



National Science Foundation
WHERE DISCOVERIES BEGIN

EPRI

ELECTRIC POWER
RESEARCH INSTITUTE

Overview of NSF-EPRI Power Plant Dry Cooling Science and Technology Innovation Program (2014-2017)



Sumanta Acharya, Ph.D.
NSF Program Director



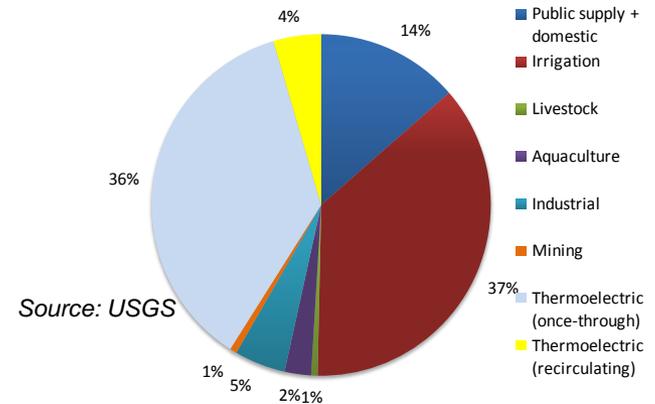
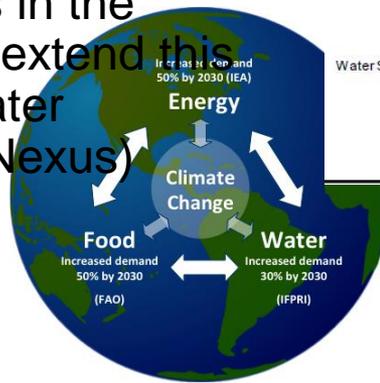
Jessica Shi, Ph.D.
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ARPAE Dry Power Plant Cooling Workshop, May 12-13, 2014 Chicago, IL

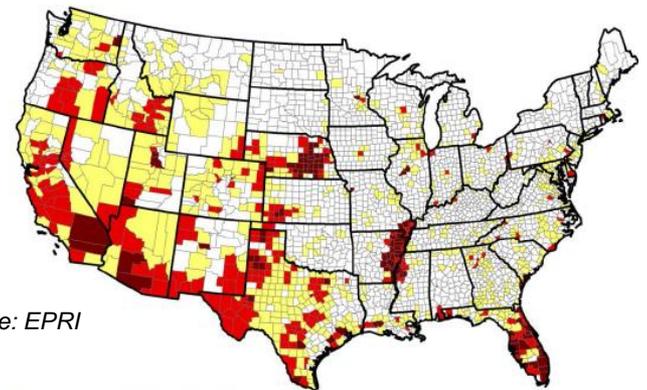
Eliminate Water Use in Electricity Generation- An NSF-EPRI Partnership

- Nearly 40% of the freshwater withdrawal in the US is for Thermal-electric power plants; 90% of this is used for cooling.
- EPRI study suggest lack of water in many regions that put nearly 25% of power production at risk.
- Goal of the NSF-EPRI Collaboration: **To eliminate or minimize the use of water for cooling** in Thermal-electric power plants. Likely impact will be very significant in terms of water availability for other sectors
- Ten projects exploring novel transformational ideas funded at universities with industry participation/oversight; NSF & EPRI contribute equally.
- Future aim is to explore new directions in the energy-water security research and to extend this to include the other major source of water withdrawal-food (Energy-Water-Food Nexus)

Source: King, AIChE 2013



Water Supply Sustainability Risk Index (2030)



Source: EPRI

Water Supply Sustainability Risk Index (2030)
Business as usual

- Extreme (106)
- High (247)
- Moderate (695)
- Low (2034)



How did we get here?

- MOU established between NSF and EPRI in 2012
- Joint technical workshop held in ASME IMECE 2012 to define most favorable research opportunities for water saving advanced cooling technology development
- \$6 M joint solicitation developed and issued in 2013
- Keys to successfully attract exceptional proposals
 - Strong technical guidance
 - ✓ Comprehensive background info. and data provided to potential researchers
 - ✓ Well defined selection criteria
 - Engagement of the thermal-science community towards this important societal problem



NSF vs. EPRI Research Interests

- NSF

Transformational ideas and gaining fundamental understanding of the associated fundamentals involving:

- Modeling
- Lab scale testing
- Fundamental technology development

- EPRI

Applied research and development

- Game changing idea development
- Modeling, design optimization, and prototype testing
- Technical and economical feasibility study



Summary of Projects with \$6 M Total Funding

Project Title	Organization	Funder
Direct Contact Liquid on String Heat Exchangers for Dry Cooling of Power Plants	UCLA	NSF
On-demand Sweating-Boosted Air Cooled Heat-Pipe Condensers for Green Power Plants	U of S Carolina	NSF
Ejector Cooling Systems with Evaporation/Condensation Compact Condensers	Univ of Missouri Columbia/SPX	NSF
Novel Thermosyphon/Heat Pipe Heat Exchangers with Low Air-Side Thermal Resistance	Univ of Kansas /Univ of Connecticut	NSF
Auto Flutter Enhanced Air Cooled Condensers	GaTech/Johns Hopkins/Southern Company/SPX	NSF-EPRI
Advanced Air Cooled Condensers with Vortex-Generator Arrays between Fins	UIUC	NSF-EPRI
Indirect Dry Cooling Towers with Phase-Change Materials as Intermediate Coolants	Drexel/ACT/Worley Parsons	NSF-EPRI
Novel Heat-driven Microemulsion-based Adsorption Green Chillers for Steam Condensation	UMD/Worley Parsons	EPRI
Nanostructure Enhanced Air-Cooled Steam Condensers	MIT/HTRI	EPRI
Porous Structures With 3D Manifolds For Ultra-Compact Air Side Dry Cooling	Stanford	EPRI



