Ultra-Low Global Warming Potential Fluids to Reduce Carbon Footprint in Data Centers

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Project Summary

Objectives

- Perform heat transfer evaluations of Ultra low GWP fluids for Data Center "immersion" applications
- Performance evaluation of actual equipment (two-phase immersion cooling tank) with new fluids
- Energy modeling/simulation of current and future Data center buildings, including LCCP evaluations

outcome

- Thorough evaluation of low environmental impact technologies for data center buildings

Team and Partners

Principal Investigator: Samuel Yana Motta

ORNL Researchers: Saad Ayub Jajja, Cheng-Min Yang

CRADA Partner: Chemours - Gustavo Pottker

Stats

Performance Period: FY23-FY24

DOE budget: $500k/year, Cost Share: $300k/year

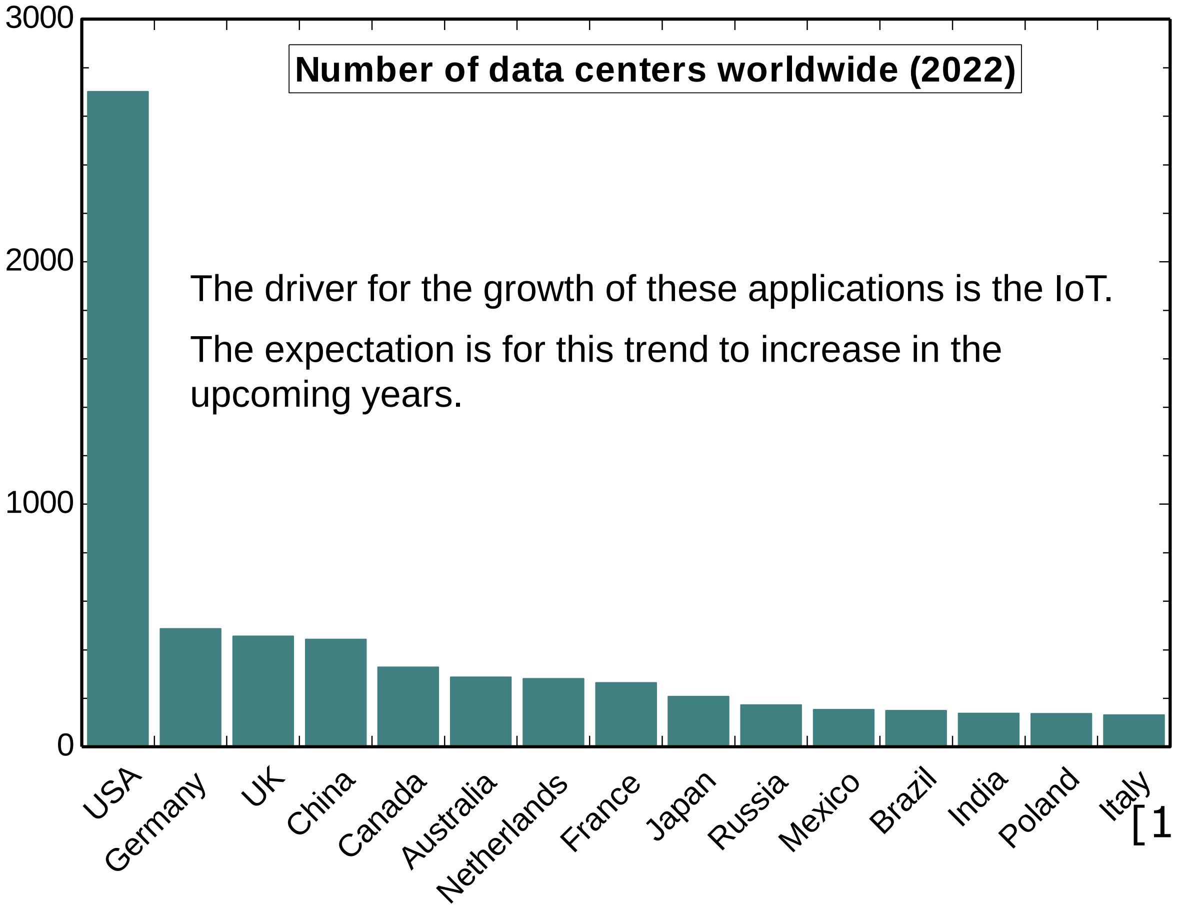
Milestone 1: Pool Boiling Evaluations (FY23 Q3)

