InfiniteCooling

Water Recovery from Cooling Tower Plumes

DE-FE0031828 – Spring R&D Meeting

5/17/21

DE-FE0031828 – Water Recovery From Cooling Tower Plumes

Program Dates:
10/1/19 – 9/30/22

Funding (Cooperative Agreement):
Govt. share: $1.5M
Cost share: $375K
Total: $1.875M

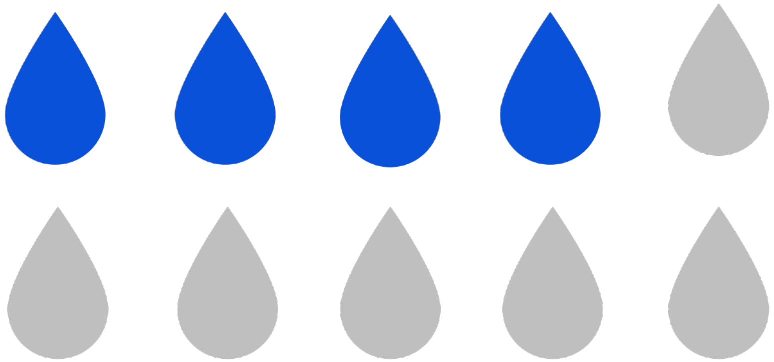
Karim Khalil, PhD
PI, CTO
MIT PhD ’18
Co-founder

Maher Damak, PhD
CEO
MIT PhD ’18
Co-inventor & Co-founder

Prof. Kripa K. Varanasi
Chairman of the Board
MIT Professor
Co-inventor, co-founder

Program Manager: Jessica C. Mullen, PhD - US DOE/NETL

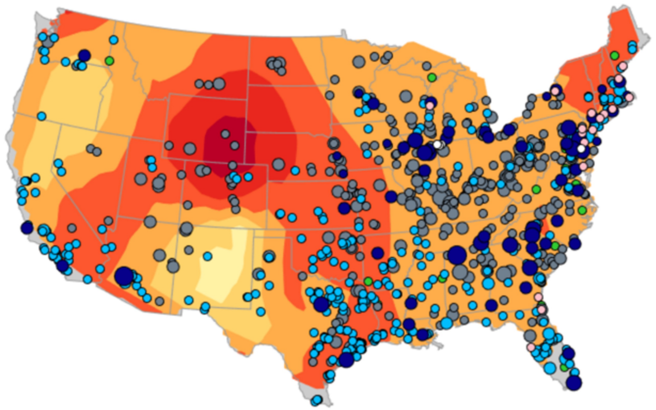
~40% of freshwater withdrawals in the US is for industrial use



1 Trillion Gallons

consumed in industrial cooling in the US in a year

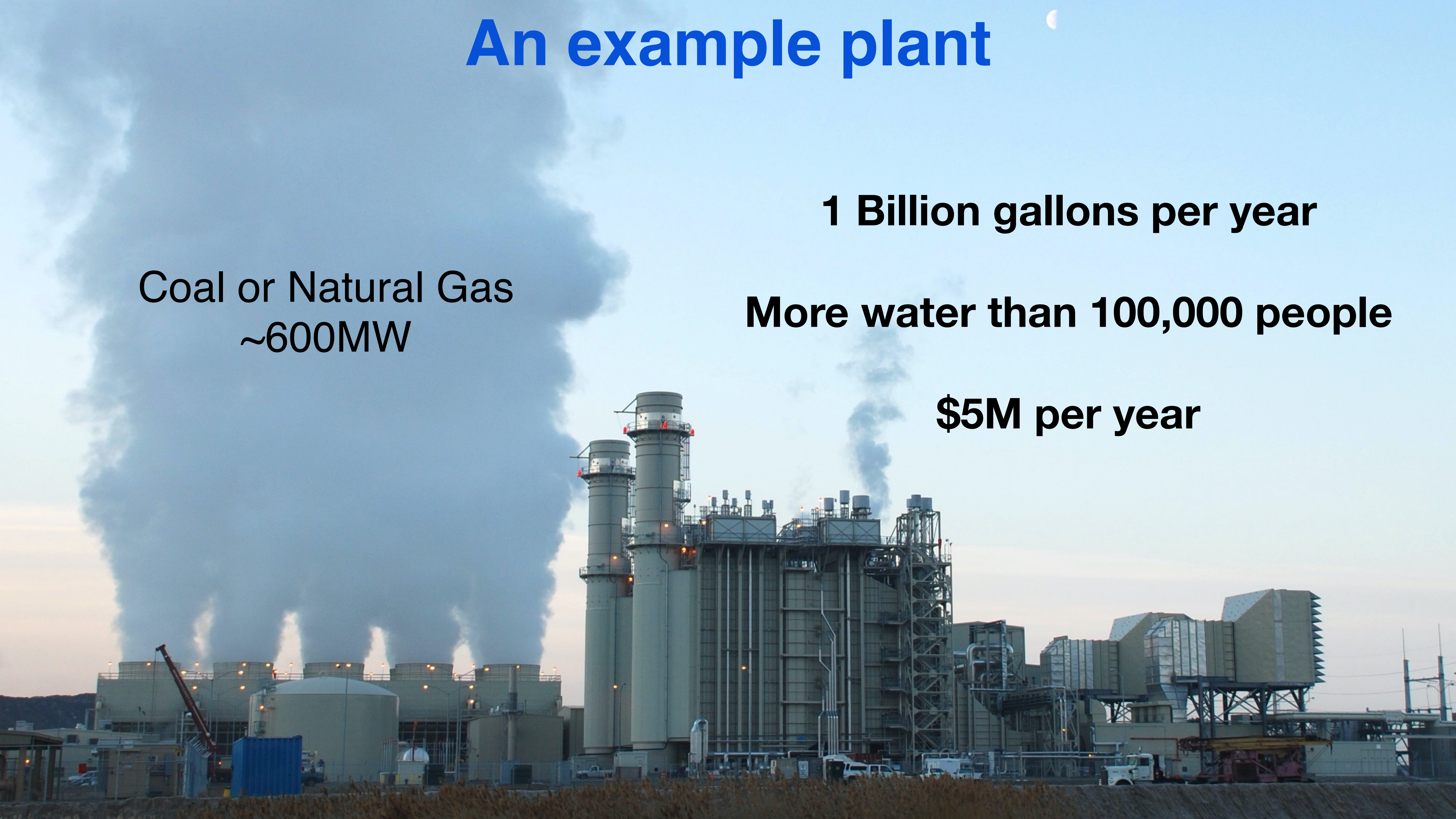
At considerable cost to industrial plants



