

*Breakthrough Technology*

# Multifunctional Nanoparticles for Reducing Cooling Tower Water Consumption



Technology Innovation

*Innovative technology for decreasing power plant water requirements by up to 20%, minimizing operational impacts from water shortages, and broadening siting options.*

### STRATEGIC DRIVERS

**Water Resource Management**

**Long-Term Operations**

### INNOVATION TARGETS

- **Reduce freshwater withdrawal and consumption**
- **Minimize cost-performance penalties associated with current water-conserving technologies**

EPRI's Technology Innovation Program is developing a breakthrough nanoparticle technology for enhancing the thermophysical properties of heat transfer fluids used in wet cooling towers and significantly reducing water usage at both existing and new steam-electric power plants.

### Strategic Value

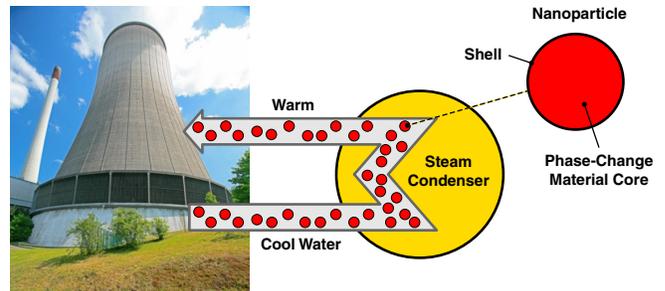
Power plant coolants incorporating nanoparticles with phase-change material cores that melt to absorb heat from steam turbine condensate and solidify as cooling proceeds promise to reduce overall water consumption by as much as 20%. The improved thermal properties offered by these multifunctional nanoparticles also are expected to decrease coolant flow rates by about 15%, helping lower the associated pumping loads and thus parasitic energy losses.

Assuming successful development, this innovation will represent a cost-effective and relatively simple retrofit option for increasing water efficiency at operating fossil and nuclear plants with closed-cycle recirculating or hybrid wet-dry cooling systems, as well as a low-cost alternative for reducing the water requirements of new thermoelectric plants. It will help power producers meet

water use restrictions at reduced cost and decrease exposure to operational and regulatory risks. It also will increase siting flexibility for new steam-electric generating capacity. Initial field-scale demonstrations are anticipated to begin in 2014.

### Innovation Challenge

U.S. steam-electric plants account for approximately 40% of the nation's total freshwater withdrawals and—due primarily to evaporative and drift losses from wet cooling towers—approximately 3% of overall consumption. High water use rates at plants with closed-cycle wet cooling may not be sustainable in some locations, while thermal discharges from once-through cooling face increasing regulatory scrutiny. Already, some plants operate under water use restrictions or are being required to install water-conserving technologies. Furthermore, the siting of new capacity increasingly is challenged by water supply constraints.



*Nanoparticles incorporating phase-change materials are expected to significantly improve the thermophysical performance of steam-condensing coolants, reducing freshwater withdrawal and consumption by nuclear and fossil power plants with wet cooling towers.*

Looking ahead, increasing growth pressures, tightening regulations, and changing water balances are expected to represent strong drivers for higher water efficiency in the electric power sector. EPRI has been leading industry-wide efforts to understand and address water availability challenges. Current air-cooled steam condensers—the most water-efficient cooling option—have high capital costs, energy penalties, and operations and maintenance (O&M) impacts. Advanced technologies for

reducing the water requirements of closed-cycle wet and hybrid wet-dry systems represent a critical industry need.

At Argonne National Laboratory (ANL), researchers are developing an innovative nanotechnology-based cooling concept. It involves addition to the coolant stream of nanoparticles with a metallic or ceramic shell encasing a core of phase-change material designed to melt at condenser temperatures and solidify as the heat transfer fluid (HTF) travels through the cooling tower. Adding heat absorption nanoparticles to the coolant is expected to significantly increase its heat transfer coefficient, heating capacity, and heat of vaporization. These improved thermophysical properties will allow the same volume of coolant to absorb more heat in the condenser and to dissipate the heat in the cooling tower with lower vaporization. This translates into a reduction in the amount of water required to achieve a given level of cooling, as well as that lost to evaporation and drift.

To support power industry applications, the first priority is to improve understanding of the heat transfer characteristics of these specialized nanoparticles, alone and incorporated within coolants. Next, candidate core/shell nanoparticles need to be synthesized, evaluated, and optimized and improved thermophysical properties demonstrated at the laboratory scale. Practical methods must be developed for adding nanoparticles to power plant cooling circuits to replace losses through drift, evaporation, and blowdown. Also, impacts on power plant economics and O&M need to be assessed, and environmental health and safety risks associated with nanoparticle releases need to be evaluated. Ultimately, full-scale field demonstrations will be required.

### Strategic Response

In early 2011, EPRI released a Request for Information (RFI) from researchers and developers pursuing water-efficient technologies with potential power industry applications. Among the more than 70 RFI responses was one from ANL. Subsequent evaluations of nanoparticle-enhanced cooling as a possible breakthrough technology by EPRI and external reviewers led to a decision to accelerate development and demonstration of the ANL-proposed concept as a working nanofluid.

