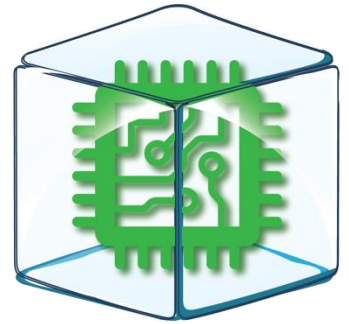
arpa·e
CHANGING WHAT'S POSSIBLE



Hyperefficient Data Centers for Deep Decarbonization of Large-scale Computing

Saeed Moghaddam, U. of Florida

COOLERCHIPS Annual Meeting
November 20 & 21, 2025

Total Project Cost:	$3M
Length	36 mo.

Brief COOLERCHIPS Project Overview

Team member	Location	Role in project, core competencies
University of Florida	Gainesville, FL	Lead, heat sink and system design and integration
Boyd Corporation	Laconia, NH	Manufacturing, liquid cooling and phase change
University of Maryland	College Park, MD	Reliability assessment
NREL	Golden, CO	Packaging and DC-level testing
TRINA	Ann Arbor, MI	Thermomechanical Modeling

Project Vision

- 126 kW rack with 1000 W chips operating at PUE < 1.04 (@ 40 ℃ ambient)
- Water-based phase-change system
- ~70 ℃ exit primary loop temperature

arpa·e
CHANGING WHAT'S POSSIBLE

Opportunity and Challenges

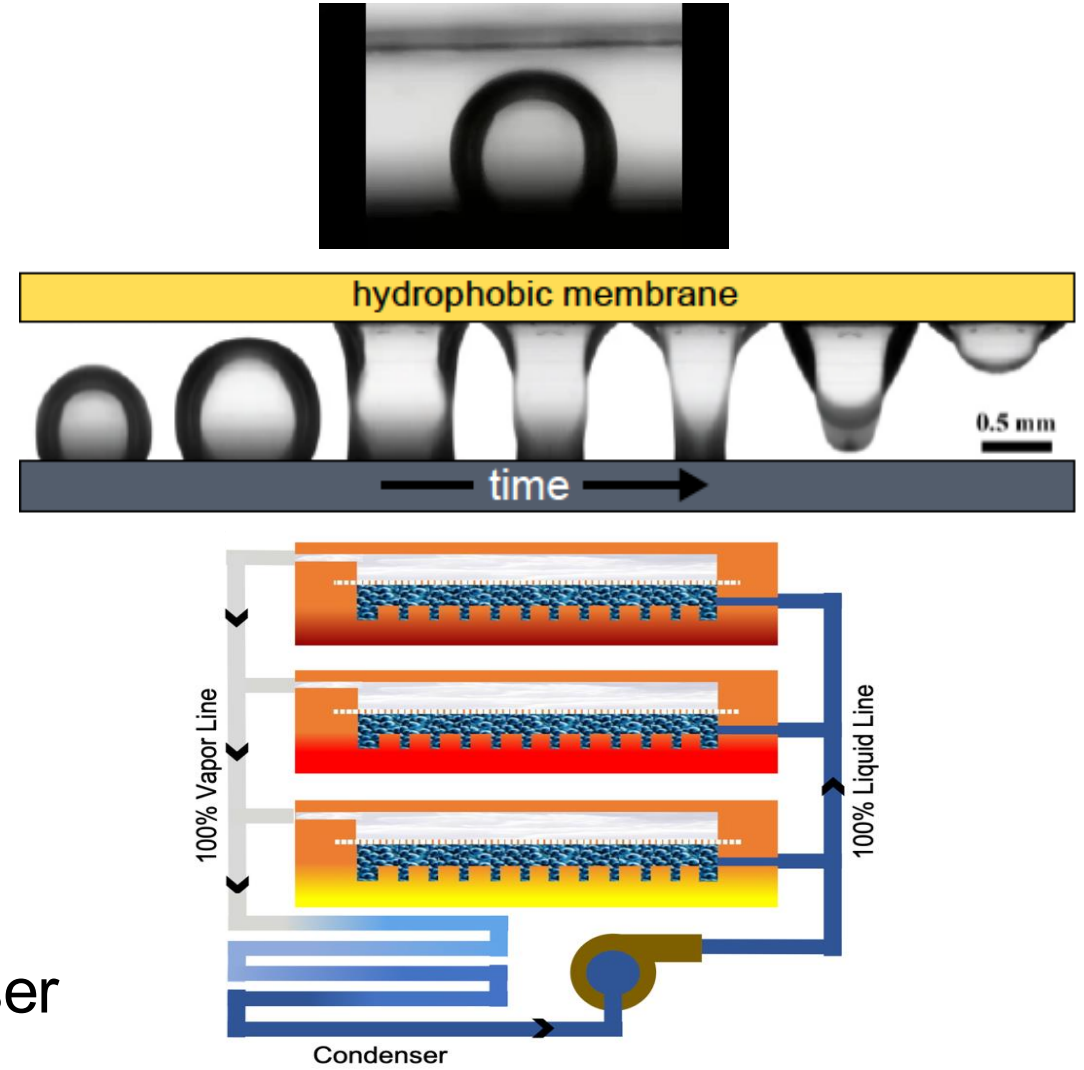
Taking advantage of unique properties of water, a new heat sink and system-level innovations

Property	R-1234ze(E)		Water
Thermal Conductivity	~0.105 W/m·K	6x →	~0.6 W/m·K
Latent Heat	~145 kJ/kg	15x →	~2260 kJ/kg
Temperature (°C)	100 (1 atm)		70 (0.4 atm)
Vapor Volume (m^3/kg)	1.672	4.5x →	7.555

- Sensitive to pressure drop and hydrostatic pressure
  - ➢ Conventional heat sinks do not work
  - ➢ Major hydrostatic pressure difference along the rack height
- Sub-ambient pressure operation and ingress of non-condensable gas (NCG)