$30B

on freshwater for cooling

An example plant



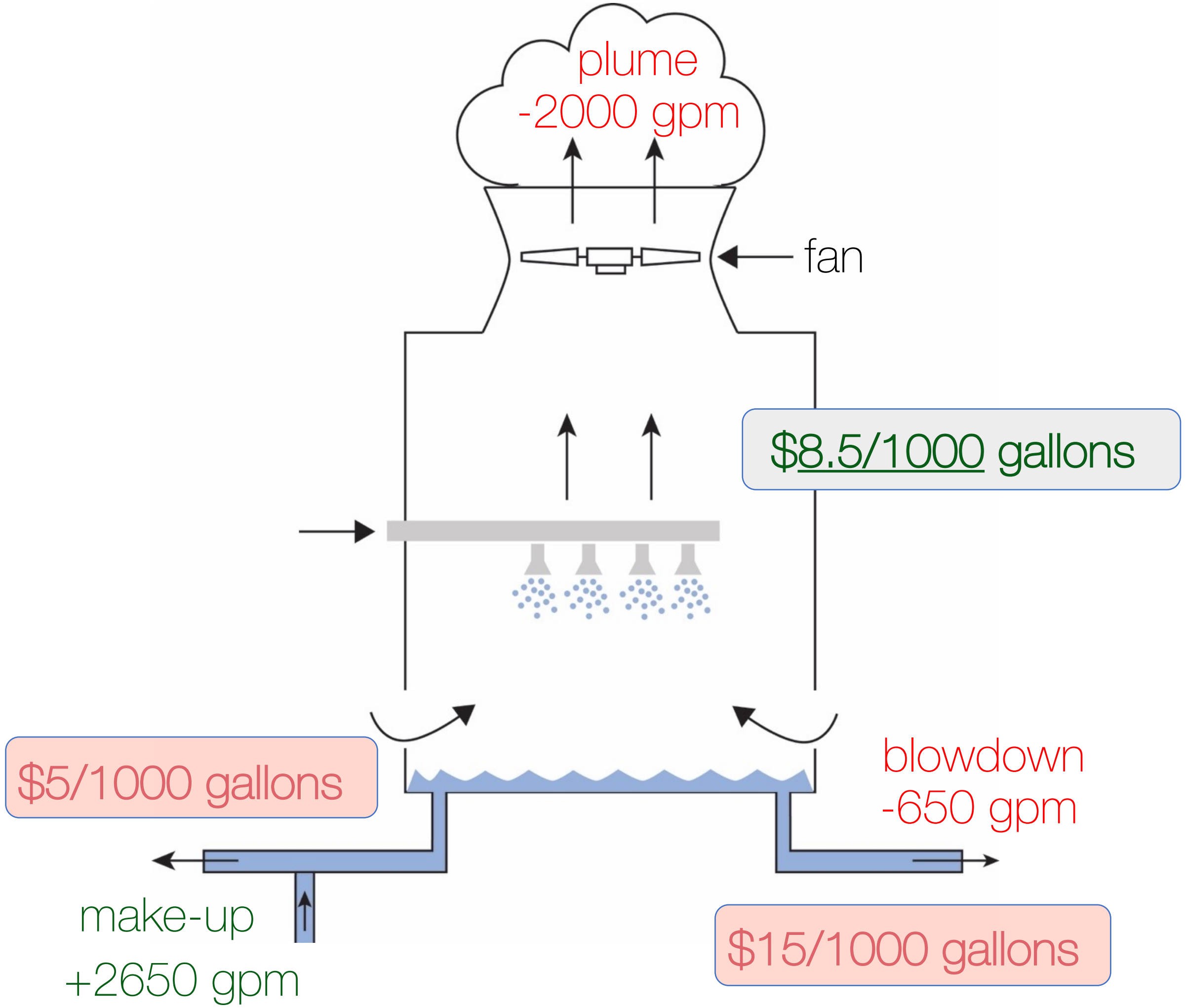
Coal or Natural Gas
~600MW

1 Billion gallons per year

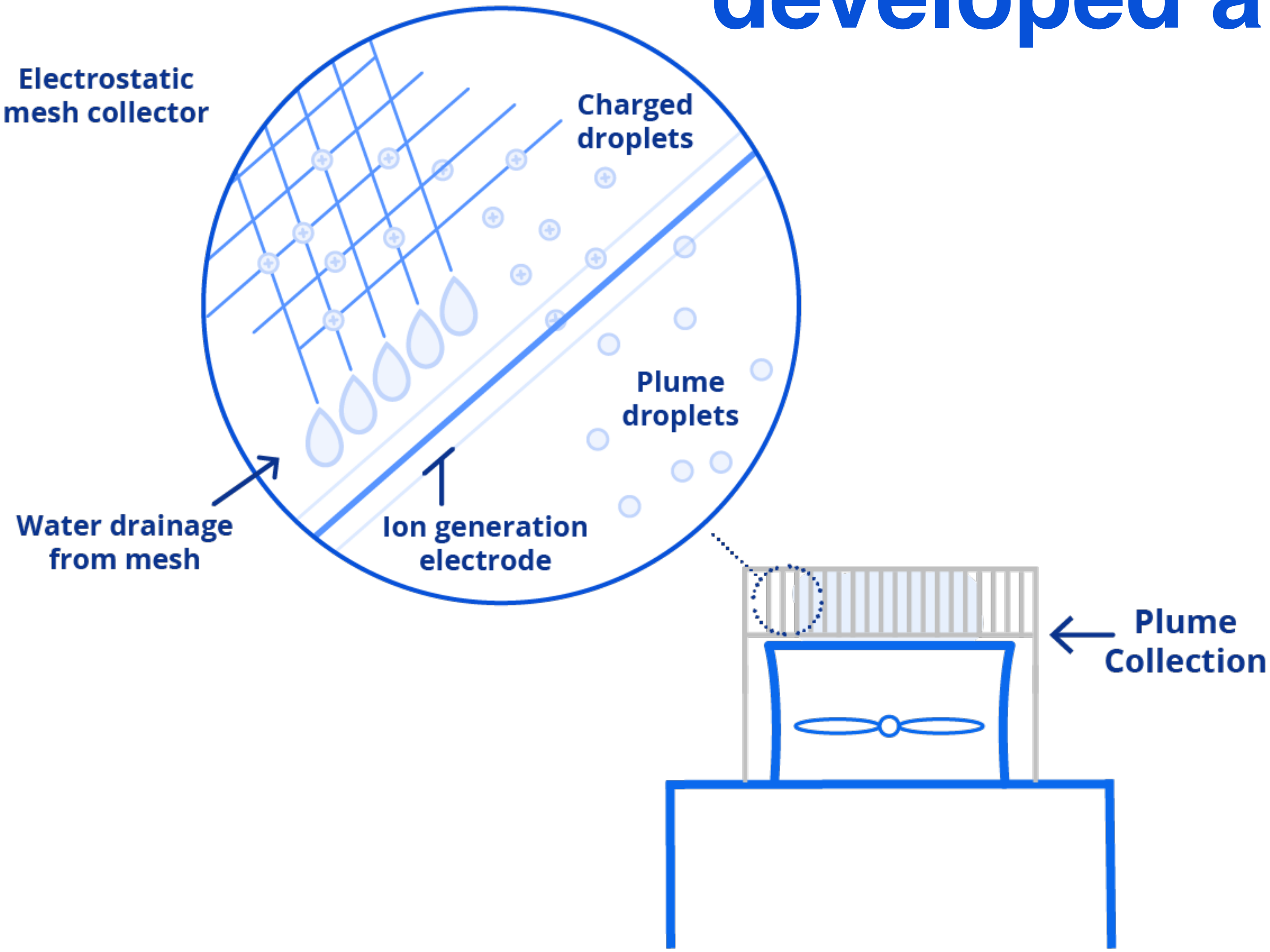
More water than 100,000 people

$5M per year

How Cooling Towers Work



The WaterPanel™ is a patented technology developed at MIT



- **Full plume capture**
- **High-purity water**
- **Plume abatement**

Technology Value

Water-related Costs