Broad Themes

- Heat Pipes/Thermo-Siphons
- Alternative Working Fluids/Materials
- Innovations in Dry Air Cooling
 - Air Side
 - Steam Side



Heat Pipes/Thermo-Siphons

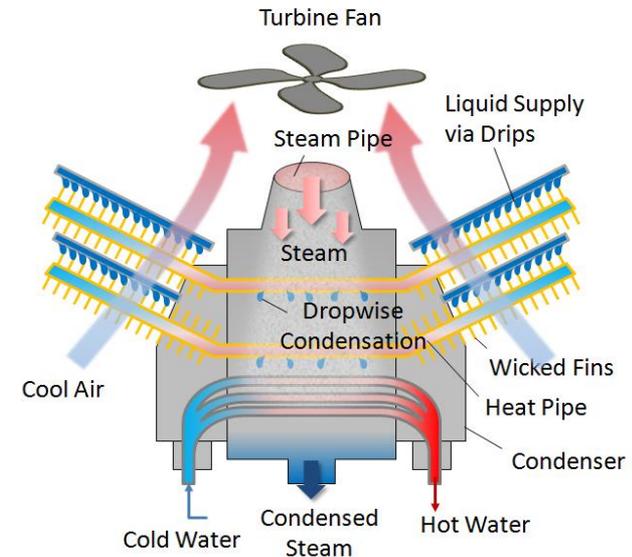
- On-demand Sweating-Boosted Air Cooled Heat-Pipe Condensers for Green Power Plants (Univ. of S. Carolina)
- Novel Thermosyphon/Heat Pipe Heat Exchangers with Low Air-Side Thermal Resistance (KU/Uconn)
- Ejector Cooling Systems with Evaporation/Condensation Compact Condensers (University of Missouri)



On-demand Sweating-Boosted Air Cooled Heat-Pipe Condensers for Green Power Plants

Project Scope

- Develop highly efficient alternative dry cooling systems by optimizing heat acquisition via long-lasting dropwise condensation (DWC), heat transport from steam to the air-side through highly conductive heat pipes, and finally heat rejection by sweating-boosted air cooling
- Design and evaluate impacts of the proposed air cooled heat-pipe condensers on power plants in a VTB
- Develop sweating-boosted air cooling
- Achieve long-lasting DWC with Ni coatings using atmospheric plasma spray (APS)
- Develop high performance heat pipes with microscale hybrid wicks
- Test a lab-scale ACC prototype

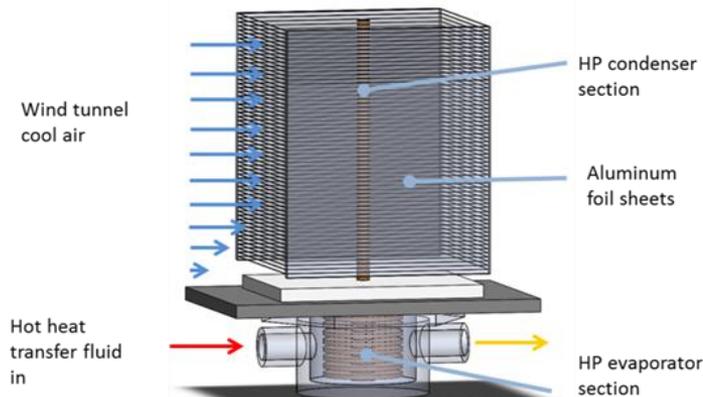
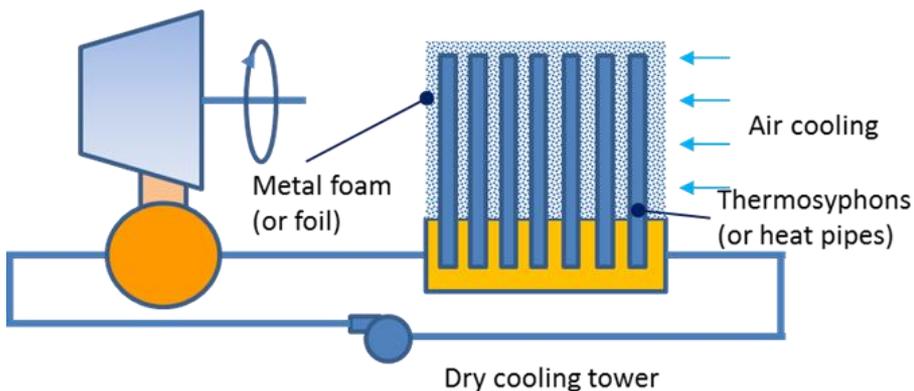


Key Potential Benefits

- 4X better air side heat transfer coefficient up to ~ 200 W/m²K
- 2X higher steam side heat transfer coefficient
- Reduced air side heat transfer area up to 68%
- Reduced footprint up to 50%
- Potentially save nearly 70% water using dripping system compared to cooling towers
- Reduced capital and maintenance costs of ACC



Novel Thermosyphon/Heat Pipe Heat Exchangers with Low Air-Side Thermal Resistance (KU/UConn)



- 3D computational domain of experimental test section.
- Test section is snapped into the bottom wall of a wind tunnel.
- Full 3D mixed convection, conjugate heat transfer, evaporation, condensation, and condensable vapor flow inside the heat pipe.