Milestone 2: Equipment Evaluations (FY24 Q2)

Milestone 3: Energy and LCCP analysis (FY24 Q4)

Problem

- Data centers facilities consume 0.3–0.7 quads of energy or about 2–5% of the total annual US energy consumption[2]
- Most data centers are air-cooled with an average Performance Usage Effectiveness (PUE) of 1.7, which means that the cooling system uses 70% of the total information technology (IT) power to remove heat from the building
- Reduction of Total Environmental Impact:
  - Two-phase immersion cooling using highly-efficient fluids is a leading technology that can reduce PUE (and energy consumption) to as low as 1.02, with little to no water consumption
  - To reduce the direct emissions in a reliable and sustainable way, ultra-low-GWP/Dielectric fluids need to be used.



[1]

[1] **https://www.statista.com/statistics/1228433/data-centers-worldwide-by-country**
[2] de Bock, P., V. Lecoustre, C. Noyes, T. Bress, R. Radhakrishnan, and J. Gallagher. 2021. "Cooling Compute Systems Efficiently, Anytime, Anywhere." *Energy Efficiency Computing Workshop*, December 21, 2021. [Online] Available at https://www.arpa-e.energy.gov/sites/default/files/4.%20Vision%20Pitch%20-%20deBock.pdf

Alignment and Impact

- **Indirect Effect in the power decarbonization due to reduction of Energy consumption**

	Typical Air Cooling	Two-Phase Immersion Cooling with High-GWP Fluid	Two-Phase Immersion Cooling with very low GWP fluid
PUE (typical/average in the United States)	1.70	1.03	1.03
GWP of fluid	0	9,500	~10
Total average annual energy consumption per Data Center (GWh)	54.9	32.9	32.9
Average cooling annual energy consumption per Data Center (GWh)	22.6	0.6	0.6
CO_2 emissions due to total energy use per DC (thousand Tons of CO_2)	23.1	13.8	13.8
CO_2 emissions due to cooling energy use (thousand Tons of CO_2)	9.5	0.3	0.3
Total amount of immersion cooling fluid per DC (t)	0.0	55.3	55.3
Total amount of leak fluid from tanks per year per DC (t)	0.0	1.1	1.1
CO_2 emissions due to leaks per year per DC (kTons of CO_2)	0.0*	10.5	0.0
Annual CO_2 emissions per DC (kTons of CO_2)	23.1	24.3	13.8
Percent change in CO_2 total annual emissions (%)	Baseline	+6%	**−40%**

- **Direct reduction of GHG emissions by using new ultra low GWP heat transfer fluids**
  - New fluids developed by CRADA partner have very low GWP
- **Indirect effect on Energy justice by accelerating the sustainable deployment of IoT.**

Approach – Why?

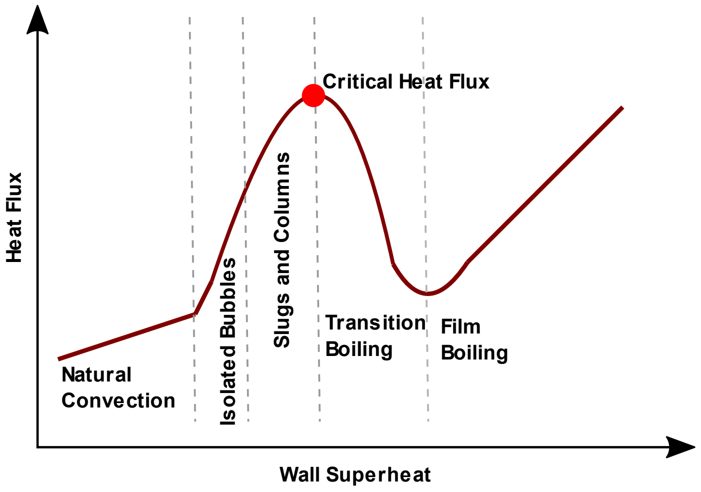
		Commercially Available Fluids			New Fluid
		FC-3284 / FC-72	HFE 7100	Novec 649	Fluid 1
Thermal Properties	Normal boiling point (°C)	50/56	61	49	~50
	Heat of vaporization at normal boiling point (kJ/kg)	100/88	118	88	100-120
	Estimated heat transfer coefficient (kW/m^{2}K)	10.6/10.0	11.6	10.3	10-12
Electric Properties	Dielectric strength (kV, 0.1 in. gap)	~40	~40	~40	>40
	Volume resistivity (Ohm-cm)	1.0E+15	1.0E+8	1.0E+12	>1.0E+14
	Dielectric constant	1.8	7.4	1.8	<2.0
Environmental	GWP – 100 years	>9,000	297	1	~10
Reliability	**Sensitivity to common contaminants**	ok	ok	Poor	OK