$

Water make-up

Water treatment

Blowdown disposal

Demineralized water production

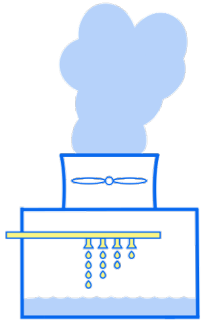
Water Risk

Sustainability Efforts – PR

Water supply uncertainty

Rapidly rising water costs

Plume Hazards



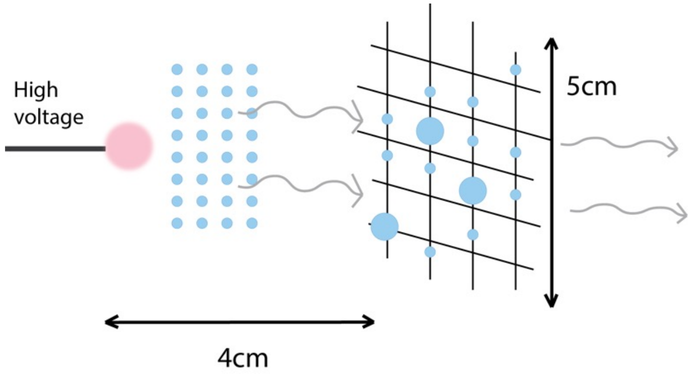
PR – community buy-in

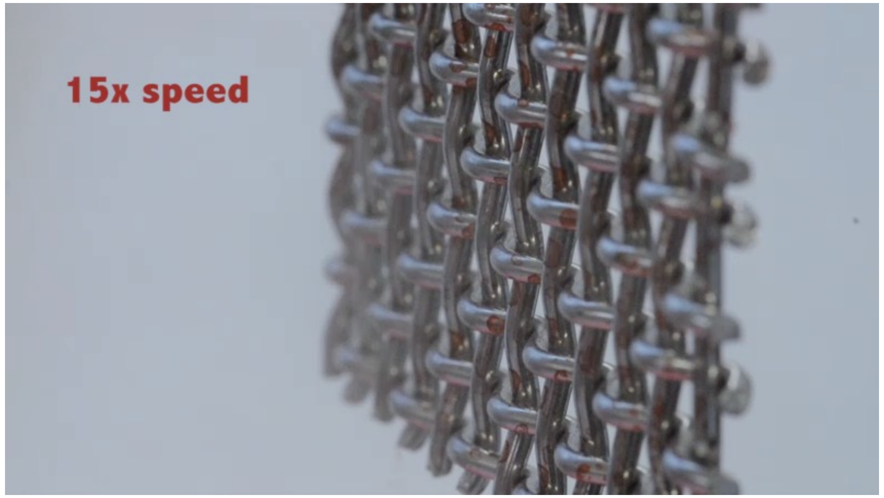
Safety (visibility, icing)

Reliability (corrosion, turbine inlet icing)

