ELECTRIC POWER RESEARCH INSTITUTE

Strategic Program

Water Use & Availability

Technology Innovation

Advanced cooling, water treatment, and other innovations are critical for reducing freshwater use and enhancing regulatory compliance at existing power plants, siting new generation capacity, and meeting competing demands for finite resources.

STRATEGIC DRIVERS

Water Resource Management

Long-Term Operations

Near-Zero Emissions

INNOVATION TARGETS

- **Minimize water withdrawal and consumption**
- **Enable use of alternative water sources**
- **Increase energy conversion efficiency**
- **Reduce cost-of-energy impacts**

EPRI is pursuing game-changing cooling concepts and advanced treatment and reuse technologies to mitigate water-related operational and siting constraints and to improve cost and performance for steam-electric power plants. In addition, a nanofluid-based cooling approach identified through innovation scouting is undergoing accelerated development as a *Break-through Technology* (1024884).

Strategic Value

This program incubates cooling, water treatment, and other innovations for transfer to EPRI's Nuclear, Generation, and Environment & Renewable Energy sectors for full-scale demonstration in collaboration with power producers and commercial vendors. By enabling continued cost-effective operation of existing power plants and facilitating the siting of new capacity, individual innovations may have substantial economic benefits across the industry while helping balance competing needs for water resources and protect aquatic ecosystems. Dew-point and thermosyphon cooling technologies, for example, offer the potential for achieving significant and cost-effective reductions in evaporative losses and makeup water requirements for plants with wet recirculating cooling towers. Higher-performance cooling also could lower steam-condensing temperatures and thus turbine outlet backpressures, which would help increase plant productivity.

Technology Gaps

Ongoing strategic work is advancing the technology readiness level (TRL) of innovations to address the following capability gaps:

- Cooling with reduced water withdrawal, water consumption, capital cost, energy penalty, and operations and maintenance (O&M) impacts
- Higher-performance cooling to increase plant output, both absolutely and per unit of water input
- Reclamation and reuse to enable the use of nontraditional water sources
- Wastewater treatment capable of meeting effluent discharge standards at reduced costs

This pilot-scale thermosyphon cooling unit is providing field performance data on an innovation that could provide a more flexible, lower-cost approach to hybrid cooling at thermoelectric power plants.

R&D Highlights

Technology Assessment. In 2011-12, a broad-based request for information (RFI) process generated 114 responses from the worldwide research community, and a 2013 RFI is planned in conjunction with the U.S. National Science Foundation. These solicitations, along with an aggressive innovation scouting program, emphasize two areas. First, advanced cooling could reduce water consumption and increase plant productivity, as wet cooling systems typically account for more than 90% of water use due to evaporative losses and drift, and current water-conserving options have adverse cost and performance impacts. Second, water treatment innovations could facilitate use of nontraditional sources and lead to cost-performance improvements, particularly if integrated with other plant systems.

Based on independent assessment of RFI responses and input from an external group of experts, this program has initiated early-stage work on four advanced concepts (described below) that have the potential for significant water efficiency gains at steam-electric plants. In addition, the heat transfer characteristics of coolants based on solid-state nanomaterials and water-based nanofluids are being examined in modeling studies to assess theoretical performance gains and practical potential. New projects scheduled to begin in 2013 address an enhancement to air-cooled condenser design and three membrane-based cooling and treatment concepts. Exploratory research will be conducted on other promising ideas identified through the RFI process and innovation scouting, potentially leading to follow-on EPRI work.

2013-14 Milestones

- Continue assessment and exploration of concepts identified through RFI and innovation scouting processes (TRL1-3) and initiate dedicated projects on promising technologies

Dew-Point Cooling Tower. Cooling tower fills typically employ wet evaporative channels to cool hot water leaving the steam condenser, which constrains their cooling capacity to the wet-bulb temperature of ambient air. Dew-point cooling technology enhances the standard tower fill by positioning dry channels between wet channels, separating them with a thin-walled surface, and exploiting evaporative cooling of the surface's wet side to extract heat from ambient air passing over its dry side. Design development and proof-of-concept modeling initiated in 2012 focus on optimizing the fill configuration to maximize the pre-cooling of incoming air in dry channels and to reduce evaporative losses in wet channels by allowing condensate cooling to occur at well below the ambient wet-bulb temperature and as close as possible to the dew-point temperature—for example, from about 27°C (80°F) to about 13°C (55°F) in a hot and arid climate.

