CHANGING WHAT'S POSSIBLE

Driving Innovation in Dry-Cooling at ARPA-E

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Princeton E-ffiliates Meeting
Princeton, NJ

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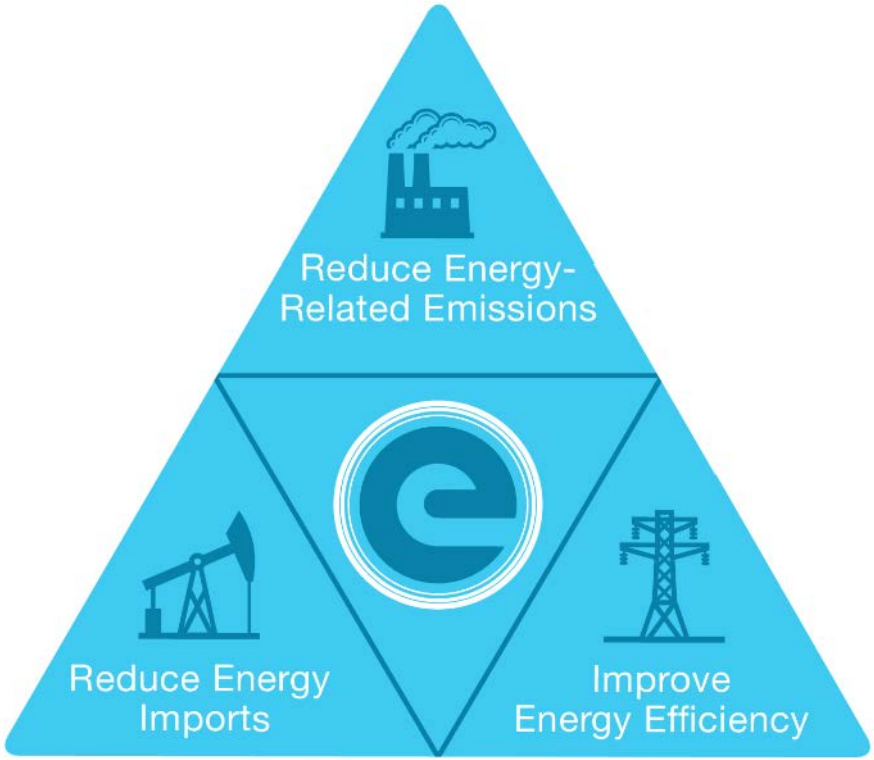
ARPA-E Mission

Catalyze the development of transformational, high-impact energy technologies



Ensure the U.S. maintains a lead in the development and deployment of advanced technologies

Focused Program Portfolio

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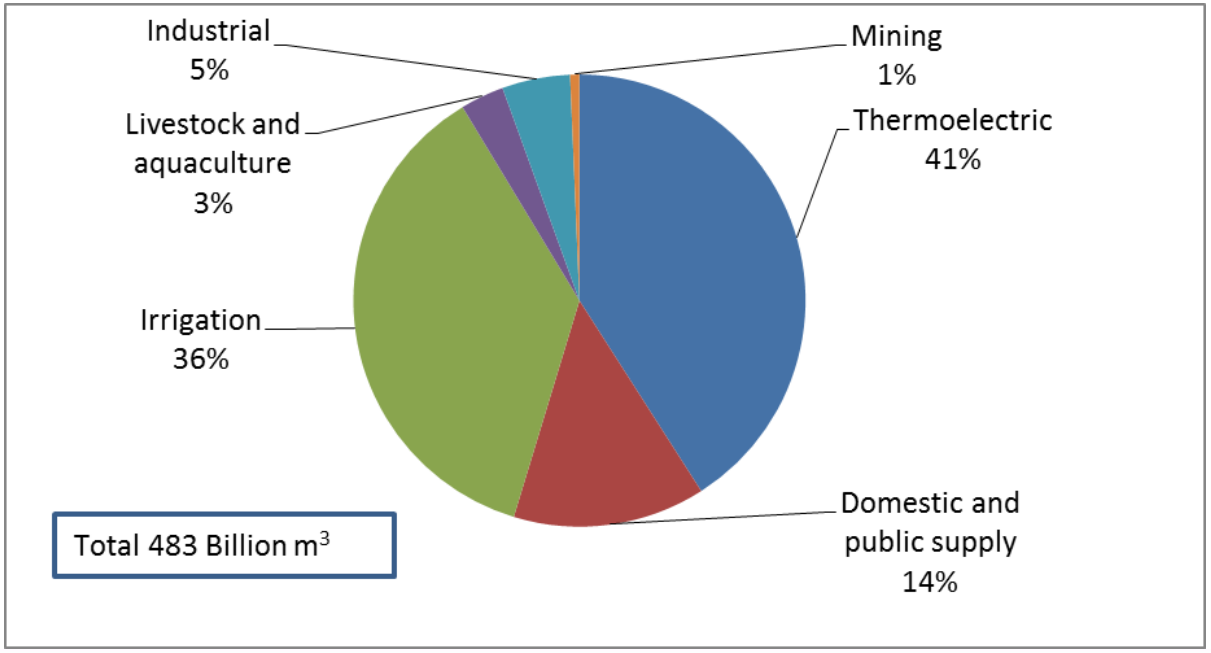
Energy as a Water Problem