Addressing Flow Maldistribution and High Pressure Drop



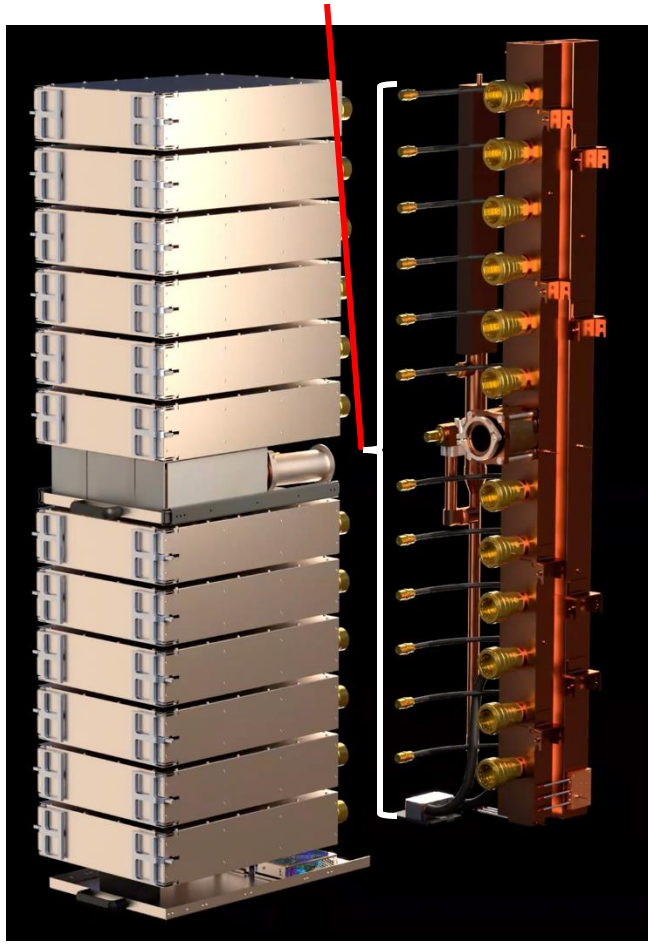


- Membrane servers as mass controller
  - ➢ GPUs can operate at 0-100% load without affecting each other
- Vapor exit quality is 100%
  - ➢ Enabling compact in-rack condenser

