, at

KaVroom@epri.com

Together…Shaping the Future of Electricity

Appendix Selected EPRI Research Reports on Water/Energy Sustainability

TOPIC	PUBLISHING INFORMATION	
Cooling Requirements and Water Use Impacts of Advanced Coal-fired Power Plants with CO_2 Capture and Storage: Interim Results	1021663	2010
Evaluation of Stormwater as a Resource for Power Plant Cooling	1021124	2010
Water Resource Trends and Implications for the Electric Power Industry	1019866	2010
Sustainable Water Resources Management, Volume 1: Executive Summary	1019582	2010
Sustainable Water Resources Management, Volume 2: Green Building Case Studies	1020602	2010
Sustainable Water Resources Management, Volume 3: Case Studies on New Water Paradigm	1020587	2010
Managing Water Resource Requirements for Growing Electric Generation Demands	1017946	2009
Program on Technology Innovation: Electric Efficiency Through Water Supply Technologies—A Roadmap	1019360	2009
Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use	1016460	2008
Use of Alternative Water Sources for Power Plant Cooling	1014935	2008
Water Use for Electric Power Generation	1014026	2008
Management of Non-Cooling Water Releases	1014023	2008
Program on Technology Innovation: Power Generation and Water Sustainability	1015444	2007
Running Dry at the Power Plant – EPRI Journal	1015362	2007
An Energy/Water Sustainability Research Program for the Electric Power Industry	1015371	2007
Program on Technology Innovation: Water Resources for Thermoelectric Power Generation	1014487	2006
Air-Cooled Condenser Design, Specification, and Operation Guidelines	1007688	2005
Framework to Evaluate Water Demands and Availability for Electric Power Production Within Watersheds Across the U.S.: Development and Applications	1010116	2005
The Formation and Fate of Trihalomethanes in Power Plant Cooling Water Systems	1009486	2004
Comparison of Alternate Cooling Technologies for U.S. Power Plants: Economic, Environmental and other Tradeoffs	1005358	2004

Continued - Appendix Selected EPRI Research Reports on Water/Energy Sustainability

TOPIC	PUBLISHING INFORMATION	
A Survey of Water Use and Sustainability in the U.S. with a Focus on Power Generation	1005474	2003
Spray-Cooling Enhancement of Air-Cooled Condensers	1005360	2003
Use of Degraded Water Sources as Cooling Water in Power Plants	1005359	2003
Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply and Treatment – The Next Half Century	1006787	2002
Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production – The Next Half Century	1006786	2002
Water & Sustainability (Volume 2): An Assessment of Water Demand, Supply and Quality in the U.S. – The Next Half Century	1006785	2002
Water & Sustainability (Volume 1): Research Plan	1006784	2002

Down Load Reports at epri.com