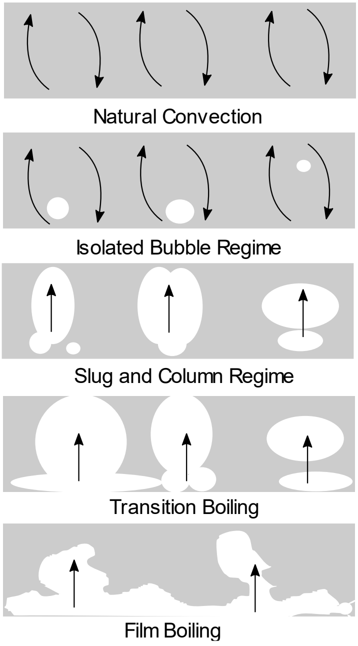
Limitations of some of the current options:

- High GWP (FC-3284 / FC-72)
- Poor dielectric properties (HFE 7100)
- Reliability (Novec 649) – High sensitivity to common contaminants present in immersion cooling (moisture), requiring very stringent contaminant controls

Approach – How?

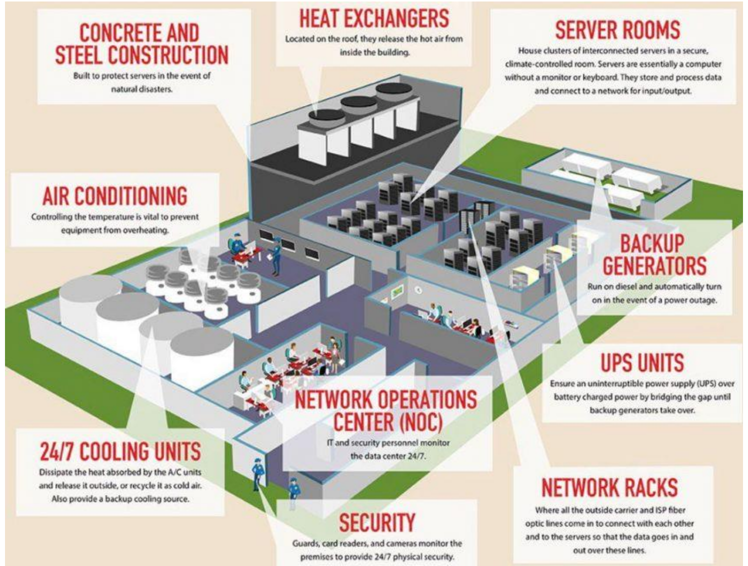
Fundamental Heat Transfer Characterization of the Working Fluid
(verify good thermal properties)