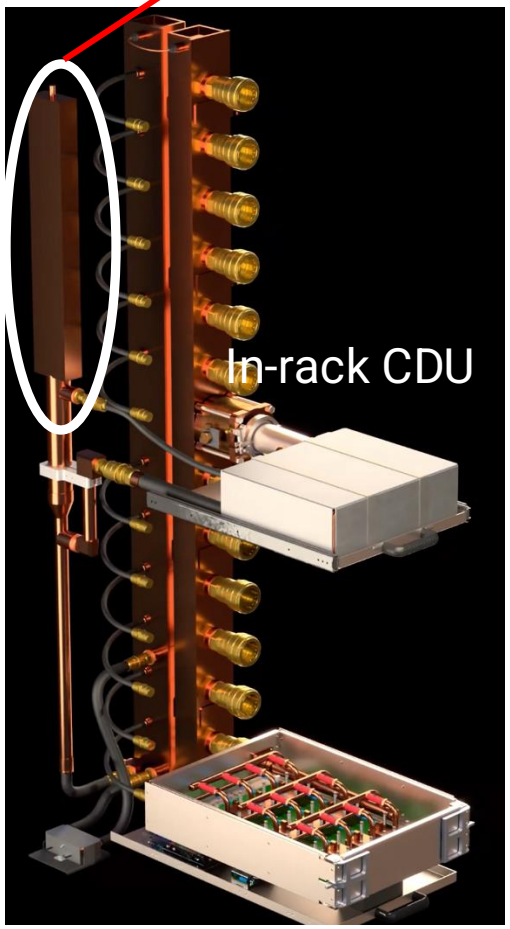
arpa·e
CHANGING WHAT'S POSSIBLE

Rack Architecture and Implementation in Data Centers

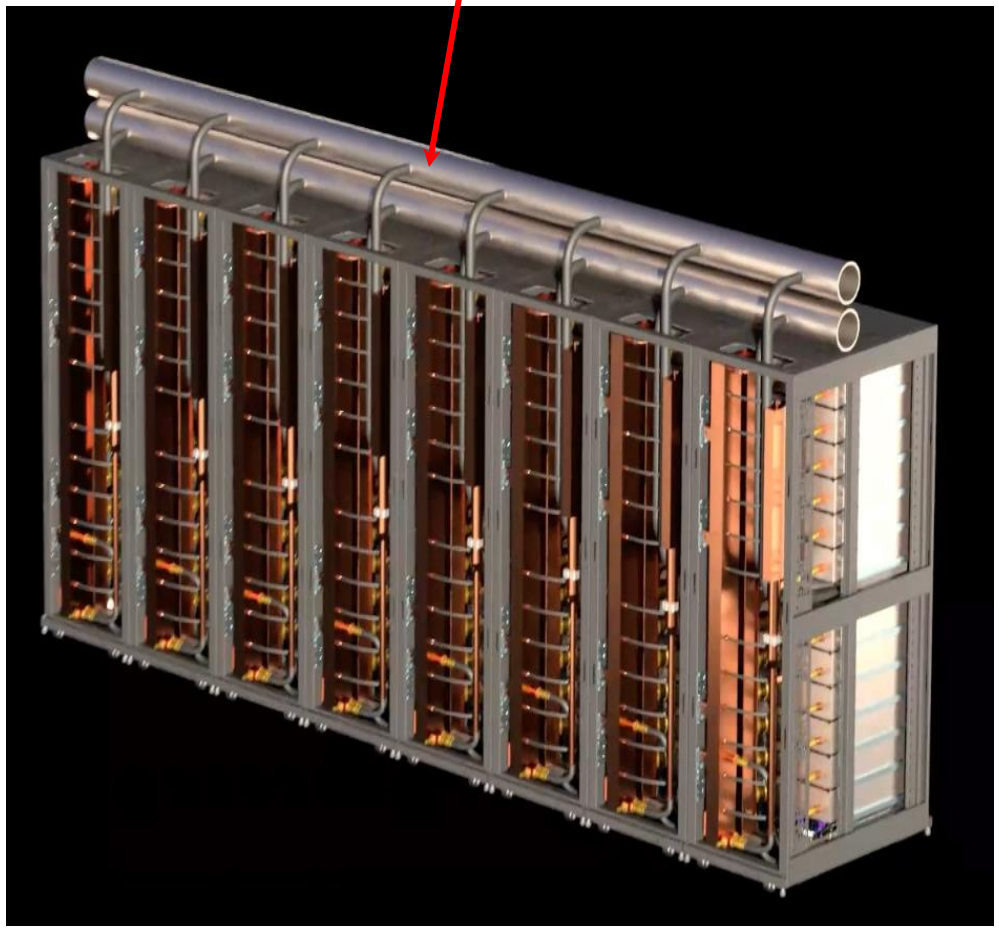
- Constant liquid supply pressure



NCG Removal



Direct Integration with Primary Loop

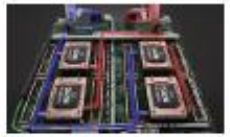


arpa·e
CHANGING WHAT'S POSSIBLE

Generations of Data Center Liquid Cooling

Drive energy efficiency

LIQUID TO AIR LIQUID COOLED DATA CENTER



COOLING LOOP



SERVER RACK + LIQUID TO AIR CDU



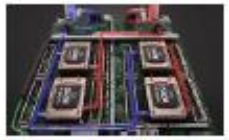
COMPUTER ROOM AIR HANDLER



AIR COOLED CHILLER

PUE: 1.54*

LIQUID TO LIQUID LIQUID COOLED DATA CENTER



COOLING LOOP



SERVER



COOLANT DISTRIBUTION UNIT



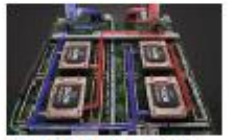
AIR COOLED CHILLER

PUE: 1.40*

UF COOLERCHIPS

DEVICE POWER >2500W

TWO-PHASE LIQUID COOLED DATA CENTER



COOLING LOOP

~~Refrigerant~~



CPU/GPU COOLING/ CONDENSING UNIT

~~Refrigerant~~



DRY COOLER

PUE: 1.08*

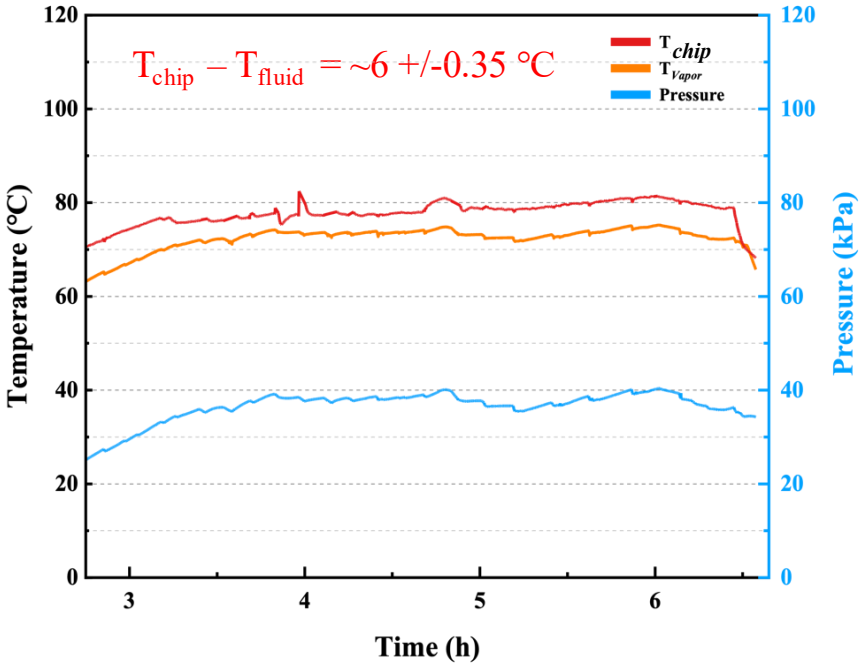
* PUE numbers include 3% for Lighting and accessories

CHIP TO AMBIENT

Component-level Performance Validation

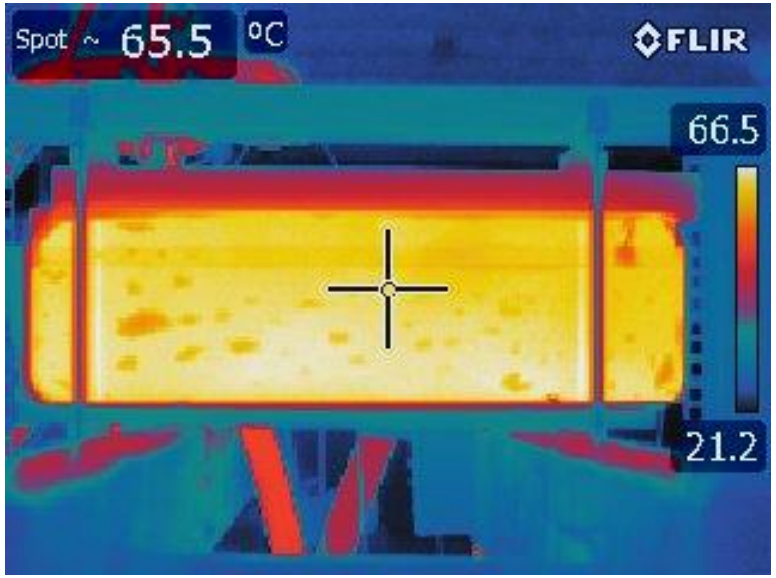
- Cold Plate Thermal Performance: chip-to-secondary Coolant