Project Scope

- Integrate high capacity thermosyphons/heat pipes with air-side metal foil/foam to minimize overall thermal resistances of heat exchangers.
- Perform experiments and develop multi-phase physical models
 - To measure and predict thermal performance
 - To enable a simulation capability for full-scale design.
- Assess the economic viability of a scaled-up design (500 MWe).

Key Potential Benefits

- Develop the knowledge base that will enable the design of a economical, high-performance, completely-dry cooling towers *or* condensers.
- Estimated improved performance at half the cost of conventional dry cooling towers or condensers.
- Specifically, integrate high capacity heat pipes/thermosyphons with air-side metal foil/foam .



Ejector Cooling Systems with Evaporation/Condensation Compact Condensers (University of Missouri)

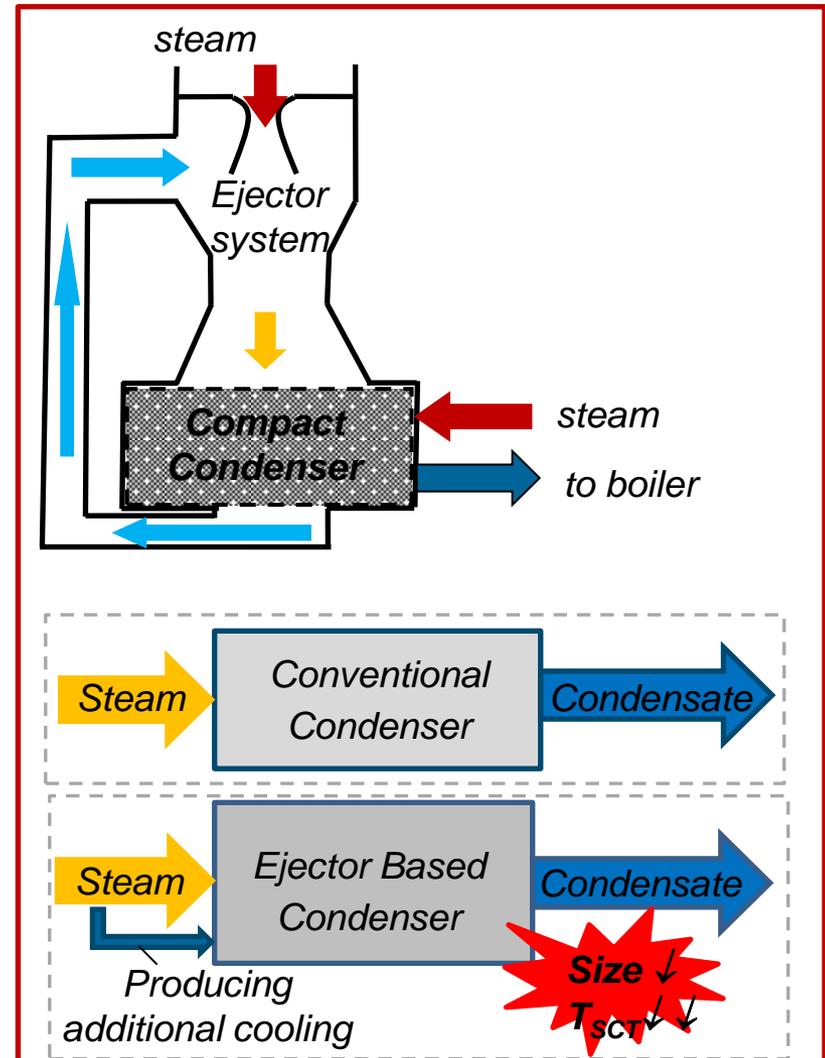
Project Scope

- Demonstrate a new generation of ejector-based cooling technology resulting in significant reduction or elimination of the use of water for cooling power plants
- Develop mathematical model predicting the heat transfer performance
- Demonstrate a 5 kW prototype

Key Potential Benefits

- Effective utilization of low grade thermal energy of steam for cooling
- Significant cost reduction of the ACC system
- Significant reduction (35% for wet cooling) or elimination (100% for dry cooling) of the use of water
- Condensation temperature decrease from 50 °C to 35 °C at an ambient temperature of 30 °C
- Easy integration of ongoing cooling systems
- Simple, reliable and compact cooling system
- SPX assessment ensuring satisfaction in real world needs

nr&c



Alternative Working Fluids/Materials

- Indirect Dry Cooling Towers with Phase-Change Materials as Intermediate Coolants (Drexel University/ACT)
- Novel Heat-driven Microemulsion-based Adsorption Green Chillers for Steam Condensation (UMD)
- Direct Contact Liquid on String Heat Exchangers for Dry Cooling of Power Plants (UCLA)



Indirect Dry Cooling Towers with Phase-Change Materials as Intermediate Coolants (Drexel University/ACT)