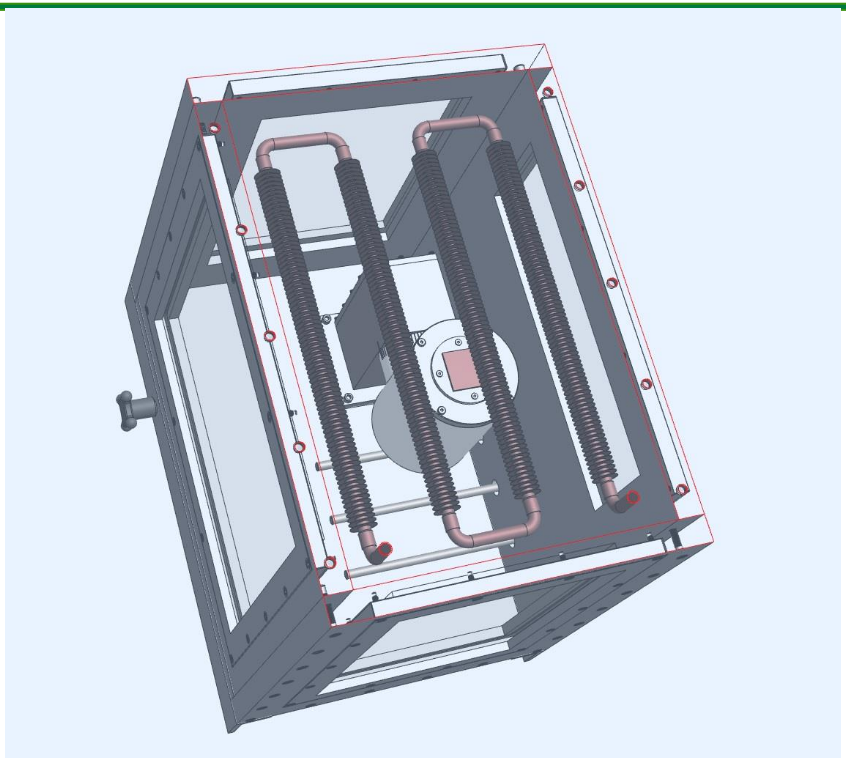


Server Level Testing
(thermal Performance of equipment)

Energy Modeling
(environmental impact)