➢ Measured thermal resistance on TTV (1000 W over 4×4 cm^2 representing Nvidia GB300 GPU heat flux): 0.006 °C/W



- Condenser Thermal Performance: secondary coolant to primary coolant

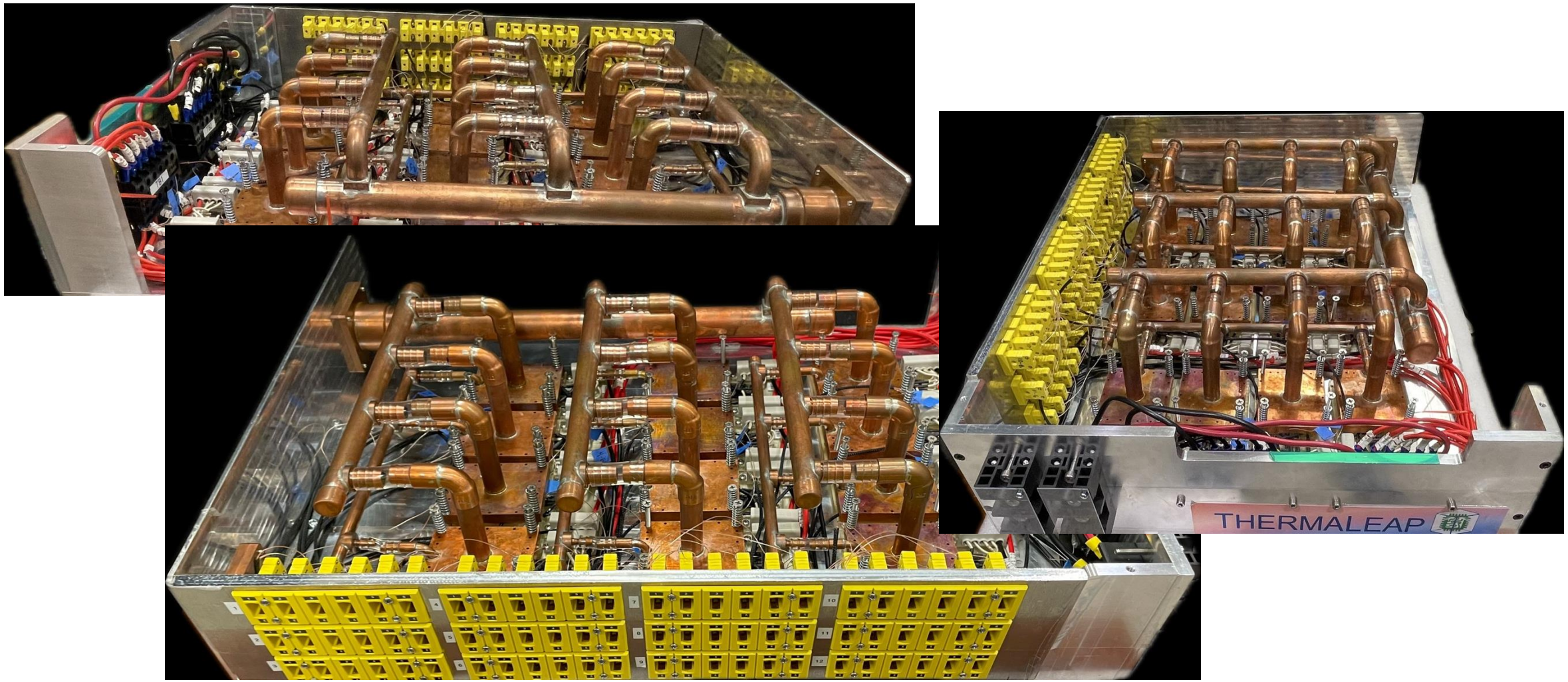
➢ Measured thermal resistance: 0.00016 °C/W