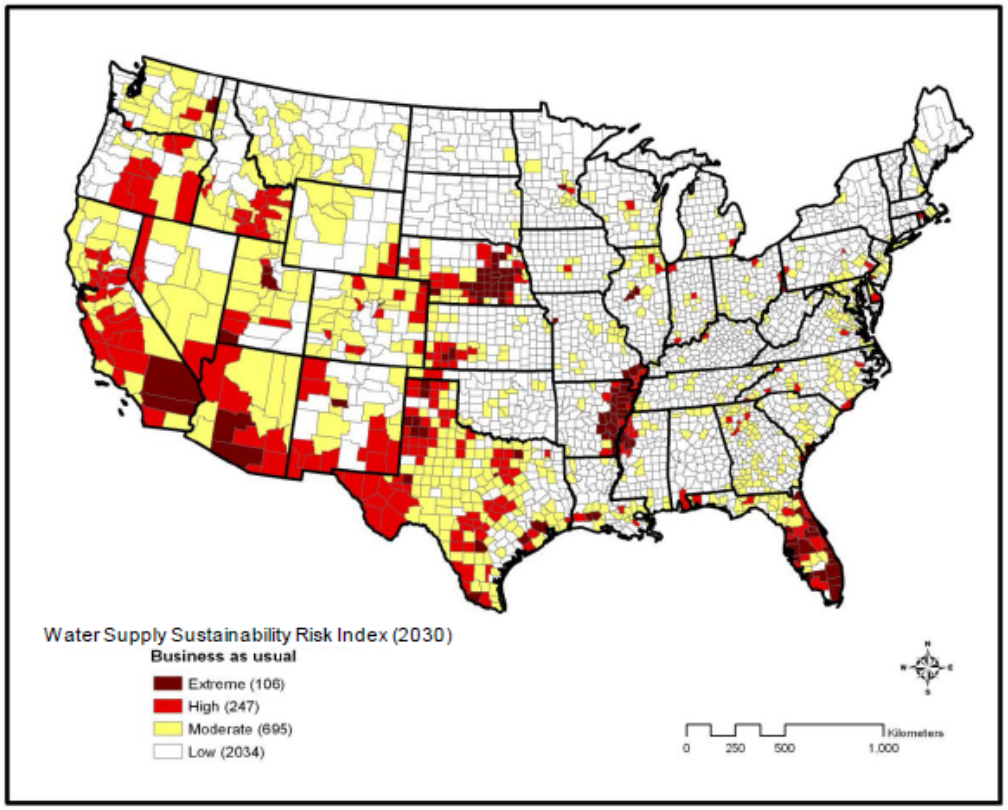
Energy/Water as a U.S. Problem

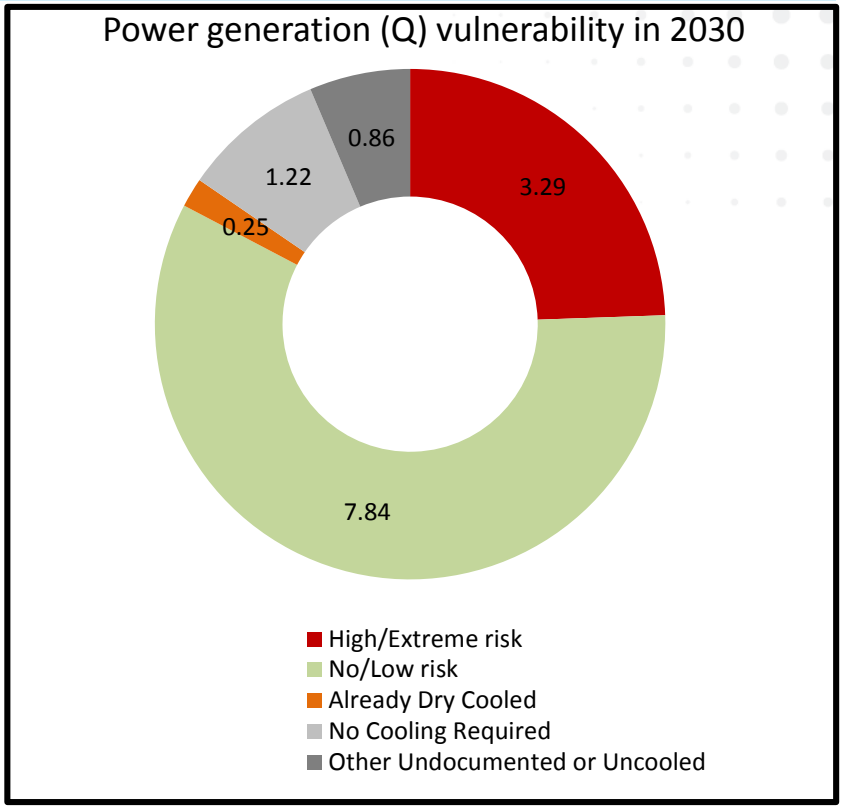
- 41% of freshwater drawn in the U.S. is for thermoelectric power plant cooling
- 3% of cooling tower water load is evaporated and dissipated
- Approximately 2.1 billion fish, crabs, and shrimp killed per year due to power plant intake on once through cooling
- Warming trend and over-pumping of natural water bodies puts water cooling for thermoelectric power at risk



EPRI Study Suggests that Water Availability in 2030 puts >3 Quads Electricity Generation at Risk