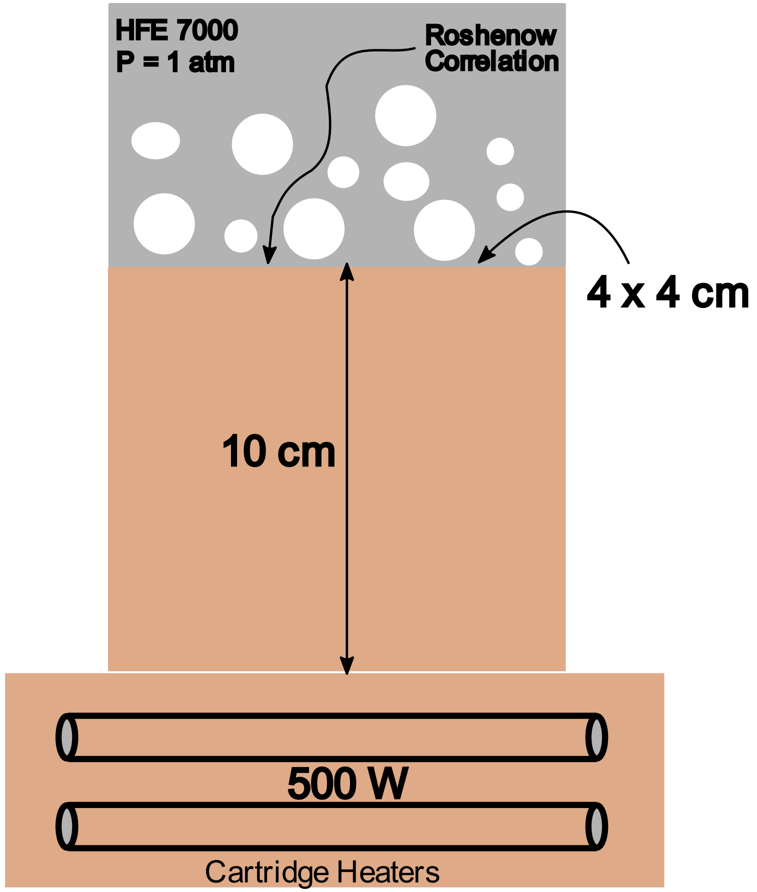


Approach: Design of Fundamental setup - Calculations



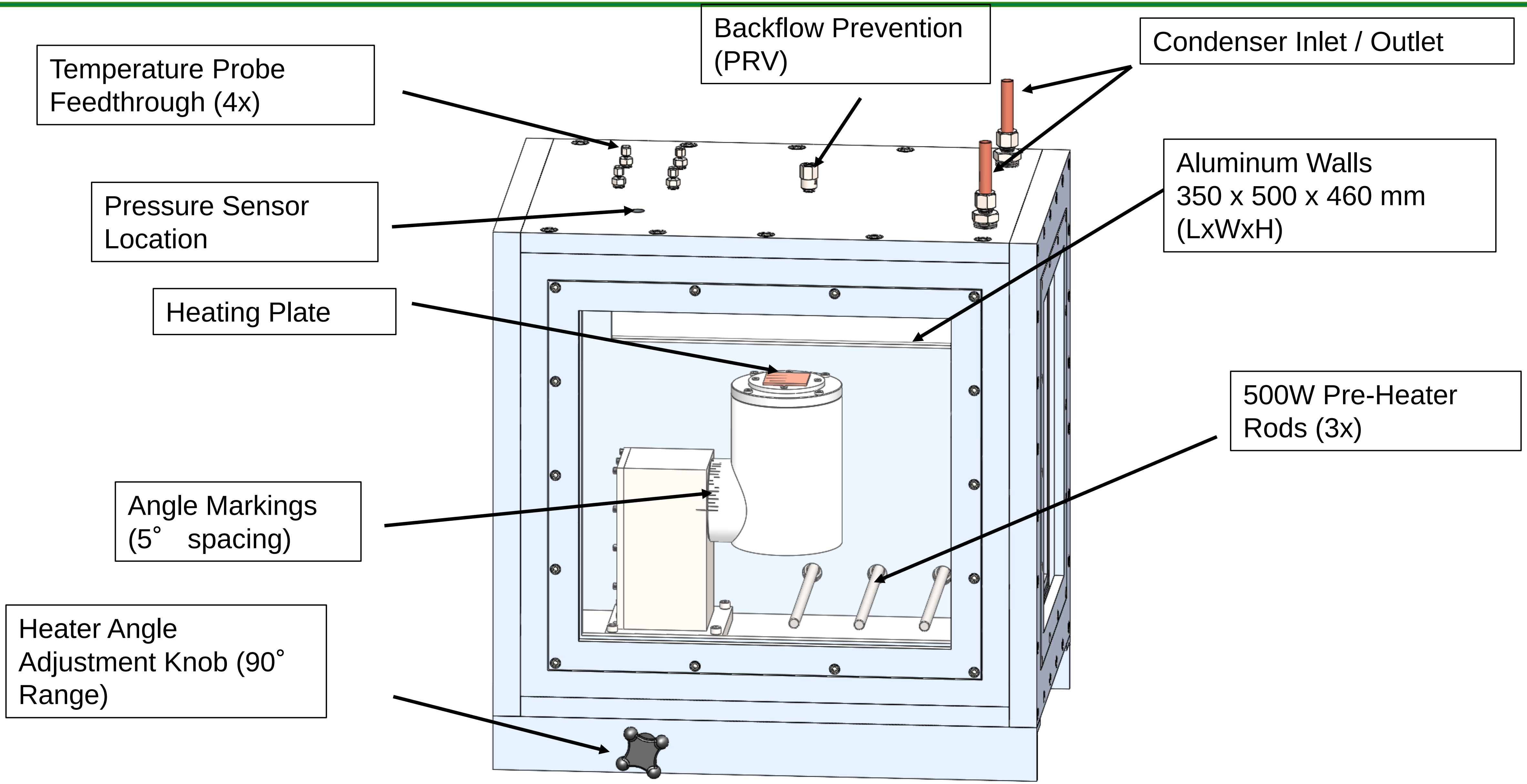
Design Characteristics:

- 2 kW cooling capacity
- Water flow rate 1.5 gpm and temperature of 10 C
- Finned Copper tube
- 4 passes ~ 40 cm pass length (see attached pdf for calculation details)
- Capable of changing the heat transfer surface orientation



Test Section Design using fundamental conduction calculations

Approach: Chamber Design (3-D)



Approach: Testing of actual equipment

Test Setup Concept and Plan

- Fully instrumented 6 kW immersion tank
- Use actual immersion server with boiler plates to simulate the load
- Testing planned with at least one current fluids and one or two alternative fluids.
- Fluid chemical analysis (GC, ions, acidity, residues) by CRADA partner
- Measurement of main parameters (Energy consumption) at a wide range of operating conditions will allow validation of a system model
- System model can be used to extrapolate performance of larger systems