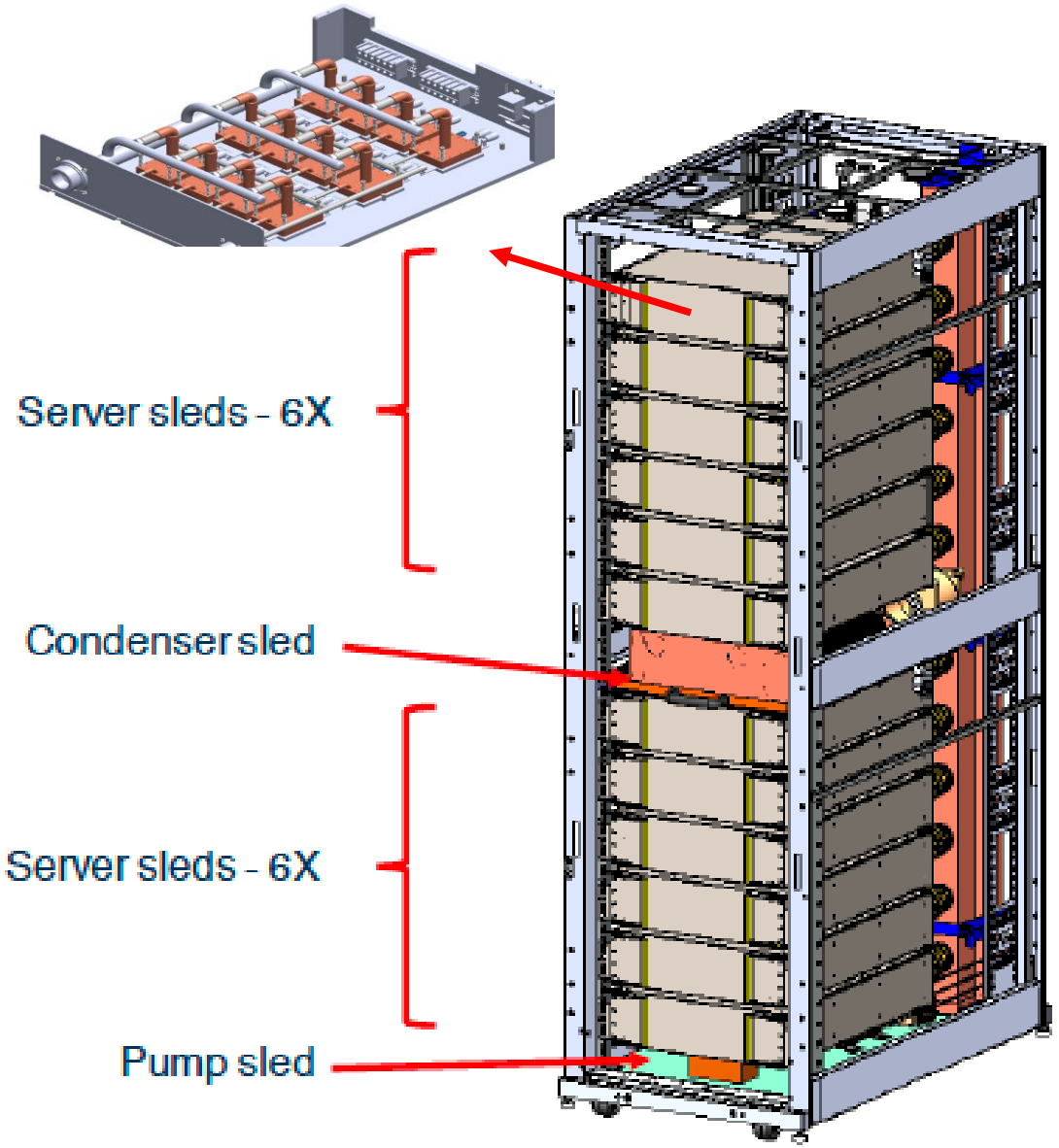
Rack Power Density: > 100 kW/m^3

arpa·e
CHANGING WHAT'S POSSIBLE

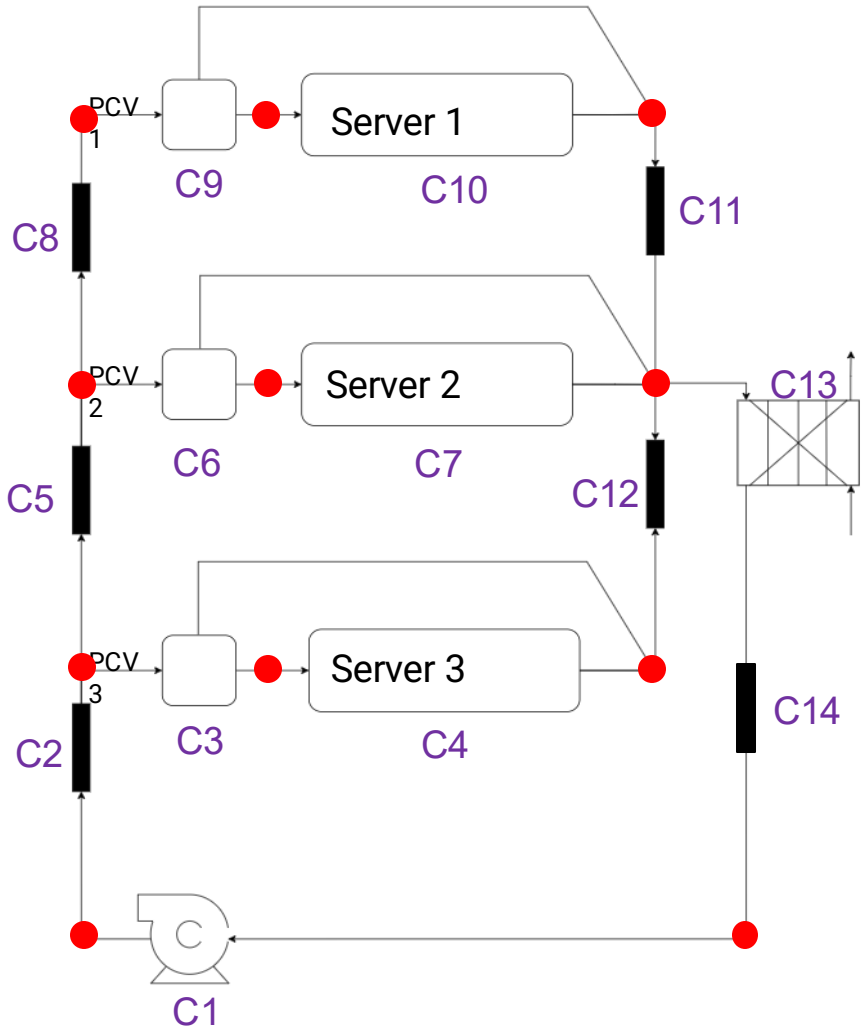
Full-scale Server



Full-scale Rack Performance Validation



Scaled Down Rack Model



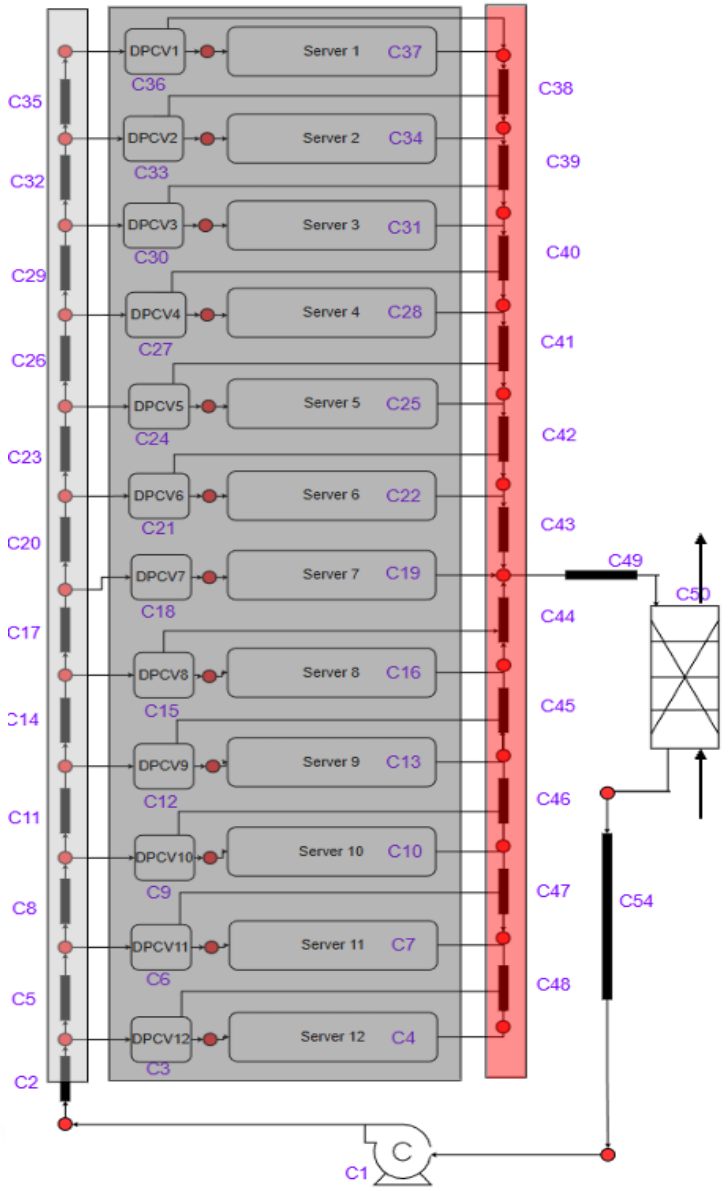
12 Membrane Heat Sinks
1 kW each → 12 kW total load