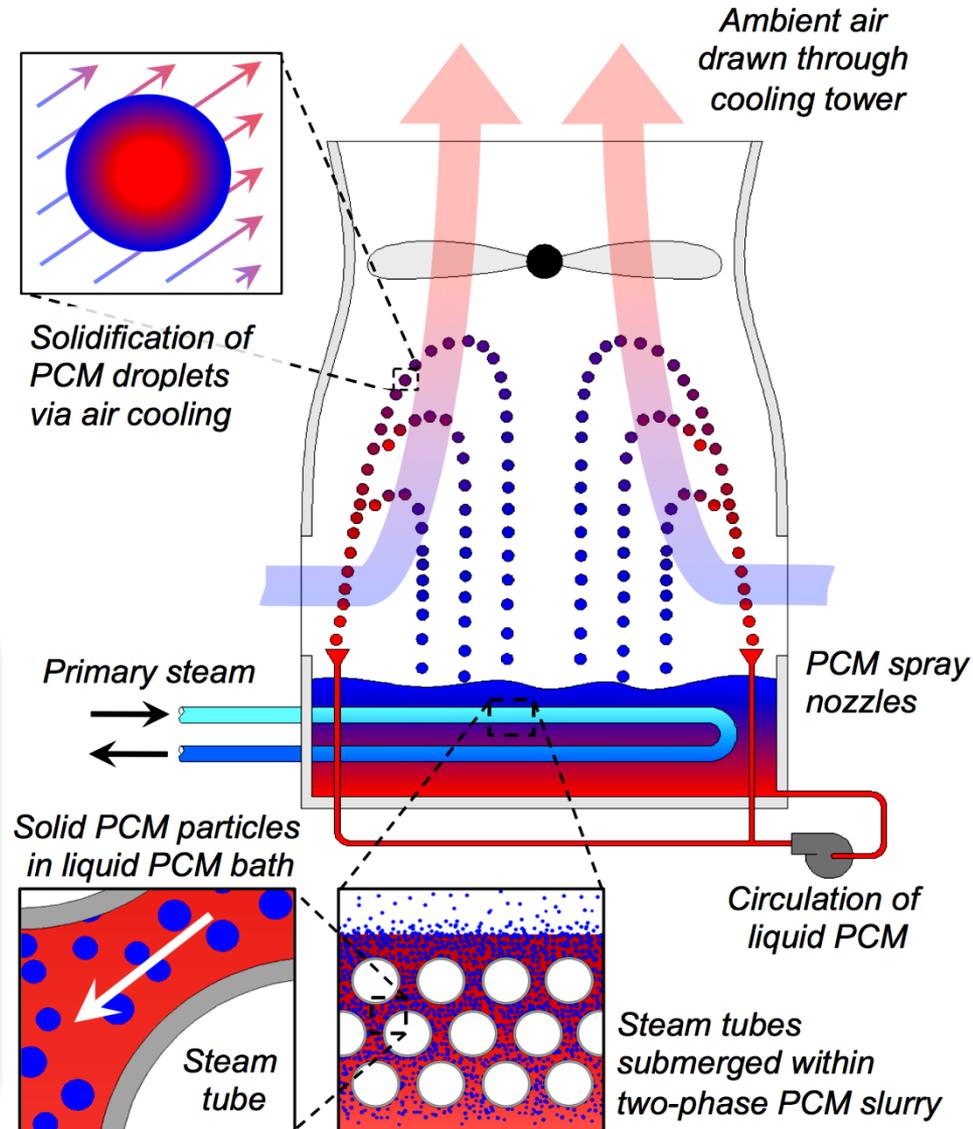
Project Scope

- Develop air-cooled PCM spray-freezing technology with enhanced thermal and fluidic performance.
- Perform technical & economic feasibility evaluation including environmental impact study.
- Perform testing and characterization of components and scaled prototype.

Key Potential Benefits

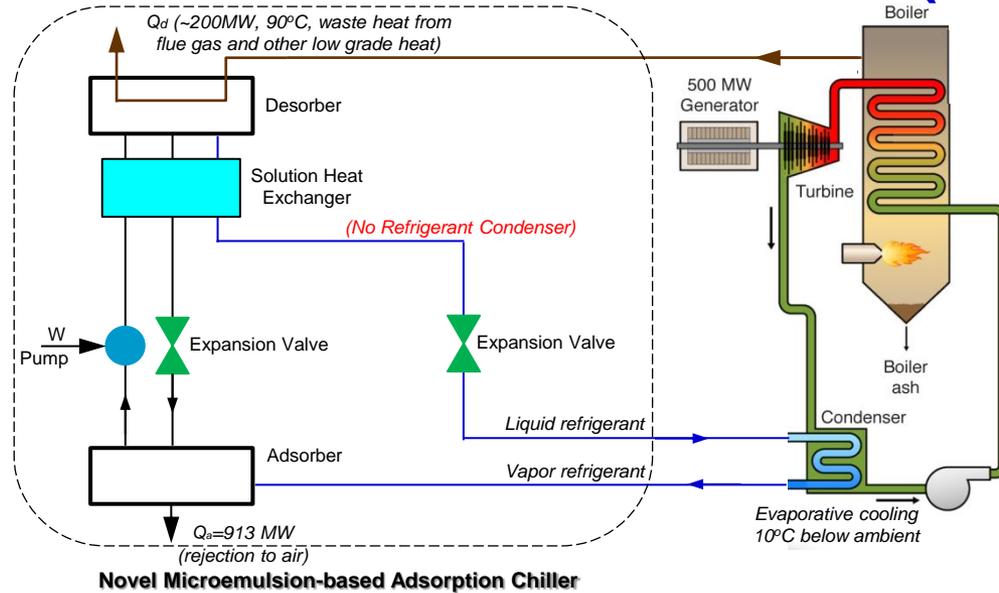
Compared to traditional ACCs

- Improved air-side heat transfer coefficient due to use of sprayed droplets.
- Reduced steam condensation temperature in hot weather would lead to significant production gain
- Reduced primary steam tubing and pressure drop.
- Significantly reduced system cost and size