Local regulations

Underlying Technology



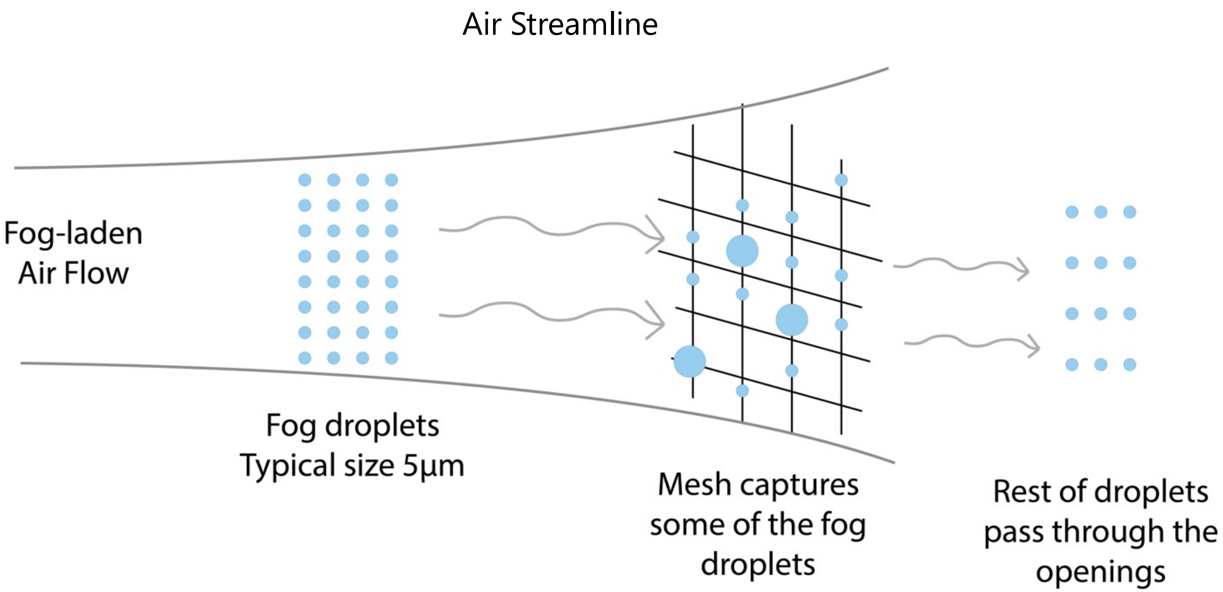


Without field

With field

Damak, M. & Varanasi, K. **Electrostatically-driven fog collection using space charge injection.** *Science Advances 4.6,* (2018).

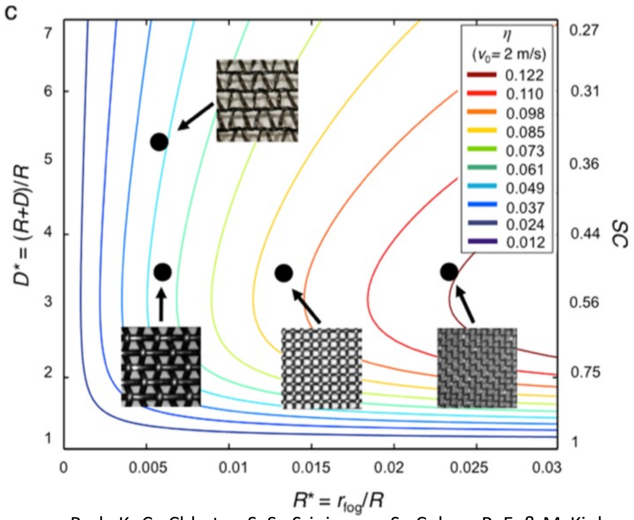
Fog collection and limitations



Main limitations:

- Aerodynamic efficiency
- Shedding efficiency
- Deposition efficiency

Ju, J. *et al.* A multi-structural and multi-functional integrated fog collection system in cactus. *Nat. Commun.* **3,** 1247 (2012).



Park, K.-C., Chhatre, S. S., Srinivasan, S., Cohen, R. E. & McKinley, G. H. Optimal design of permeable fiber network structures for fog harvesting. *Langmuir* **29,** 13269–13277 (2013).

Parker, A. R. & Lawrence, C. R. Water capture by a desert beetle. *Nature* **414,** 33–34 (2001).

Deposition rate is the bottleneck

InfiniteCooling

Project Alignment

From DOE/NETL Crosscutting DE-FOA-0002001:

"Power plant cooling technologies with lower cost, higher performance, and decreased water consumption will be advanced – consistent with the Water Security Grand Challenge, a White House initiated, U.S. Department of Energy led framework to advance transformational technology and innovation to meet the global need for safe, secure, and affordable water…Research is desired that lowers the overall water usage and/or impact on water quality from power plants through advances in cooling technology. Emphasis is placed on near-term solutions that have the potential to assist existing coal-fired power plants to operate in a more water efficient way. New methods will need to be economically viable in the near term."