Actual two-phase Immersion Server

Actual 2P Immersion Tank

Approach: Modeling of Data Centers

Current type of buildings

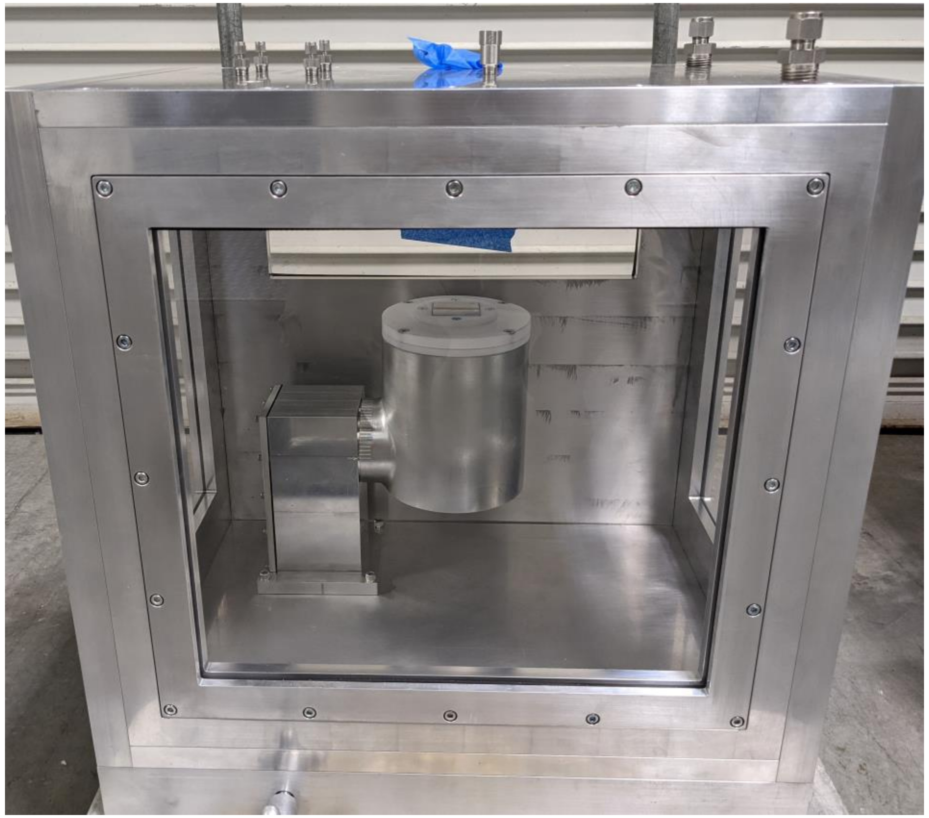
- Designing and sizing a standard air-cooled data center facility
    - Different types of air cooling systems under consideration. Will pick at least one.
    - Include exterior walls, roof, and facility cooling systems
- Design and sizing a two-phase immersion cooled data center facility with same total installed IT power
- Consider about 3 different geographical locations (climates), variable IT load