Novel Heat-driven Microemulsion-based Adsorption Green Chillers for Steam Condensation (UMD)

Joint UMD-EPRI
Patent Pending



Project Scope

- Develop advanced microemulsion adsorbents
- Develop advanced microemulsion-based adsorption chillers for power plant steam condensation
- Perform system integration energy and mass flow balance analysis for 500 MWe coal plant
- Perform prototype testing
- Perform technical and economic feasibility evaluation

Key Potential Benefits

Compared to the currently used ACCs

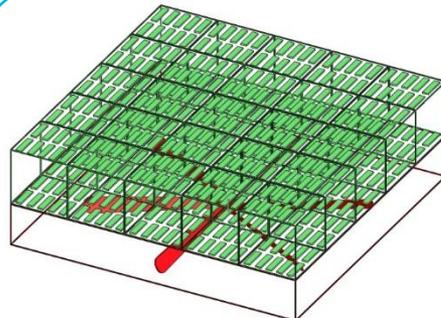
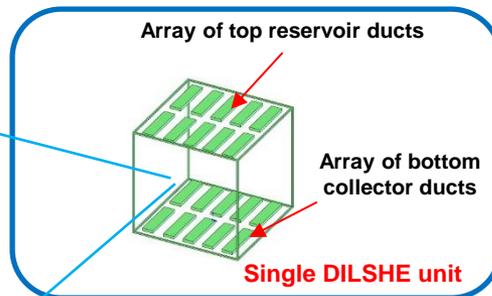
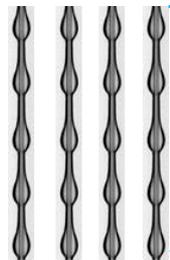
- More efficient evaporative cooling
- Reduced condensation temperature

Compared to the conventional green chillers

- No refrigerant condenser needed -Smaller size
- Reduced waste heat requirement (10X predicted)
- 4X higher COP and lower cost

Direct Contact Liquid on String Heat Exchangers for Dry Cooling of Power Plants

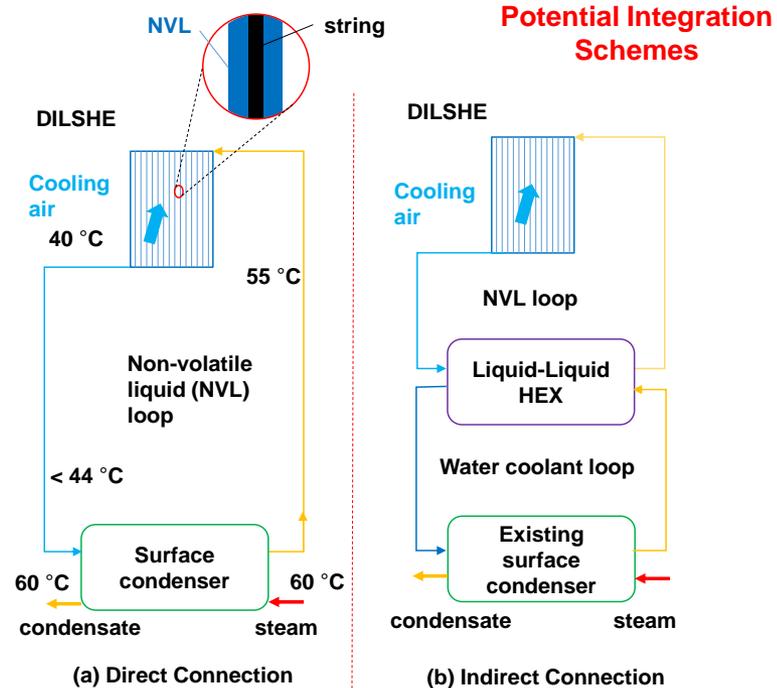
Thin liquid films flowing down on arrays of strings



DILSHE module assembly with a central cooling air fan

Project Scope

- Develop Direct-contact Liquid-on-String Heat Exchangers (DILSHE) for indirect dry cooling of a steam power plant.
- Perform fundamental studies of the fluid mechanics of thin liquid film flows on high-curvature surfaces and associated heat/mass transfer phenomena.
- Perform design, construction, and testing of a scaled-down DILSHE prototype.



Key Potential Benefits

- The DILSHE uses inexpensive polymer strings to create very large heat transfer areas.
- By reducing the use of heavy metals, highly economic and light-weight dry cooling heat exchangers with zero water consumption can be achieved.
- Each DILSHE unit is also readily field serviceable and/or replaceable without disrupting plant operation.