3.29 of 13.5Q electricity generation at risk due to population growth alone

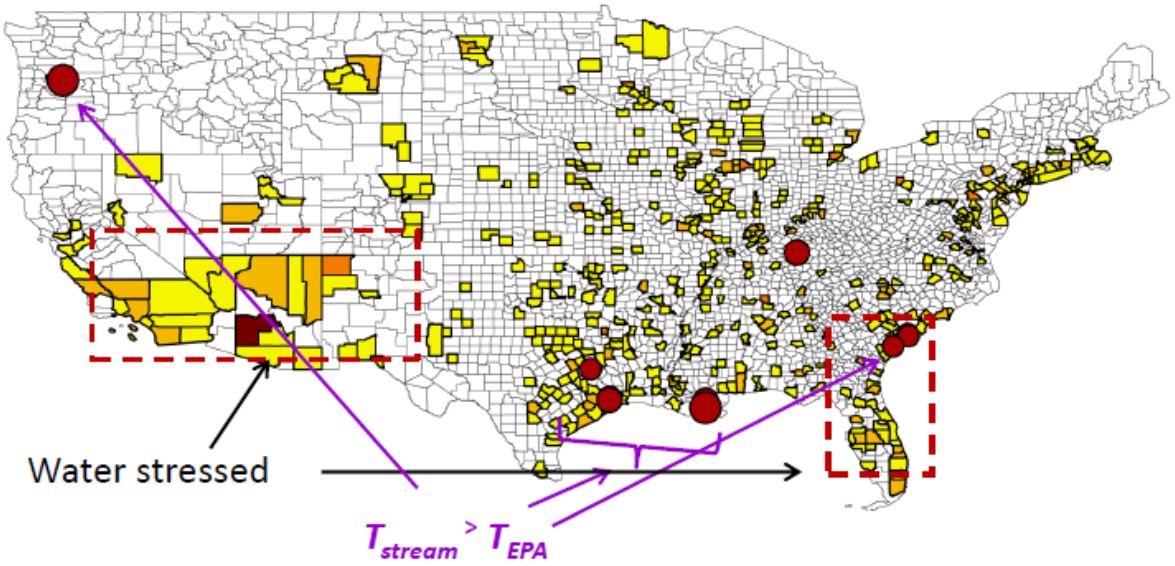




Notes/Assumptions
- Only considers existing production
- Water use *per capita* remain at 2005 levels
- Population growth ~1%/yr (US Census Bureau)
- Water supply/trends at 2005 levels, *No climate change*

How will climate change impact water availability? ARPA-E contract with Northeastern University addresses issue

Between 4.5 and 9 Quads of power production could be at risk between 2030 and 2040



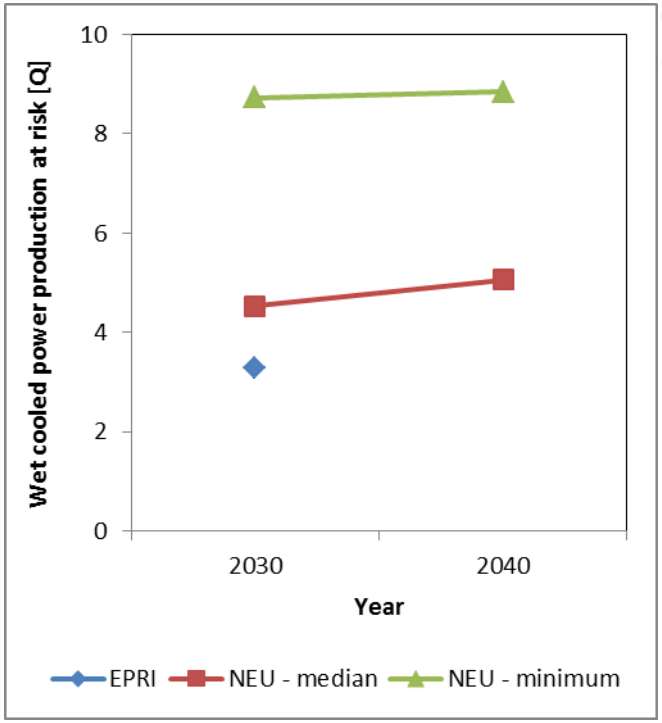
Total Capacity (Quad/year)