Project Objectives

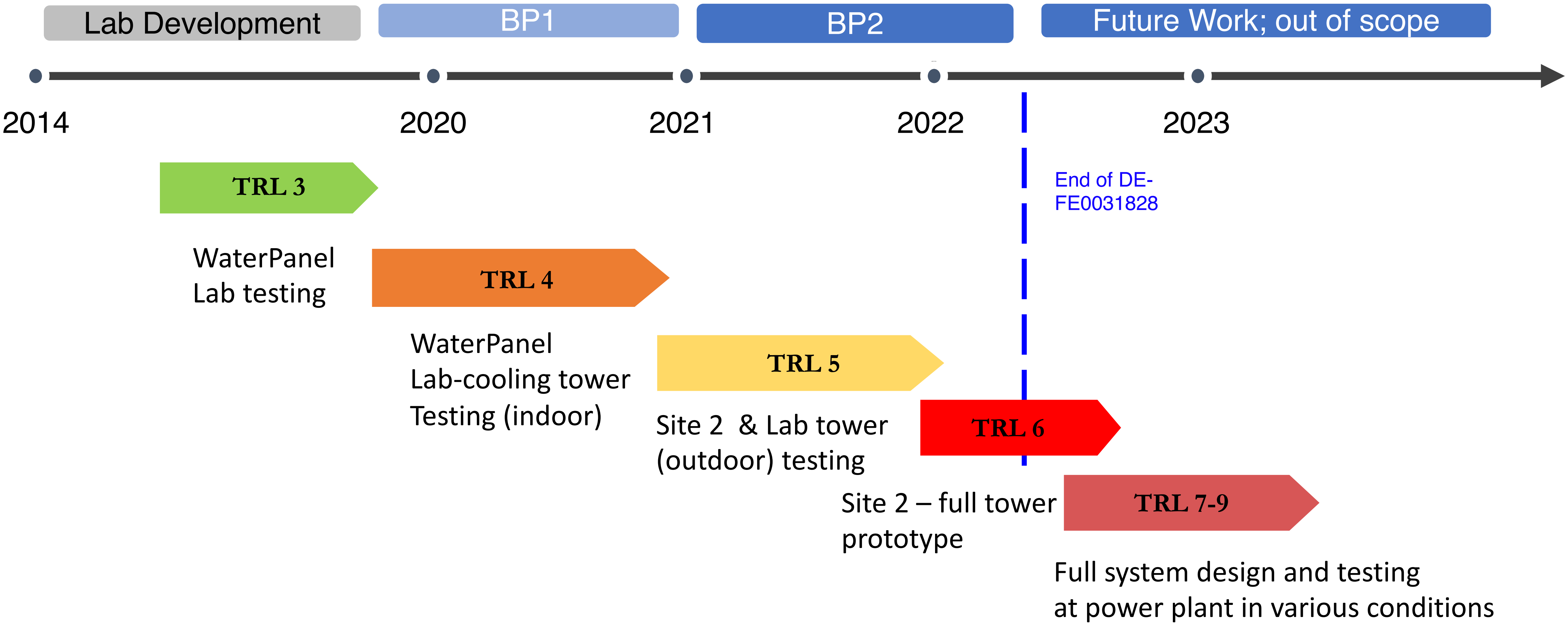
TRL 3->5

- Engineer and optimize electrical plume collection system using WaterPanels
- Testing in a high-fidelity lab setting
- Testing in actual field conditions on a “Site 2” test

Task List

1. Cooling Tower Plume Characterization – droplet size informs collector design and placement
2. CFD Modeling – parameter analysis and mixing analysis – temperature measurements to validate
3. Lab-scale Cooling Tower – high fidelity lab cooling tower setup to validate collection system designs
4. Field-Site-Ready Design – collection system development and manufacturing for field testing
5. Field Site testing – On-site testing of panels and collection system for TEA
6. Techno-Economic Analysis from testing (TEA)

Technology Development Timeline

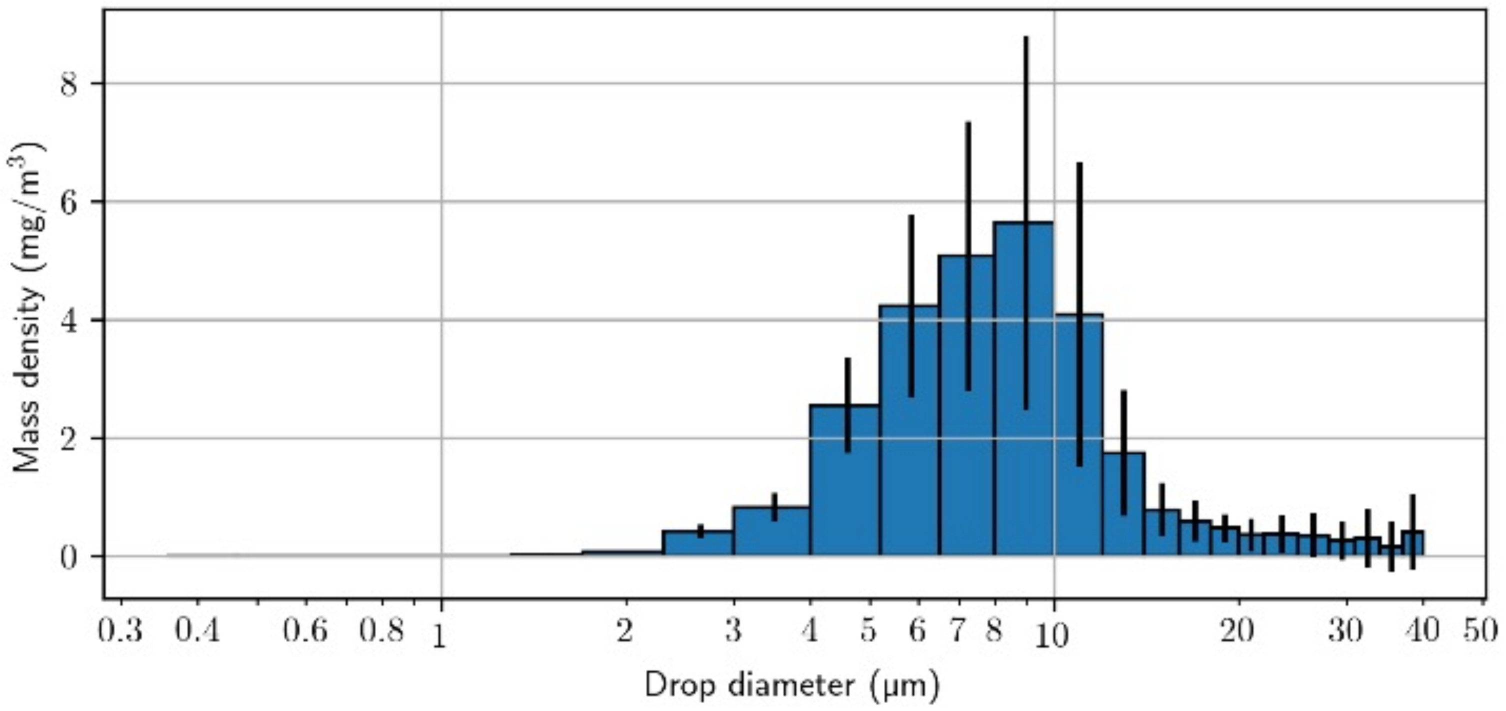


All Tasks

Task List

1. Cooling Tower Plume Characterization – droplet size informs collector design and placement
2. CFD Modeling – parameter analysis and mixing analysis – temperature measurements to validate, wind influence
3. Lab-scale Cooling Tower – high fidelity lab cooling tower setup to validate collection system designs
4. Field-Site-Ready Design – collection system development and manufacturing for field testing
5. Field Site testing – On-site testing of panels and collection system for TEA
6. Techno-Economic Analysis from testing (TEA)