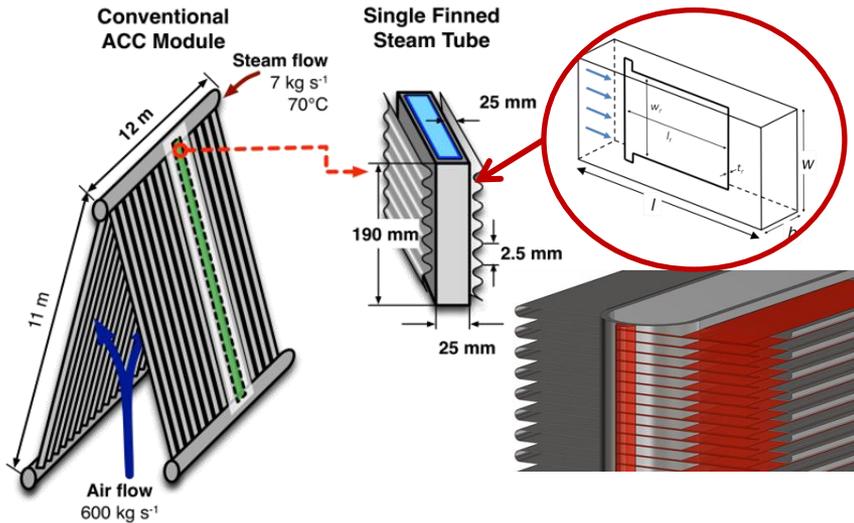
Innovations in Dry Air-Cooling

- Auto Flutter Enhanced Air Cooled Condensers (Georgia Tech/Johns Hopkins)
- Advanced Air Cooled Condensers with Vortex-Generator Arrays between Fins (University of Illinois)
- Nanostructure Enhanced Air-Cooled Steam Condensers (MIT and HTRI)
- Porous Structures With 3D Manifolds For Ultra-Compact Air Side Dry Cooling (Stanford)

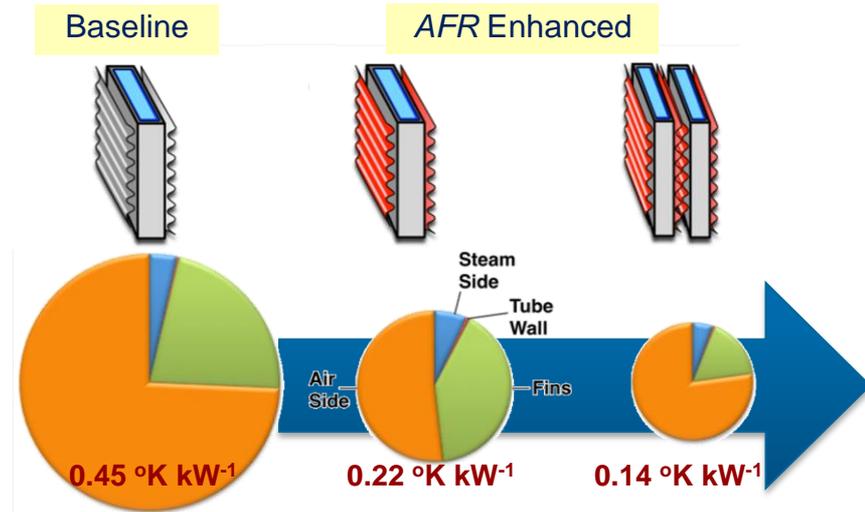


Auto Flutter Enhanced Air Cooled Condensers (Georgia Tech/Johns Hopkins)

ACC



ACC Thermal Resistance



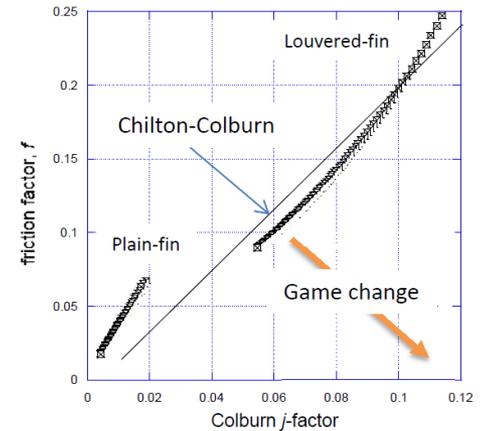
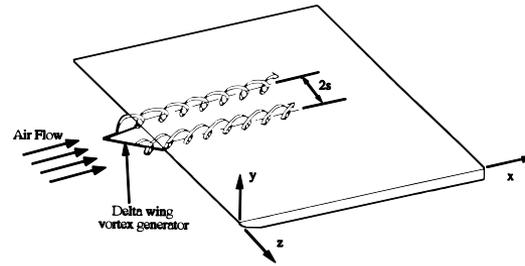
Project Scope

- Objective: Harness interactions between the cooling air flow and miniature, autonomously-fluttering reeds (*AFRs*) in innovative condensers.
- Development of design principles using laboratory experiments
- Performance evaluation in laboratory-scale condenser configurations.

Key Potential Benefits

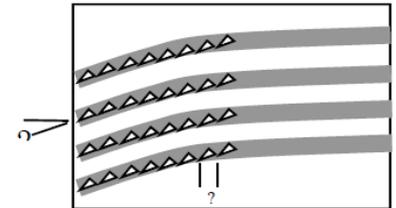
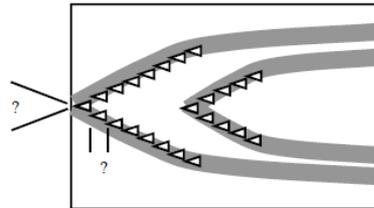
- Significantly increased heat transfer
- Power plant efficiency increased
- Inexpensive, off-the-shelf construction materials
- Retrofittable
- Clear commercialization pathway through collaborations with Southern and SPX

Advanced Air Cooled Condensers with Vortex-Generator Arrays between Fins (University of Illinois)