- ≤ 0.04
- > 0.04 - 0.08
- > 0.08 - 0.12
- > 0.12 - 0.16
- > 0.16 - 0.20

$T_{stream} > T_{EPA}$ (°C)

- 32.2 - 33.0
- > 33.0 - 36.0
- > 36.0 - 38.0
- > 38.0 - 41.0

Aggregate wet cooled power production in counties at risk



Based only on water availability

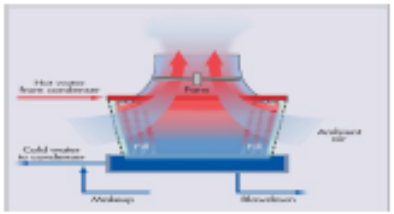
(does not account for power at risk from rising water temperatures)

U.S. Power Plant Infrastructure is Heavily Reliant on Water Cooling

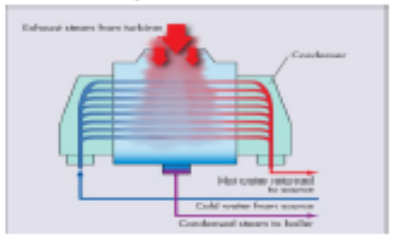
99% | 1% | <1%

Water Cooling

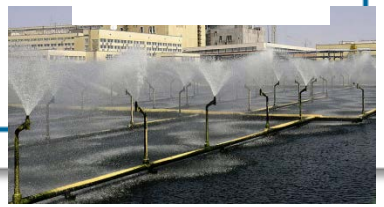
Cooling Tower[1] (42% in US)[2]