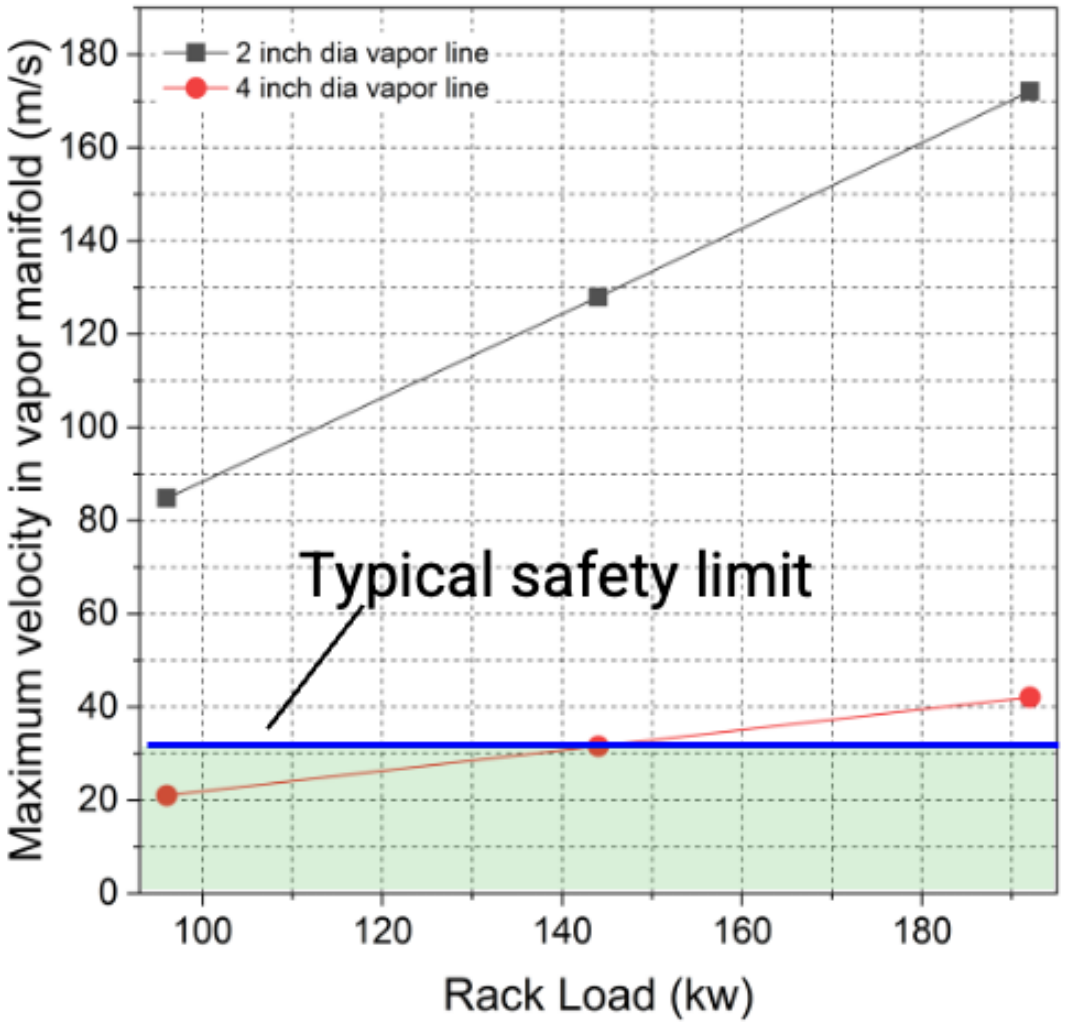
Cases:

Case	Primary loop inlet temperature (°C)	Primary loop mass flow rate (g/s)	Secondary loop inlet temperature (°C)	$\dot{m}_{secondary\ loop}$ (g/s)	Primary loop outlet temp (°C)
Case 1	30	0.143	74	4.78	50
Case 2	50	0.143	74	4.95	70
Case 3	70	1.43	74	5.13	71.3