Task 1: Plume Droplet Size measurements

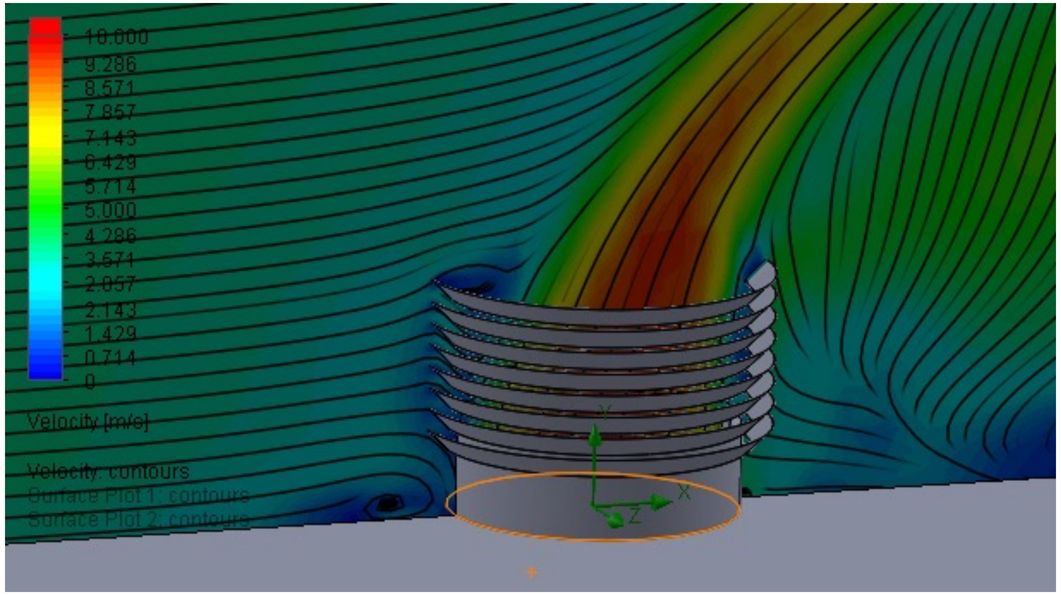


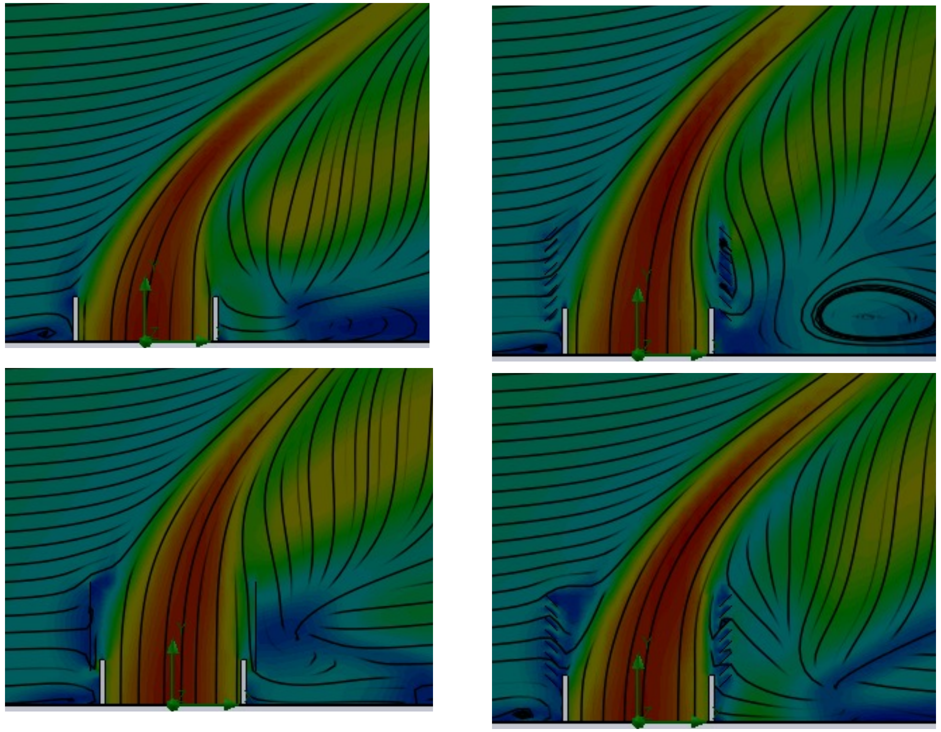
Mass histograms of droplets in the plume above the lab-scale cooling tower

Measurements taken with OPC – Optical Particle Counter

Task 2: CFD Modeling

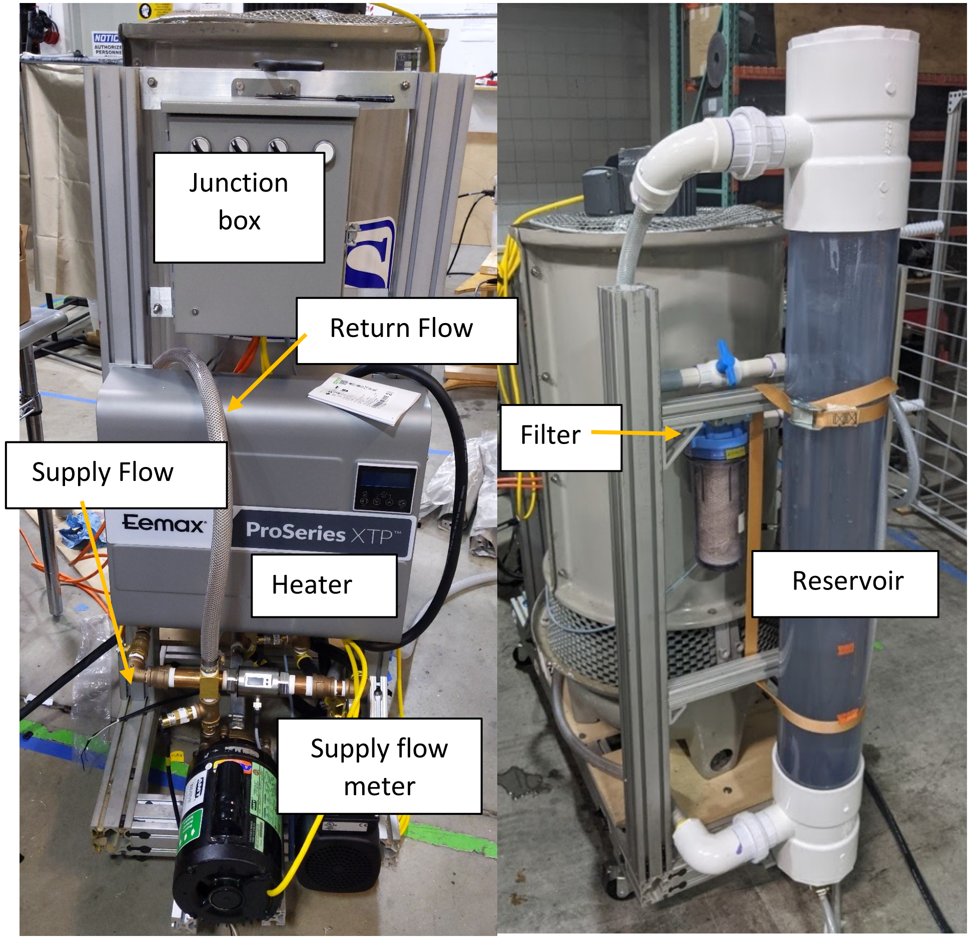
Ambient wind has a large effect on the stability of the plume in our system