Once Through Cooling[1] (43% in US)[2]

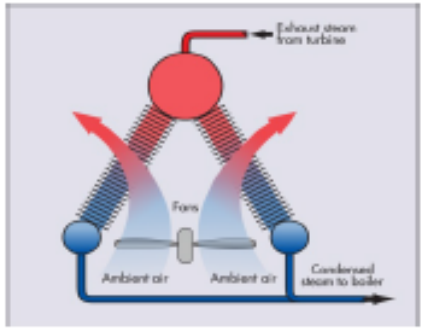


Cooling Pond (14% in US)[2]

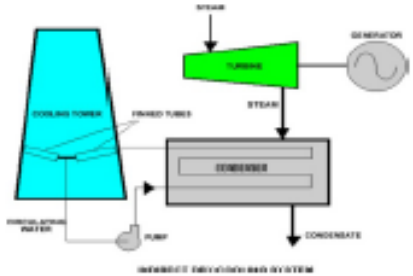


Dry Cooling

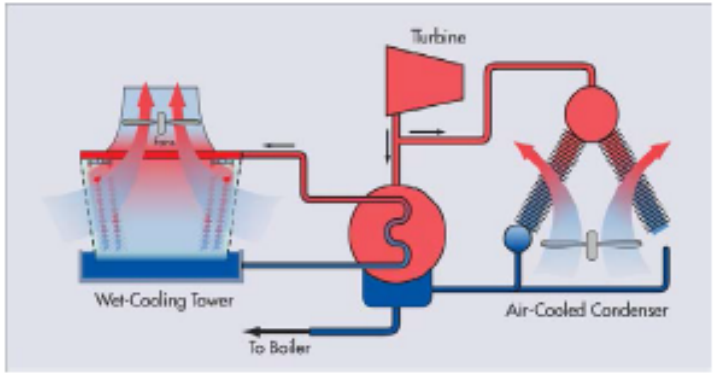
Direct Dry Cooling[1]: Air Cooled Condenser (1%Usage in US)[2]



Indirect Dry Cooling[3]



Hybrid Cooling[1]



Increasing demand for dry cooling in water scarcity regions.

1. *EPRI Report, "Water Use for Electric Power generation", No. 1014026, 2008.*
2. *Report of Department of Energy, National Energy Technology Laboratory, "Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements", DOE/NETL-400/2008/1339, 2008*
3. *http://www.globalccsinstitute.com/publications/evaluation-and-analysis-water-usage-power-plants-co2-capture/online/101181*

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Conclusion: Continued Reliance on Water Cooling for Thermoelectric Power Plants is Risky

- Negative water recharge expected to grow significantly over next 15 years
- More stringent EPA regulations on water intake and thermal discharge will render once-through cooling obsolete
- Rising water temperatures adversely impact power production and efficiency
  - Potential for more frequent curtailment events
  - **EPRI study: 3° C rise in condenser temperature results in 1% reduction in power production**

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The ARID Program Vision and Transformative Technology Solutions