In 2012, parallel modeling and laboratory studies are being conducted to understand and optimize the thermophysical properties of phase-change materials, nanoparticles, and nanofluids for power plant cooling applications. For 2013, bench-scale testing is planned, followed by prototype testing of an optimized nanofluid in a pilot-scale cooling tower and condenser system. These activities, along with power plant integration and risk assessments, will support detailed study of technical and economic feasibility for a 500-MW power plant.

### R&D Highlights

**Task 1: Nanoparticle Development & Synthesis.** To support the design and development of candidate materials formulations, theoretical modeling is under way to quantify the

## PROGRAM LEVERAGE

>100% of EPRI investment

## INNOVATION NETWORK

- Argonne National Laboratory
- American Society of Mechanical Engineers (ASME)
- American Electric Power
- Constellation
- Dominion Generation
- Duke Energy
- EDF
- National Science Foundation
- Nuclear Regulatory Commission
- Southern Company
- Unistar Nuclear
- University of Florida

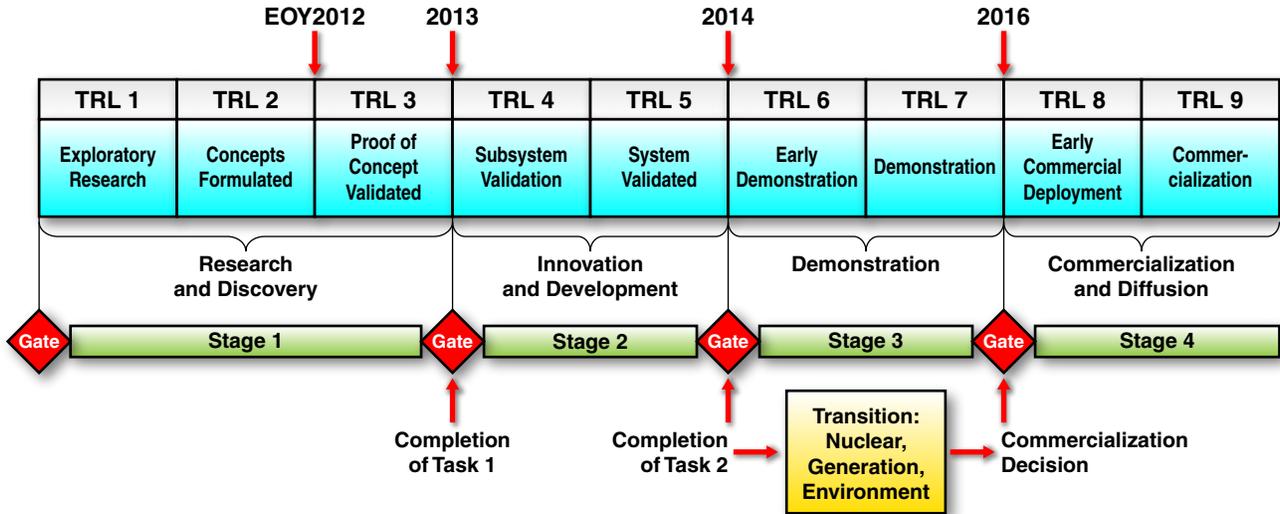
effects on nanoscale heat transfer of properties such as particle composition, size, shape, and concentration and HTF composition, temperature, and flow rate. Based on this work, candidate nanoparticles will be synthesized. Microemulsion techniques will be used for producing phase-change materials, followed by controlled chemical, photochemical, or atomic-layer deposition of the shell. Samples of candidate nanoparticles will be dispersed in alternative HTF formulations, and their performance will be evaluated in terms of thermal conductivity, heat transfer, heat capacity, heat of vaporization, viscosity, erosion, fluid stability, and other parameters. *This task will help advance the technology from TRL-2 through TRL-3.*

### 2012 Milestones

- Model thermophysical performance of nanoparticles and HTFs
- Synthesize candidate shell, phase-change material, and nanofluid formulations and conduct initial performance analyses

**Task 2: Characterization & Scale-Up Testing.** Based on successful nanoparticle synthesis and nanofluid development, thermal and physical properties will be comprehensively evaluated and optimized through iterative bench-scale testing and modeling studies in 2013. In addition, the mechanical performance of nanofluids, such as the potential for clogging and erosion in metal tubing similar to that used in cooling systems, will be examined. These activities will support design and implementation of a pilot-scale cooling system demonstration for nanofluids optimized based on thermal and mechanical performance and process simulation studies. For the most promising formulation, a

EPRI employs technology readiness level (TRL) metrics to monitor the status of individual technologies as they advance through its innovation process toward commercial application. Stage gates define specific technical milestones that are used to motivate progress and justify continued investment in breakthrough technologies. Successful innovations transition into EPRI's sector programs.



system-level design study, environmental and health risk assessment, and detailed economic evaluation will be performed for a retrofit application of nanoparticle-enhanced cooling at a 500-MW power plant. Results will address capital costs, O&M costs, water and energy savings relative to other cooling options, and additional critical parameters. *This task will help advance the technology from TRL-3 through TRL-5.*

### Transition Plan

In 2013, EPRI expects to begin working with commercial partners on the synthesis and evaluation of nanoparticle and HTF formulations, with the goal of scaling the technology up for initial field demonstration in 2014, likely as a supplemental project or through base programs in the Generation, Nuclear, and/or Environment sectors. Based on successful large-scale demonstrations of heat absorption nanoparticles in various applications, final industry delivery of the technology is expected through commercial partners. EPRI will coordinate with partners and members to provide application guidance.

### For more information

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

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