Project Scope

- Develop enhanced fin design for air-cooled condensers (ACC) based on vortex-generator arrays
- Using model experiments, validate CFD and achieve a near-optimal vortex-generator array
- Develop steam-side condensate management strategies to further enhance ACC performance
- Use system modeling to investigate integration
- Prototype fins to fine-tune design; prototype heat exchanger segment to validate predictions of performance improvements
- Conduct technical and economic feasibility evaluation

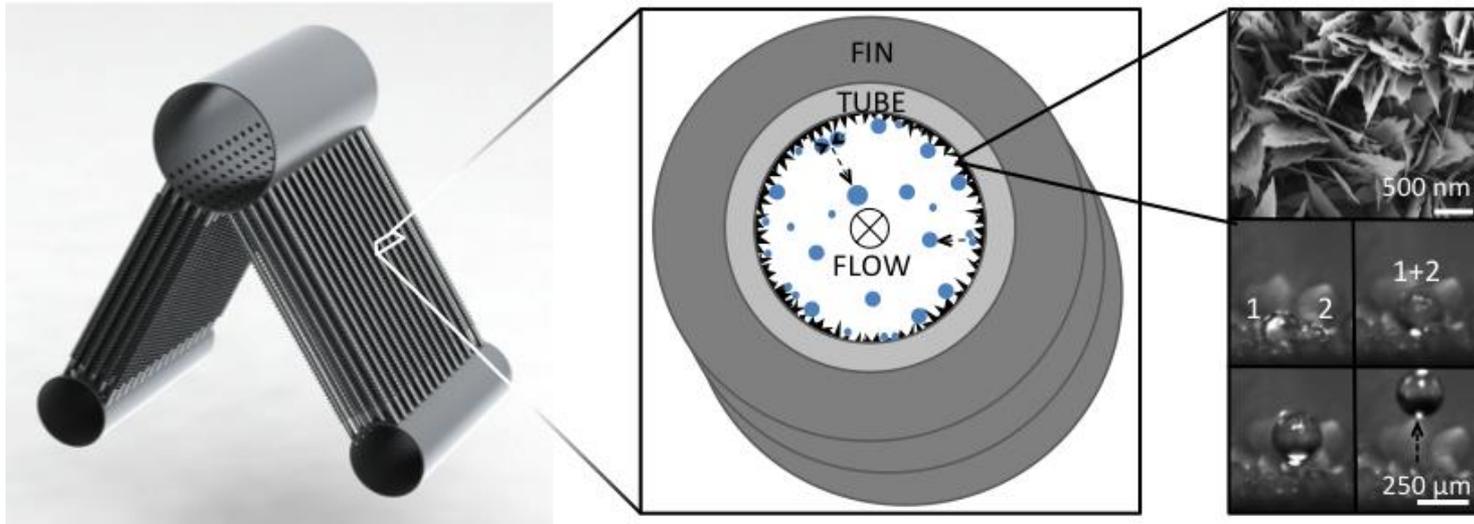


Key Potential Benefits

Compared to currently used ACCs

- 3X higher air-side heat transfer coefficient with no net fan power increase
- Improved steam-side heat transfer coefficient with decrease in steam pressure drop
- Significant cost reduction of ACC systems

Nanostructure Enhanced Air-Cooled Steam Condensers (MIT and HTRI)



Project Scope

- Develop nanostructure enhanced air-cooled A-frame design that maintains same overall dimensions, but with increased number of smaller tube diameters, and enhanced air-side fin surface areas.
- Develop and investigate scalable and robust superhydrophobic nanostructure surfaces that promote jumping droplets with enhanced heat transfer in internal flows
- Optimize the proposed A-frame design and to demonstrate performance enhancements in industrial steam condenser conditions