In 2013, EPRI will conduct experimental proof-of-concept studies on a test section of cooling tower fill to quantify potential water savings, which are estimated at greater than 20%. This will include an assessment of possible heat rate improvements associated with lower steam-condensing temperature, allowing operation at lower turbine backpressure. Engineering and economic modeling for a representative 500-MW coal-fired plant will assess water and energy impacts across a range of ambient conditions, investigate system integration issues, and compare cost and performance with conventional cooling tower fill for both retrofit and new construction applications.

Testing of a prototype dew-point cooling tower fill, scheduled to begin in 2014, is expected to bring the technology to TRL5. Follow-on demonstrations in retrofit applications are anticipated through the Water Management Technology (P185) and Advanced Nuclear Technology (P41.08) programs.

2013-14 Milestones

- Complete design assessment, demonstrate proof of concept in laboratory setting, design and construct dew-point cooling tower prototype, and initiate field testing (TRL3-5) to support possible future demonstrations through P185 and P41.08

PROGRAM LEVERAGE

>10%

INNOVATION NETWORK

University

- **Purdue University**
- **University of California, Berkeley**
- **University of Florida**

Public & Private Sector

- **Allcomp, Inc.**
- **American Society of Mechanical Engineers**
- **Dominion Generation**
- **EDF**
- **Gas Technology Institute**
- **Johnson Controls, Inc.**
- **Maulbetsch Consulting**
- **Southern Company**
- **Unistar Nuclear**
- **U.S. National Laboratories (Idaho, Sandia, Lawrence Livermore, Argonne)**
- **U.S. National Science Foundation**

Vapor Absorption Refrigeration Cooling. Conventional chillers use electricity to drive a vapor compression cycle, whereas adsorption/absorption chillers require only a heat input. EPRI is exploring potential use of this "green chiller" technology for refrigerant-based steam condensation with near-zero water consumption and increased power production. A modeling study launched in 2012 is investigating power plant integration issues, including the use of waste heat and solar thermal heat input, to advance this concept from TRL2. Depending on results, next steps could include prototype development to support laboratory proof-of-concept and early validation testing and to identify RD&D priorities for power plant cooling applications of green chillers.

2013-14 Milestones

- Complete integration study and technical and economic feasibility assessment (TRL3) and initiate follow-on work as warranted

Thermosyphon Dry Heat Rejection Cooling. Hybrid cooling systems typically incorporate a conventional wet cooling tower and air-cooled condensers, with the latter operating the majority of the time and the former employed to mitigate performance penalties at high ambient temperatures. A novel hybridization concept applies thermosyphon dry heat rejection, a technology developed for space conditioning in buildings. The idea is to deploy thermosyphon cooling (TSC) units, which consist of an evaporator, an air-cooled condenser, and connecting tubes, to provide pre-cooling of hot water from the steam condenser before it is further cooled by the wet cooling tower.

Ongoing design and modeling address TSC scale-up, cooling tower integration, and cost and performance relative to other cooling configurations for 500-MW plants at five locations with differing climates. Also, a pilot-scale system incorporating a 1-MW TSC unit and cooling tower is under test at the Water Research Center at Georgia Power's Plant Bowen. Results to date indicate the potential for modular addition of dry cooling capacity to achieve up to or above a 50% reduction in water consumption. These activities, expected to bring the technology to TRL5 in 2013, will guide design of a commercial-scale TSC module for demonstration at an operating power plant, potentially under a supplemental project offered by P185 and P41.08.

2013-14 Milestones

- Complete cost-performance assessment, pilot-scale testing and validation, and design development (TRL3-5) to support field demonstration through P185 and P41.08

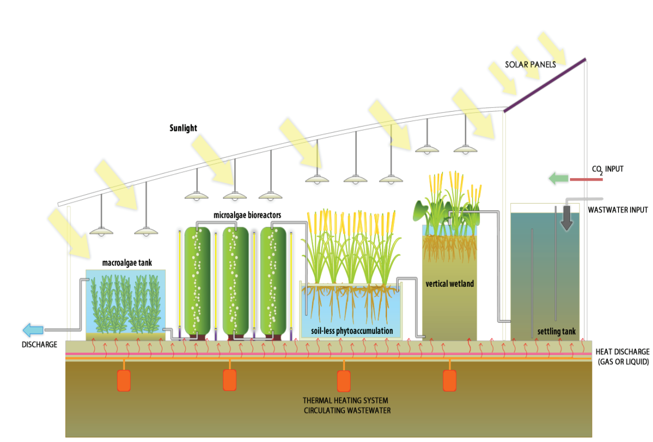
Thermoelectric Refrigeration for Steam Condensation. EPRI is evaluating possible power plant applications of thermoelectric materials capable of converting heat energy directly into electrical energy (or vice versa), without the need of a thermodynamic cycle and a working fluid. The proposed approach, currently at TRL2, employs thermoelectric fibers wrapped around flue gas exhaust, steam tubes, and/or coolant pipes. By extracting waste heat from flue gas, additional on-site electricity could be produced, and water vapor that would otherwise be exhausted could be captured to help meet makeup water requirements. Fibers wrapped around piping could generate electricity while reducing the heat load imposed on the cooling system, or they could be used for direct thermoelectric refrigeration to reduce water consumption and lower the steam condensation temperature.