Techniques proposed for modeling

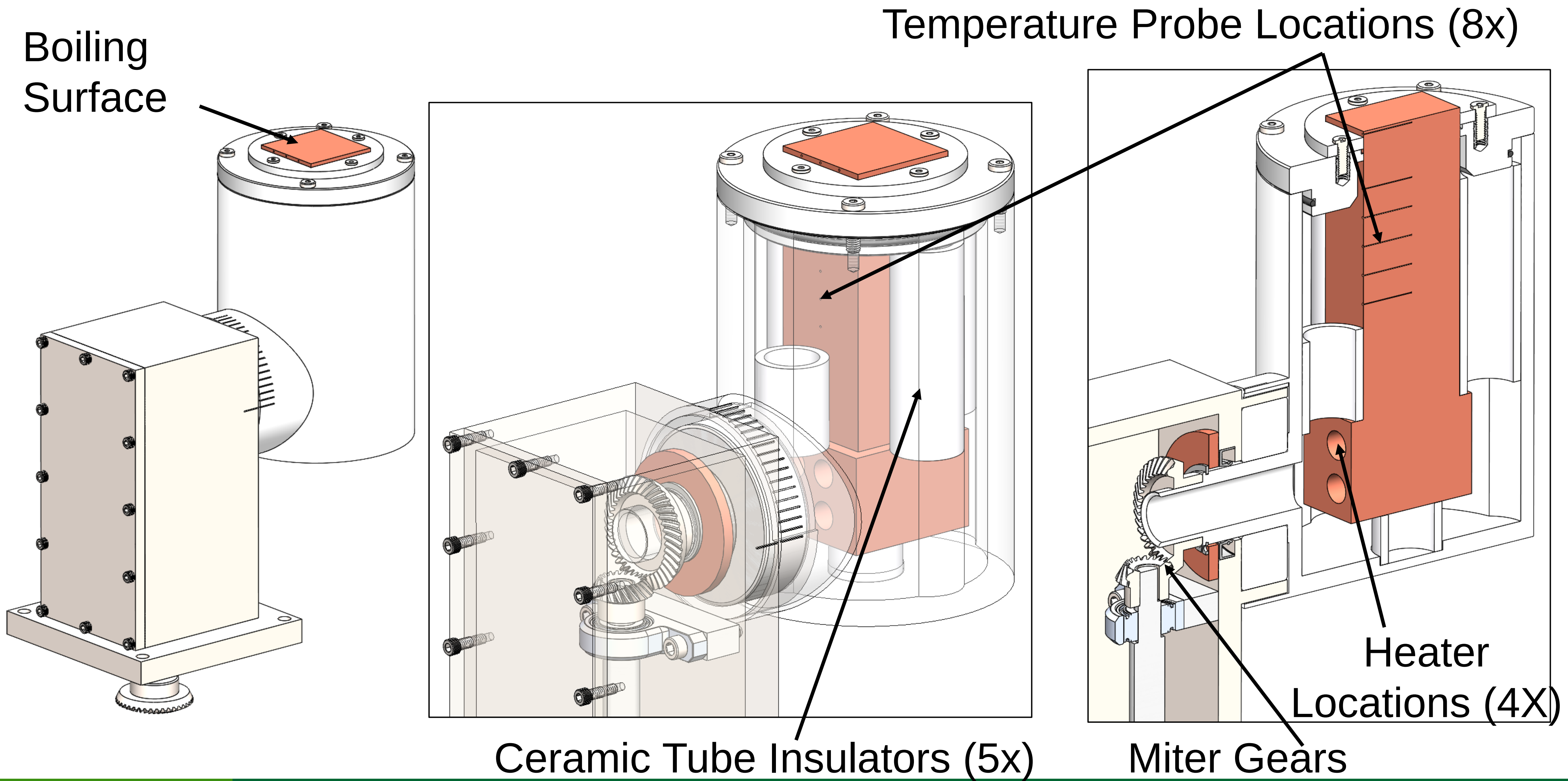
- Lump-parameter physics-based model to obtain the 2-PIC tank performance. Validation using experimental data
- Energy-plus type model (or similar) for energy building simulation
- Engineering "catalog" performance data for auxiliary components, fans, pumps, chillers (air cooled data center), others to be used as needed
- Temperature bin-approach to integrate for yearly energy consumption and PUE
- Estimate CO2 equivalent emissions (LCCP, direct and indirect) for both data center cooling technologies

Progress: Fundamental Pool Boiling

Status: 1) Fabrication of the below pool boiling has been completed, 2) Installation ongoing, 3) test to start in May 2023

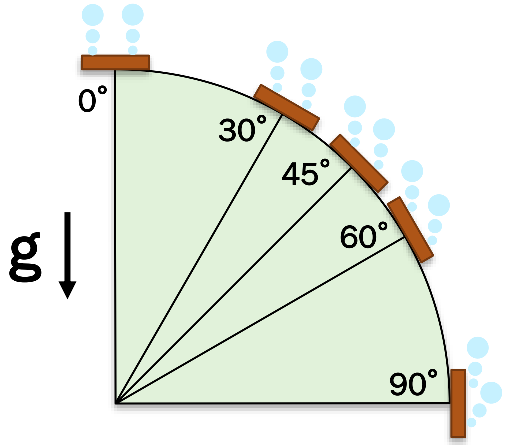


Progress: Test surface and mechanism to change angle



Progress: Testing Plan

- **Operating Conditions for fundamental tests**
  - Pressure condition: 1 atm
  - Heat Flux range: 0 to 300 kW/m^2 (until CHF)
  - Surfaces: Smooth, Enhanced (TBD)
  - Fluids: HFE-7100, Novec-649, and New fluid.
  - Orientation of the test sample: 0°, 30°, 45°, 60°, and 90°.