Key Potential Benefits

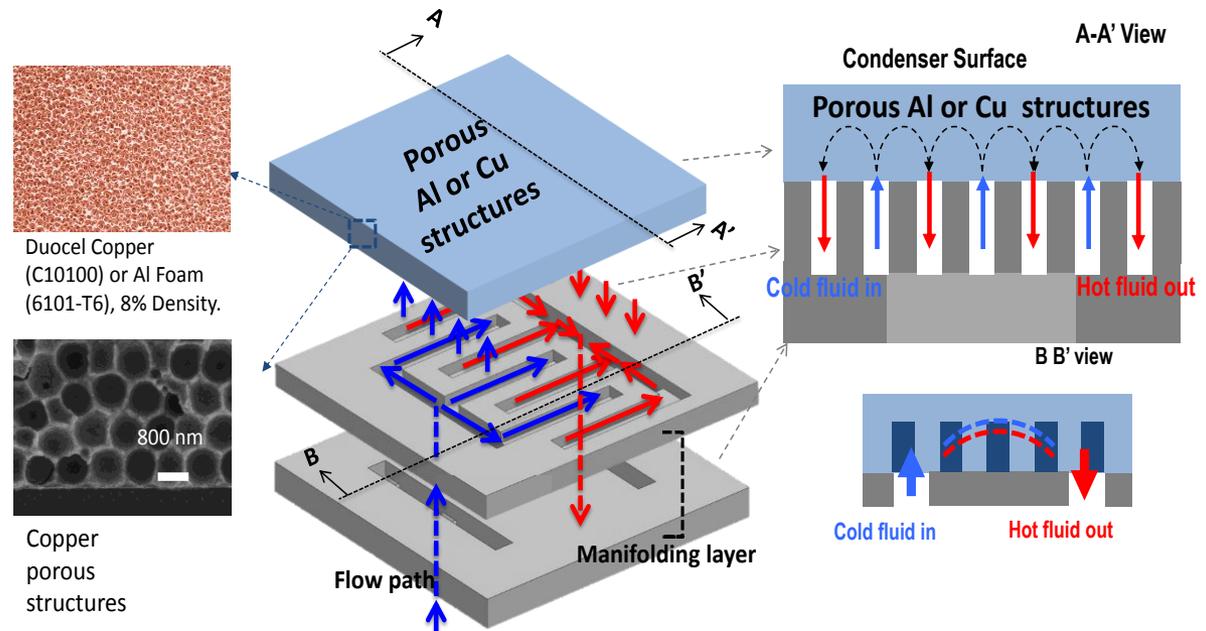
Compared to the currently used ACCs

- Order of magnitude higher condensation heat transfer coefficient
- Comparable steam side pressure drop to state-of-the-art systems with smaller diameter tubes
- Lower condensation temperature resulting in net production gain
- Similar to state-of-the-art A-frame design to facilitate use in existing plants

Porous Structures With 3D Manifolds For Ultra-Compact Air Side Dry Cooling (Stanford)

Project Scope

- Develop a breakthrough 3D manifold that delivers high velocity air to a porous metal structured I/O distributed inlets and outlets to revolutionize the design and performance of A-framed air cooled condensers.
- Validate pressure drop effects through prototype testing.



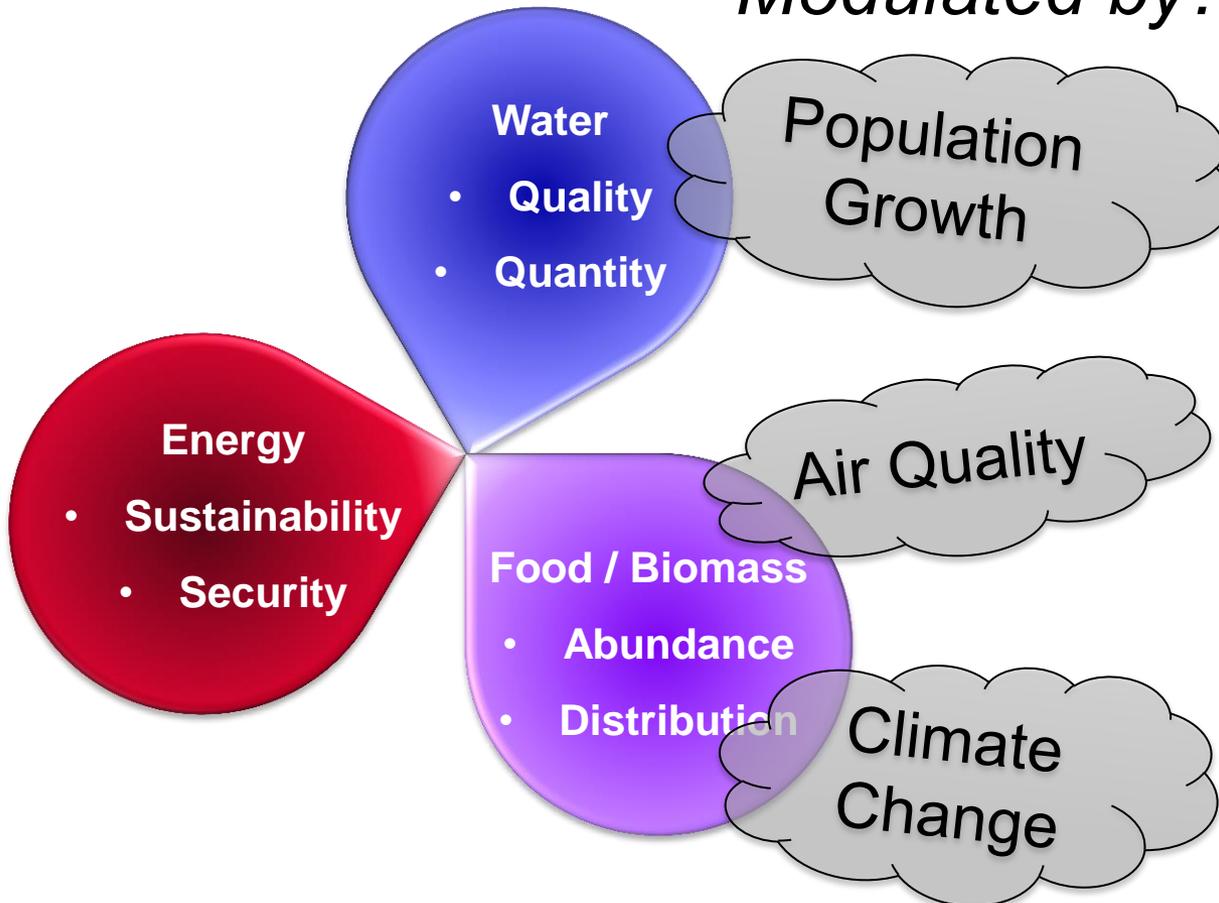
Key Potential Benefits

- Dry Cooling - No cooling water used
- More advanced than conventional air cooled condensers
 - ✓ > 20 X higher air side cooling rate
 - ✓ Lower condensation temperature (10 - 20 °C reduction) resulting in ~5% net production gain (~\$11 M annual credit)
 - ✓ Minimal air side pressure drop or fan power consumption gain
 - ✓ 10x size/footprint reduction

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