Ongoing laboratory studies focus on achieving proof of concept in power plant applications and on exploring molecular-scale nanostructures to optimize the performance of thermoelectric materials. Modeling addresses the water use, plant performance, and cost impacts of various integration strategies. Prototype thermoelectric fibers are scheduled for experimental validation testing by 2015, setting the stage for field trials.

2013-14 Milestones

- Demonstrate proof of concept for cooling and waste heat capture in power plants, develop thermoelectric material formulations with enhanced properties, and identify applications with near-term deployment potential (TRL3-4)

Bioremediation for Boron Control. Currently, no commercial treatment options allow for cost-effective control of boron (B), a contaminant commonly found in discharges from coal ash management facilities. Since 2009, EPRI has advanced the concept of applying wetland plants, bacteria, and micro- and macro-algae for B removal from TRL1 to TRL3. Multiple hyperaccumulators—species capable of growing in and treating water and soil containing very high B concentrations—have been discovered, and key genes and processes influencing B tolerance, update, and immobilization have been identified. Through laboratory greenhouse and bioreactor experiments, genetically mediated and other approaches for enhancing B removal by plant, bacteria, and algae species have been demonstrated.



Biotechnology-based solutions for controlling boron discharges at coal ash management facilities could enhance compliance with water quality standards at substantial cost savings.

In 2013-14, pilot-scale wetlands containing natural and transgenic plants will be constructed and tested on B-containing wastewaters to identify optimal substrates, species mixes, and design parameters. Also, based on experimental studies of alternative bioreactor configurations, a prototype B treatment unit will be developed and deployed for validation testing at a field site. In parallel, a biotechnology-based treatment system integrating constructed wetland, aquatic plant, and bioreactor modules will be evaluated in greenhouse experiments. Follow-on demonstration through P185 is proposed.

2013-14 Milestones

- Conduct validation studies for wetland, bioreactor, and integrated treatment systems (TRL4-5) to support possible field demonstration through P185

Recent Deliverables

Feasibility Study of Using a Thermosyphon Cooler Hybrid System to Reduce Cooling Tower Water Consumption (1025643)

New Concepts of Water Conservation Cooling and Water Treatment Technologies (1025642)

Tradeoffs Between Once-Through Cooling and Closed-Cycle Cooling for Nuclear Power Plants (1025006)

Biotechnological Approaches to Removing Boron from Electric Utility Wastewater (1023780)

For more information

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com).

Contacts

Sean Bushart, Senior Program Manager, Environment
sbushart@epri.com, 650.855.8752

Jessica Shi, Senior Project Manager, Environment
jshi@epri.com, 650.855.8516

EPRI's Technology Innovation (TI) program helps maintain a full pipeline for the Generation (GEN), Nuclear (NUC), and Environment & Renewable Energy (ERE) sectors. Technology readiness levels (TRLs) mark the progress of individual technologies and guide their transition from TI into the sector programs and toward commercial application.

Technology Development Timeline

Project Area	Exploratory Research TRL 1	Concepts Formulated TRL 2	Proof of Concept Validated TRL 3	Subsystem Validated TRL 4	System Validated TRL 5	Early Demonstration TRL 6	Demonstration TRL 7	Early Commercial Deployment TRL 8	Commercialization TRL 9
Dew-Point Cooling Tower		2011			2015	GEN NUC ERE		2016	
Vapor Absorption Refrigeration Cooling		2012			2014	GEN NUC ERE		2020+	
Thermosyphon Dry Heat Rejection Cooling		2012			2013	GEN NUC ERE		2015	
Thermoelectric Refrigeration for Condensation		2012			2015	GEN NUC ERE		2017	
Bioremediation for Boron Control	2009				2014	GEN ERE		2016	

= TI Progress Through 2012 = Future TI Progress Transition to Base Program Industry Adoption

1023486 January 2013

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com