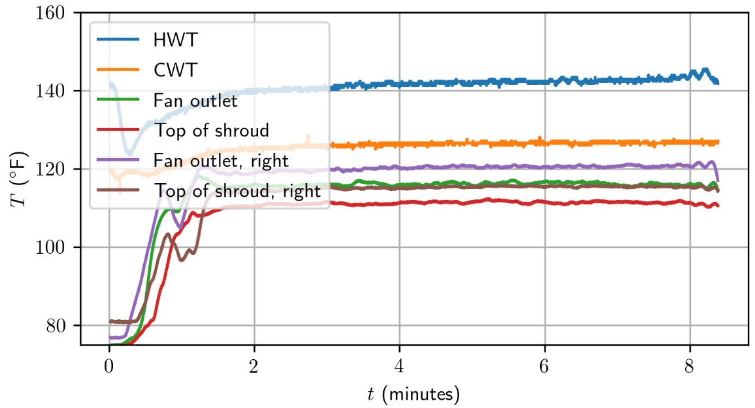


Task 3: Lab Cooling Tower

Evaporative cooling tower in lab designed and tested



Lab-scale cooling tower with shroud attached and a plume above it.



Temperature data from flow meters and thermocouples. HWT and CWT stand for hot water and cold water temperatures and refer to supply and return temperatures from the flow meters.

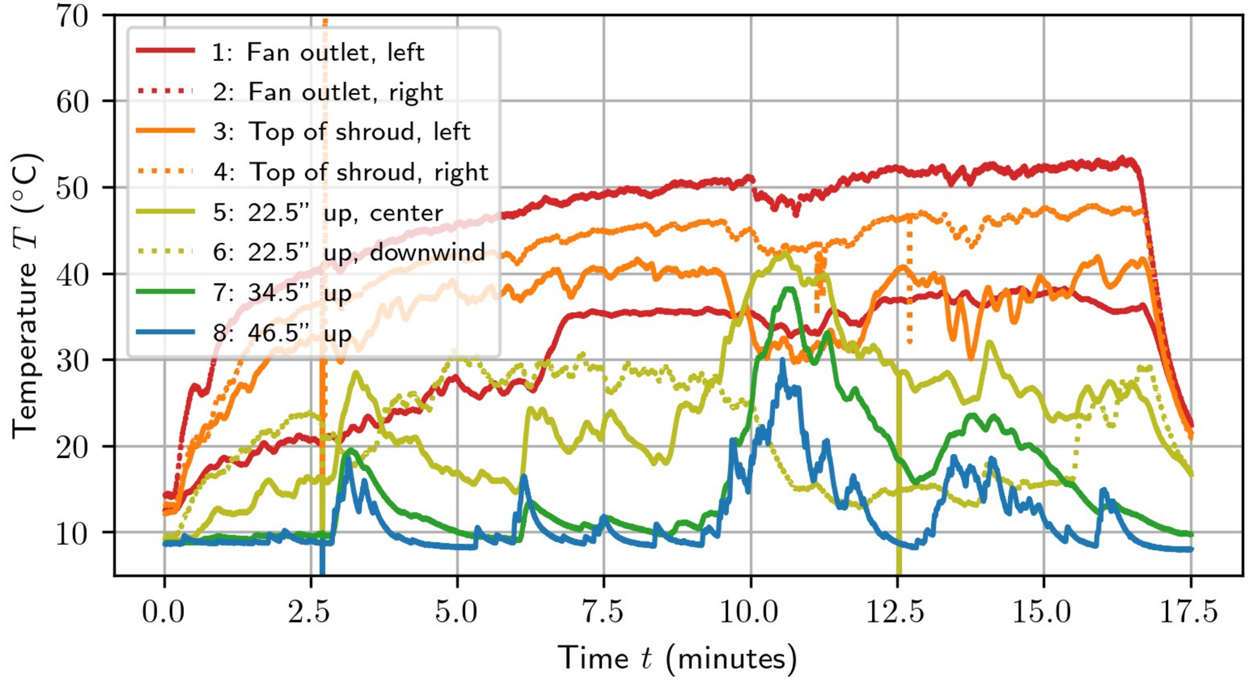
Task 3: Outdoor lab cooling tower tests

- 10 outdoor test days from August through March
  - Tested in variety of temperatures, wind speeds
- Measured collection rates and plume temperatures for varying fan speeds, voltages
  - Compared collection efficiencies to model
  - Captured plume abatement videos
- Iterated on collector design
  - Shortened collector
  - Added plates on all four sides to block wind

Plume Abatement Lab-Cooling Tower

Task 3: Lab Cooling Tower Measurements

- Thermocouples measure plume temperatures in 8 locations
- Strong effect of wind (no shrouding plates here)
- Compare to model using psychrometric chart to find optimum collection temperature and height
- Calculate optimal theoretical collection efficiencies based on ambient temperature, relative humidity, and plume temperature
    - Colder, wetter conditions give higher collection efficiencies
- Next steps:
    - Use temperature measurements to characterize mixing vs. height
    - Optimize mixing and collection height to improve experimental efficiencies



InfiniteCooling

BP1 Tasks

Task List

1. Cooling Tower Plume Characterization – droplet size informs collector design and placement
2. CFD Modeling – parameter analysis and mixing analysis – temperature measurements to validate, wind influence
3. Lab-scale Cooling Tower – high fidelity lab cooling tower setup to validate collection system designs
4. Field-Site-Ready Design – collection system development and manufacturing for field testing