Program Approach

ARID Program	
Kickoff Year	2015
Projects	14
Investment	$30 Million

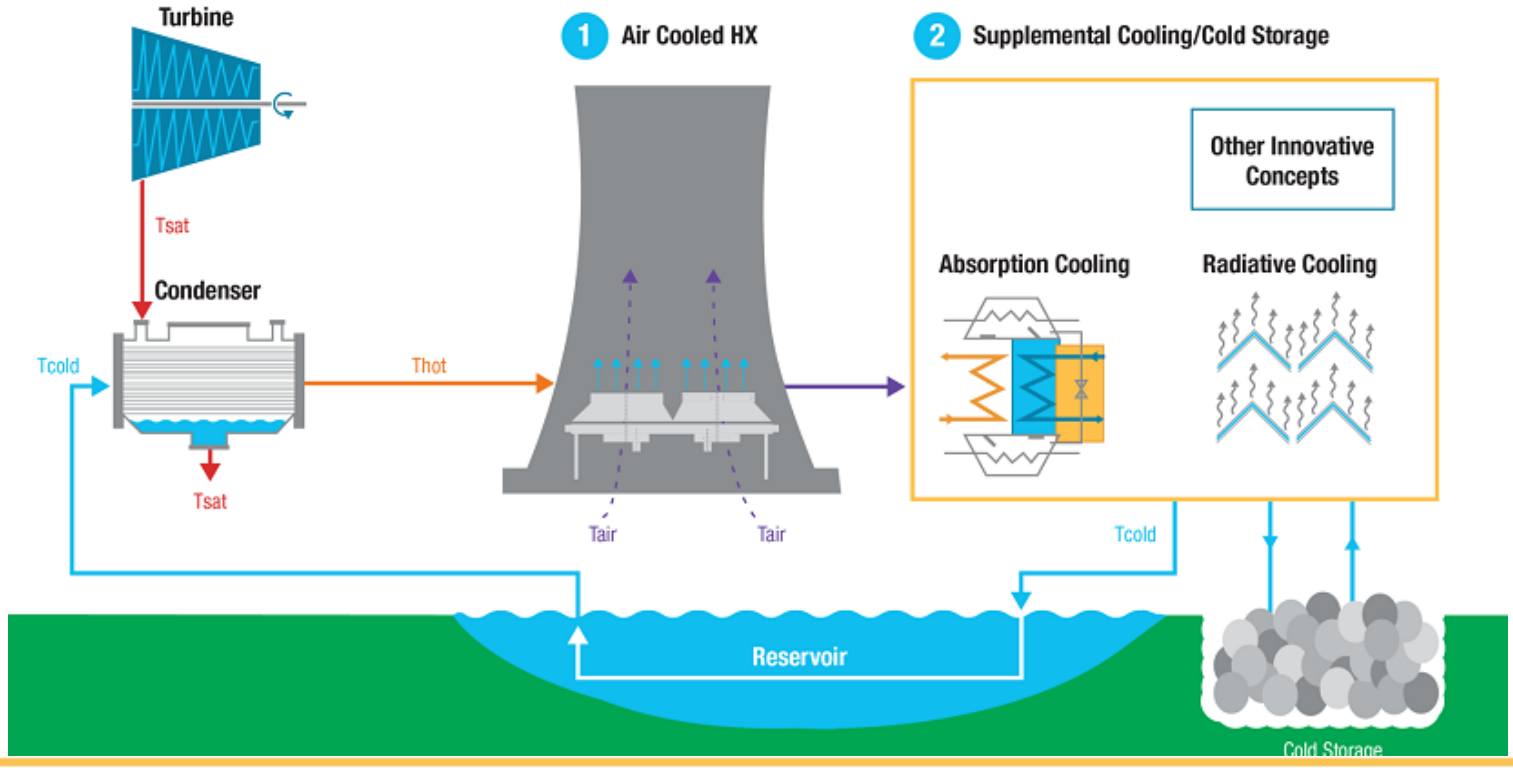
Approach:

- Combine expertise from thermal engineering and manufacturing community to realize new indirect dry-cooling concepts at low cost
- Drastically enhance air side heat transfer coefficient with minimal pressure drop increase
- Sorption cooling systems with COP >2
- Integration of cool storage systems to mitigate temperature excursions
- Radiative supplemental cooling

Program Technologies (14 total)

- Air-cooling heat exchangers (3 projects)
- Sorption & other supplemental cooling (4 projects)
- Radiative cooling and cool storage (3 projects)
- Flue gas H_2O recovery & cool storage (2 projects)
- Combined ACC & cool storage (2 projects)