- **Exit vapor quality of 1 from all the heat sinks and the exit vapor temperature is ~74°C for all cases.**
- **Pump power remains negligible compared to IT load in all scenarios.**

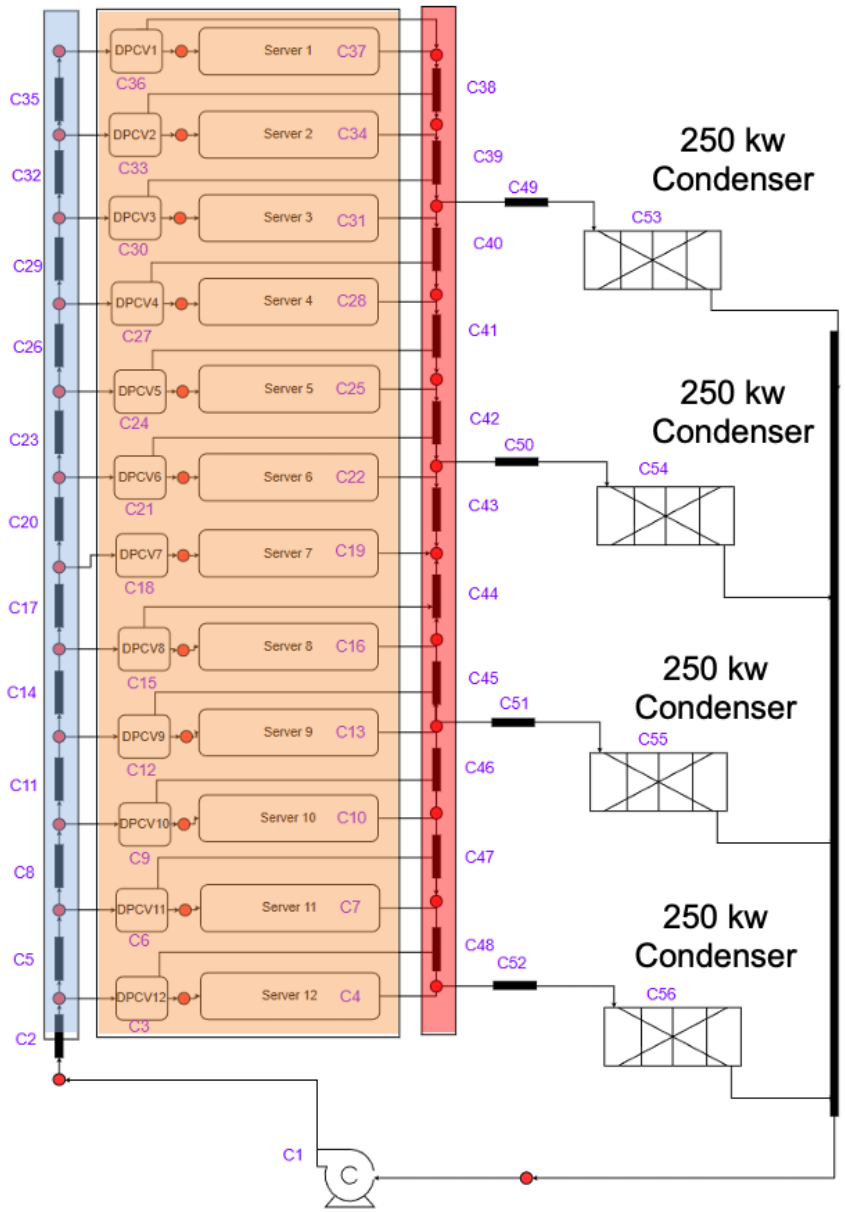
Full-scale Rack Model





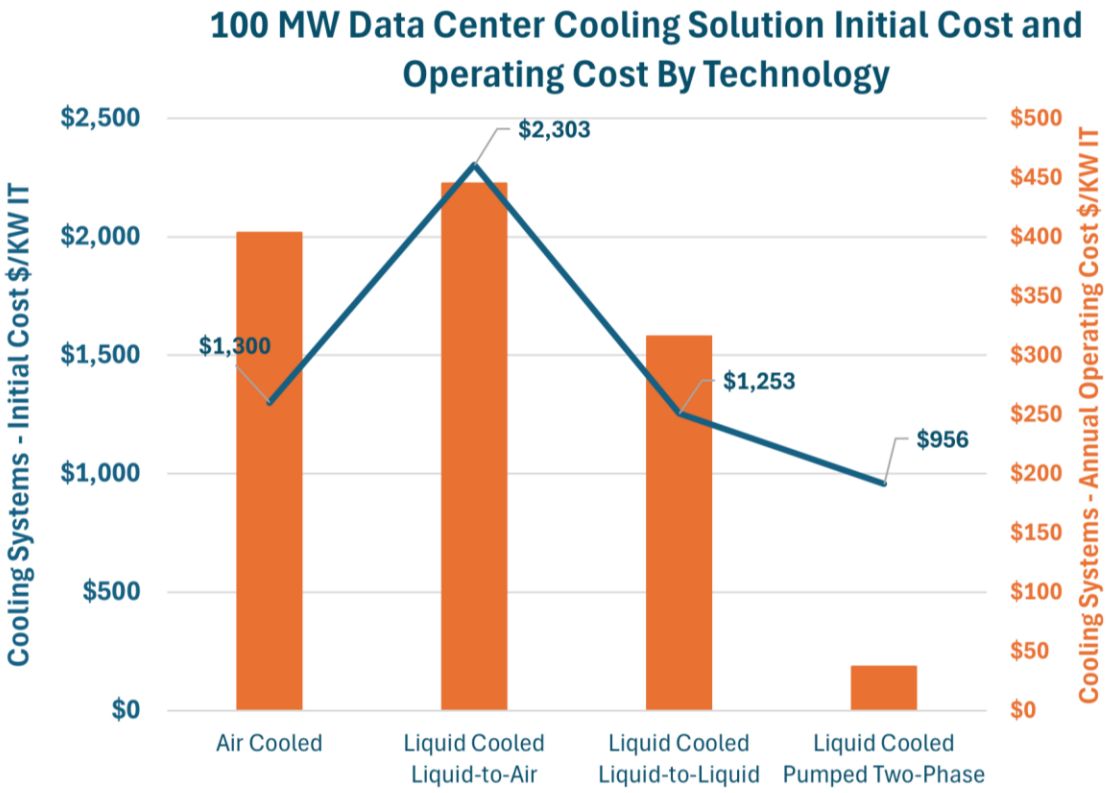
arpa·e
CHANGING WHAT'S POSSIBLE

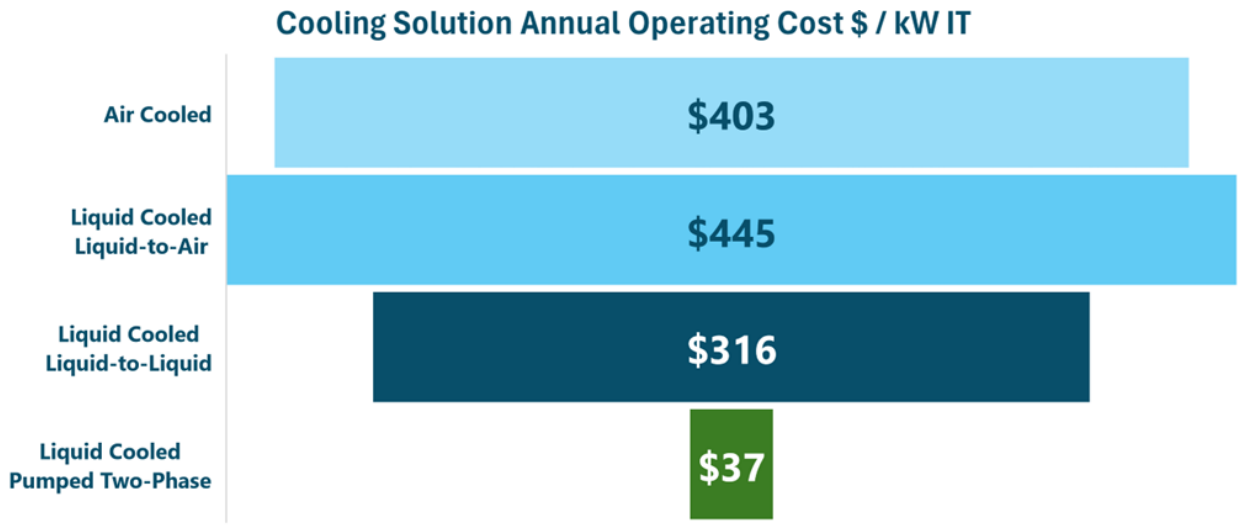
Scaling to 1 MW Rack



- **Proposed concept for 1 MW racks**: split the rack into multiple vertical zones and extract vapor at several heights instead of a single outlet.
- Each condenser handles only a fraction of the total rack load, so the vapor flow in each manifold segment is reduced and velocities remain within safe limits.
- This architecture keeps pressure drops low, reduces risk of erosion, noise and droplet carryover, and avoids the need for oversized vapor manifolds.
- **Ongoing work:** extend the existing server and 126 kW rack models to this 1 MW multi-extraction layout and compare velocity, pressure and pump power against the single-manifold baseline.

Techno-economic Analysis (@ 40 °C Ambient)





arpa·e
CHANGING WHAT'S POSSIBLE

Acknowledgement



Saeed Moghaddam
Professor
Organization: U. of Fl



Sukhvinder Kang
Chief Technology Officer
Organization: Boyd



Nelson Gernert
VP Eng. and Tech.
Organization: Boyd



Jerome Toth
Sr. Vice President, Eng. & Tech.
Organization: Boyd



Patrick McCluskey
Professor
Organization: UMD



David Sickinger
HPC Projects Oversight