Performance Attribute	Target
Lab Tower Collection Efficiency (model vs experimental)	Max ~10-20%
Lab Tower Plume abatement	70-80% plume droplets

Task 4-5: What's Happening Now

- Site 2.0 structure build complete
- WaterPanel installation (same design as Lab Cooling Tower Tests)
- Site 2.0 Sensor Installation
- **Site 2.0 Field testing into BP2**

Task List

1. Cooling Tower Plume Characterization – droplet size informs collector design and placement
2. CFD Modeling – parameter analysis and mixing analysis – temperature measurements to validate, wind influence
3. Lab-scale Cooling Tower – high fidelity lab cooling tower setup to validate collection system designs
4. Field-Site-Ready Design – collection system development and manufacturing for field testing
5. Field Site testing – On-site testing of panels and collection system for TEA
6. Techno-Economic Analysis from testing (TEA)

Site 2 Build

- MIT NRL
- 12.5x25 ft cooling towers (2x)
- TowerTech OEM
- Large Plume formations
- ~10M Gallons of water used per year
- Cooling tower water quality: 3200 uS/cm
- Cambridge City Water: 700 uS/cm

Site 2 Initial Water Quality

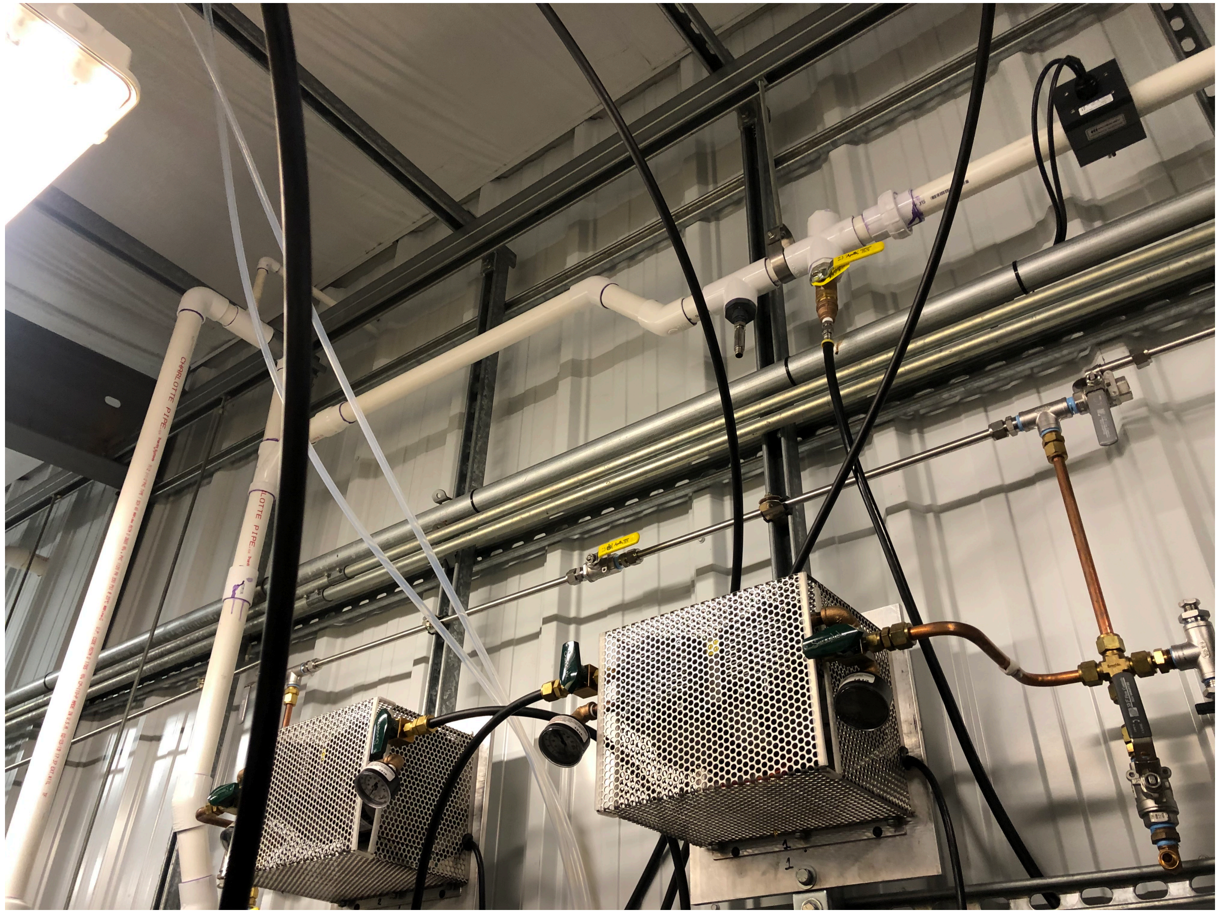
- Collected water being re-used in Nuclear Cooling cycle
- Collected water has **100-150X reduction** in conductivity (uS/cm) than site process water of 3200 uS/cm

Initial Plume water
20-30 uS/cm

	uS/cm
DISTILLED WATER	0.5 - 3
MELTED SNOW	2 - 42
TAP WATER	50 - 800
POTABLE WATER IN THE US	30 - 1500
FRESHWATER STREAMS	100 - 2000
INDUSTRIAL WASTEWATER	10000
SEAWATER	55000

Demineralized water needs 1-50 uS/cm typically

Site 2 System Integration



- Collected water from system re-used in MIT NRL plant
- Water Meter allows totalizer and instantaneous water flow rate data

Task 4-5: Future tasks & Wrap Up

TRL 4 -> 5

- Site 2 field testing: collection efficiency testing throughout various ambient conditions. Verification of plume model in operational environment ongoing
- Site 2 plume abatement data: plume abatement achieved
- Site 2 water quality data: highly pure water
- Site 2 electrical load analysis ongoing

Performance Attribute	Target
Site 2 Collection Efficiency	~10-20%
Site 2 Plume abatement	70-80% plume droplets
Site 2 water quality	>95% reduction in contaminants
Site 2 insulator parasitic losses vs. total power	15% or lower
Scaled power to full 25-30’ cooling tower	30-40kW or lower

QUESTIONS?

Acknowledgement and Disclaimer

This material is based upon work supported by the Department of Energy Award Number DE-FE0031828