Sample Indirect Dry-Cooling System that Satisfies ARID Program Objectives



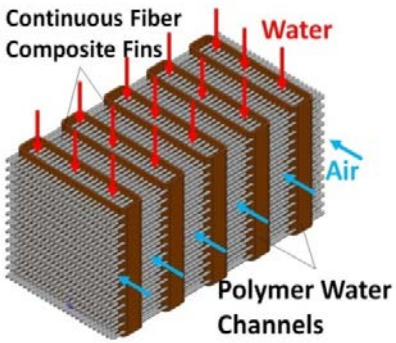
ARID Project – University of Maryland

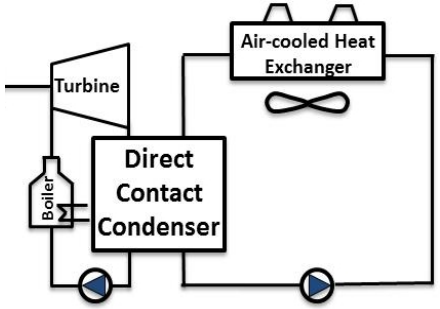
Novel Polymer Composite Heat Exchanger for Dry Cooling of Power Plants

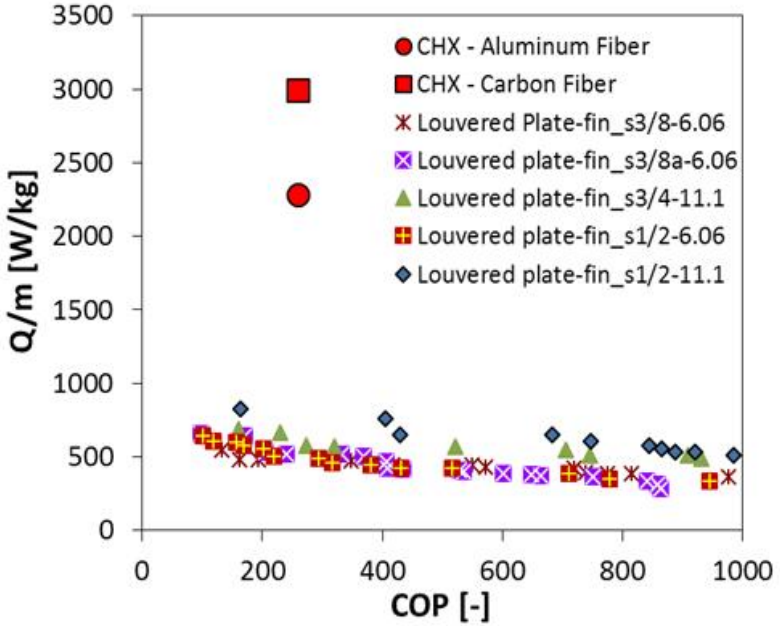
Funding:	$1.9 million
Tech Area:	Air-cooled Heat Exchangers
Location:	College Park, MD

Technology & Impact

- Polymer based composite heat exchanger manufactured via advanced additive manufacturing.
- Potential for very low-cost and high COP (>200)
- High air-side heat transfer coefficient enhancement
- Potential for on site additive manufacturing







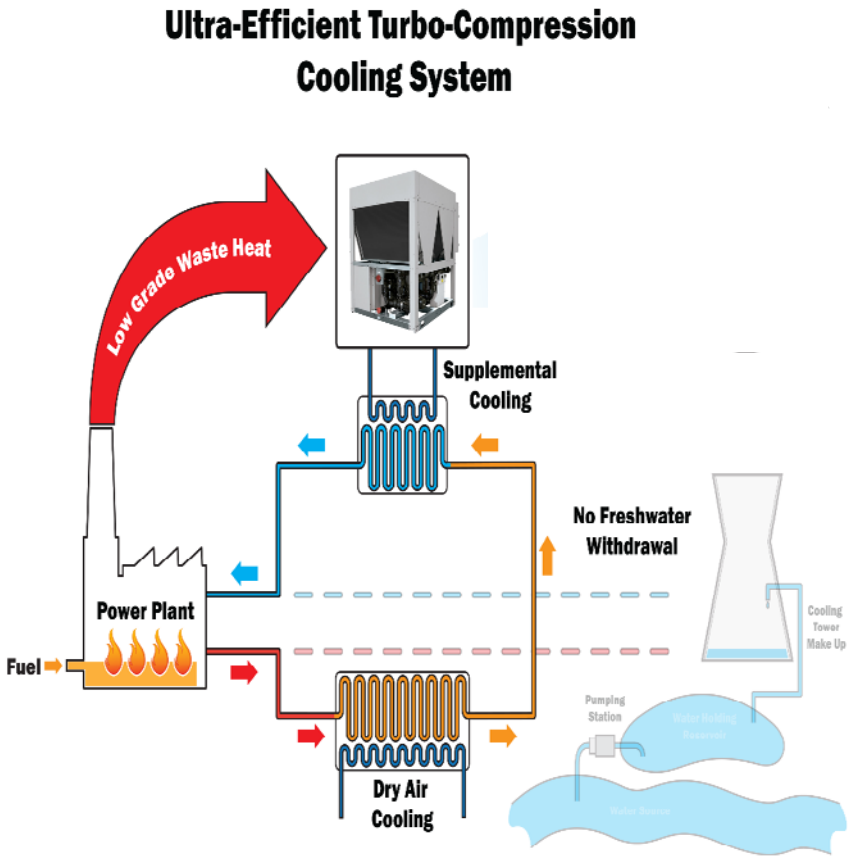
ARID Project – Colorado State University