Organization: NREL



Gilbert Moreno
Sr. Res. Eng.
Organization: NREL



Paul Paret
Title: Sr. Res. Eng.
Organization: NREL



Eric Dede
Title: Director, ERD
Organization: TRINA



Sreekant Narumanchi
Sr. Manager
Organization: NREL

arpa·e
CHANGING WHAT'S POSSIBLE

References

- Tamvada, S.R., & Moghaddam, S., “Data center energy efficiency enhancement potential of a membrane assisted phase-change heat sink“, Applied Thermal Engineering, Article 120556, 2023.
- Tamvada, S.R., Alipanah M., and Moghaddam, S. “Membrane-Based Two Phase Heat Sinks for High Heat Flux Electronics and Lasers,” IEEE Transactions on Components, Packaging and Manufacturing Technology, Vol. 11, Issue 10, October, 2021.
- S. Moghaddam and A. Fazeli, "Hierarchical Hydrophilic/Hydrophobic Micro/Nanostructures for Pushing the Limits of Critical Heat Flux," US Patent 10,897,833, January 19, 2021.
- M. Alipanah and S. Moghaddam, “Ultra-low pressure drop membrane-based heat sink with 1000 W/cm2 cooling capacity and 100% exit vapor quality,” International Journal of Heat and Mass Transfer, vol. 161, Nov. 2020.
- Fazeli and S. Moghaddam, “A New Paradigm for Understanding and Enhancing the Critial Heat Flux (CHF) Limit,” Scientific Reports, vol. 7, art. 5184, 2017.
- Fazeli, M. Mortazavi, and S. Moghaddam, “Hierarchical Biphilic Micro/Nanostructures for a New Generation Phase-Change Heat Sink,” Applied Thermal Engineering, vol. 78, pp. 380-386, 2015.

Q & A

saeedmog@ufl.edu