Thank you

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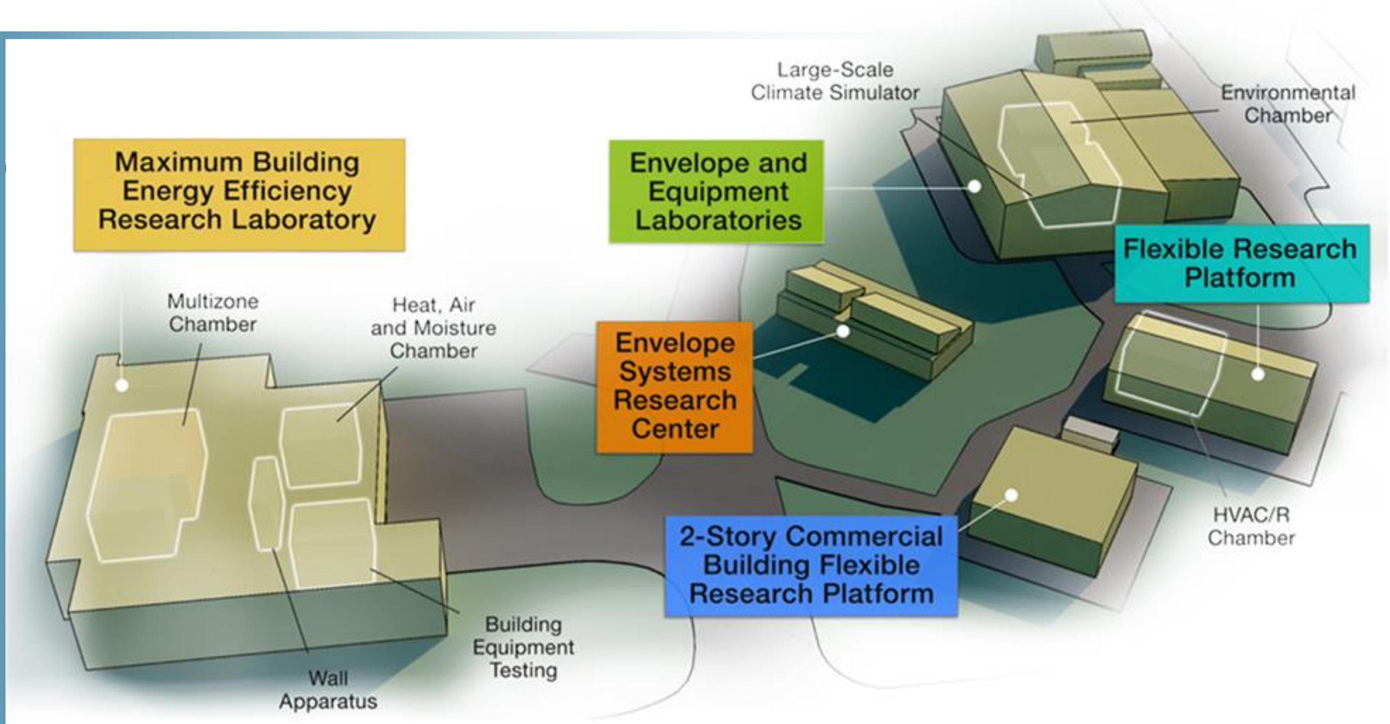

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

Backup Slides

Control Plan – Next Steps

	Year 1				Year 2			
Task Months →	1–3	4–6	7–9	10–12	13–15	16–18	19–21	22–24
1: Fundamental heat transfer evaluations								
Task 1.1: Develop a detailed test plan								
Task 1.2: Build a setup for pool-boiling heat transfer								
Task 1.3: Test new fluids w/smooth surfaces								
Checkpoint 1: Report for smooth surfaces				X				
Task 1.4: Modify to evaluate enhanced surfaces								
Task 1.5: Test fluids with enhanced surfaces								
Checkpoint 2: Report for fundamental work						X		
2: Application testing with immersion fluids								
Task 2.1: Specify/purchase immersion tank, servers								
Task 2.2: Prepare immersion tank for testing								
Task 2.3: Develop test matrix								
Task 2.4: Evaluate performance of multiple fluids								
Task 2.5: Measure fluid losses								
Task 2.6: Evaluate suitability to retrofit								
Task 2.7: Prepare a partial report and publications								
Checkpoint 3: Report for application testing								X
3: Data center building modeling and LCCP evaluation								
Task 3.1: Develop the physical model a data center								
Task 3.2: Develop/validate Energy model								
Task 3.3: Simulate data center performance/LCCP								
Task 3.4: Develop recommendations for improved design								
Task 3.5: Prepare a partial report and technical publication								
Checkpoint 4: Report for modeling/simulation								X
4: Publication in scientific journals, magazines								
Task 4.1: Produce publications and a final report								