Ultra-efficient Turbo-Compression Cooling

Funding:	$1.9 million
Tech Area:	Supplemental Cooling
Location:	Fort Collins, CO

Technology & Impact:

- Dry cooling driven by flue gas waste heat
- Optimal working fluids used in separate power and cooling cycles
- Highly efficient turbo-compressor enables transformational thermally activated cooling COP under realistic conditions.
- Heat exchanger technology developed for HVAC and large vehicle industries enables modularity and low system capital cost.
- MW-scale, domestically fueled power plants are made feasible in arid regions



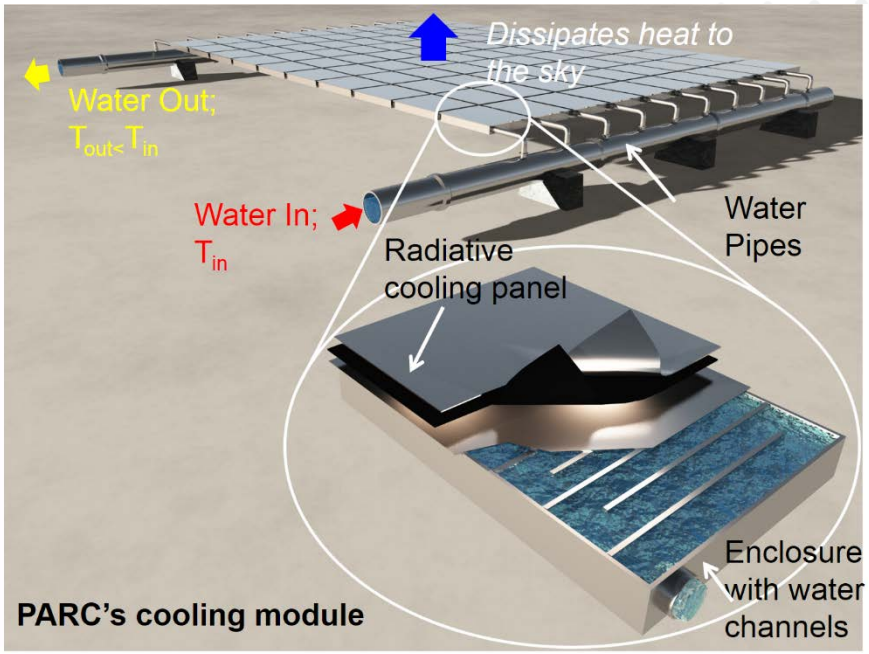
ARID Project – Palo Alto Research Center

Metamaterials-Enhanced Passive Radiative Cooling Panels

Funding:	$1 million
Tech Area:	Radiative Cooling
Location:	Palo Alto, CA

Technology & Impact

- Scalable and low-cost passive radiative cooling architecture, capable of "self-cooling" water temperatures 8^{o}C below ambient temperatures
- Novel metamaterial surface consists of engineered nanostructures tailored to exhibit an emissivity close to unity, emitting heat in the atmospheric transparency window (8-13 μm)
- Key innovation is a simple photonic design that is scalable to a large-are roll-to-roll process that does not require expensive photolithographic patterning



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