

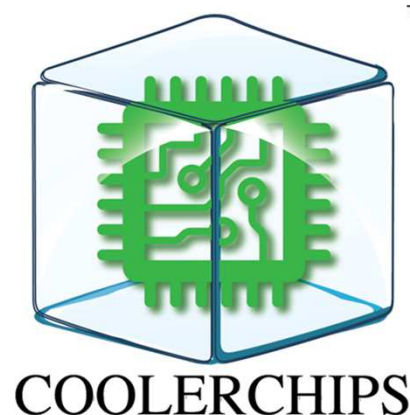
Delivering energy and exergy efficiency in the converged 5G RAN/EDGE compute network

Todd Salamon, Nokia Bell Labs

Team Members: University of Illinois at Urbana-Champaign

Project Vision

- We are solving the combined challenges of edge server densification and energy efficiency by developing a highly efficient thermal energy architecture that allows heat capture ≥ 160 °F (~ 71 °C) for economic heat reuse.

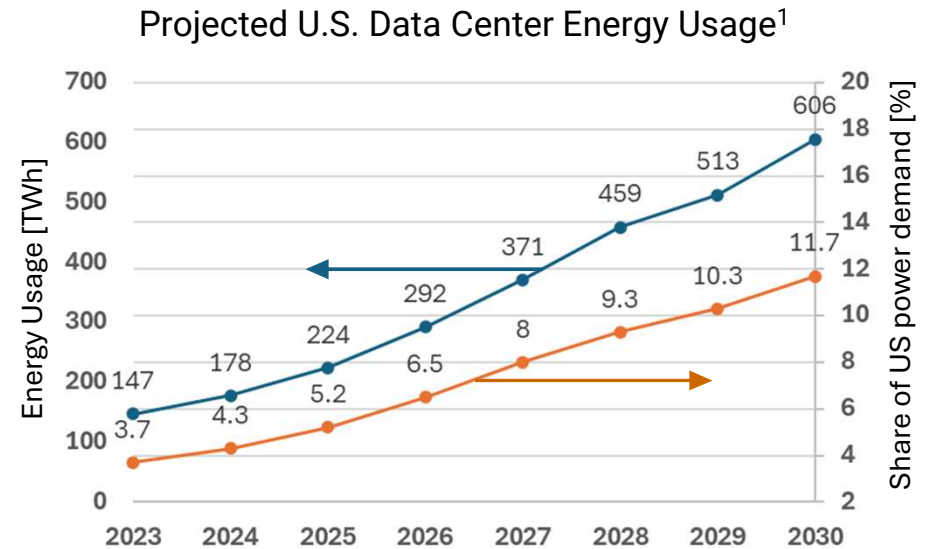


A challenging problem

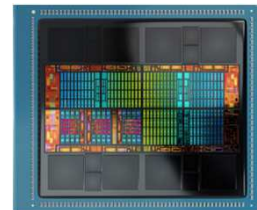
- ▶ *Projected growth of U.S. data center energy demand from 4.3% (2024) to 11.7% (2030) ¹*

¹ “How data centers and the energy sector can satiate AI’s hunger for power”, McKinsey & Company report, September 17. 2024.

- ▶ *Power dissipation of current and future GPU platforms is challenging to cool efficiently with existing thermal management approaches*

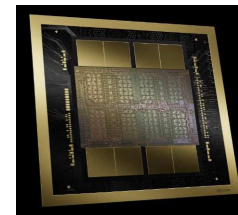


AMD CDNA 3



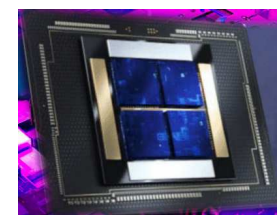
~700 W

Nvidia Blackwell



~1200 W

Intel Falcon Shores

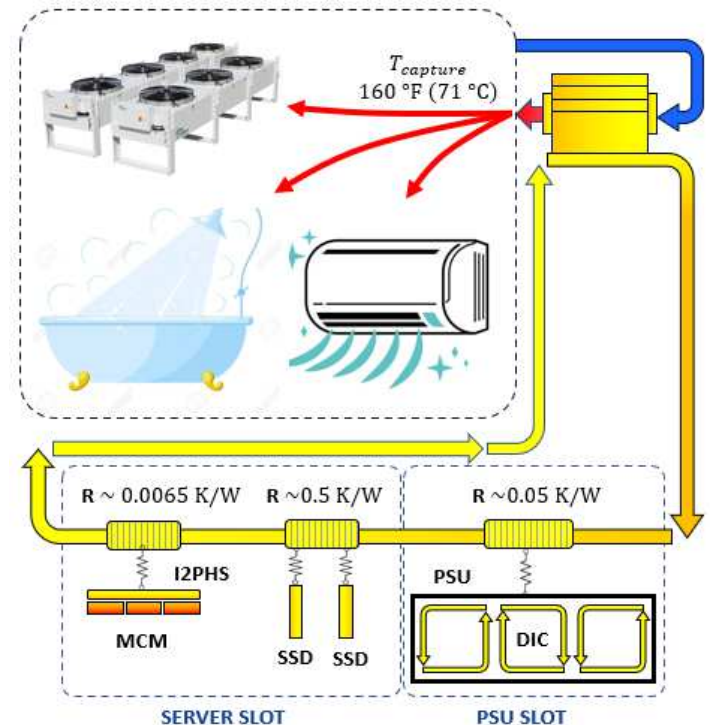


~1500 W

Our approach

- ▶ **Technology Description:**
 - Completely passive, self-regulating thermal management system based on two-phase thermosyphon and advanced integration
- ▶ **Potential impact:**
 - Enable scale-able path to increased server heat densities while reducing TUE and reusing captured heat
- ▶ **Key features:**
 - Low thermal resistance evaporators allow cooling of high-power GPUs
 - Passive nature of system reduces up-front cost, improves system reliability and reduces energy footprint

System architecture



Our approach

► *Technology Description:*

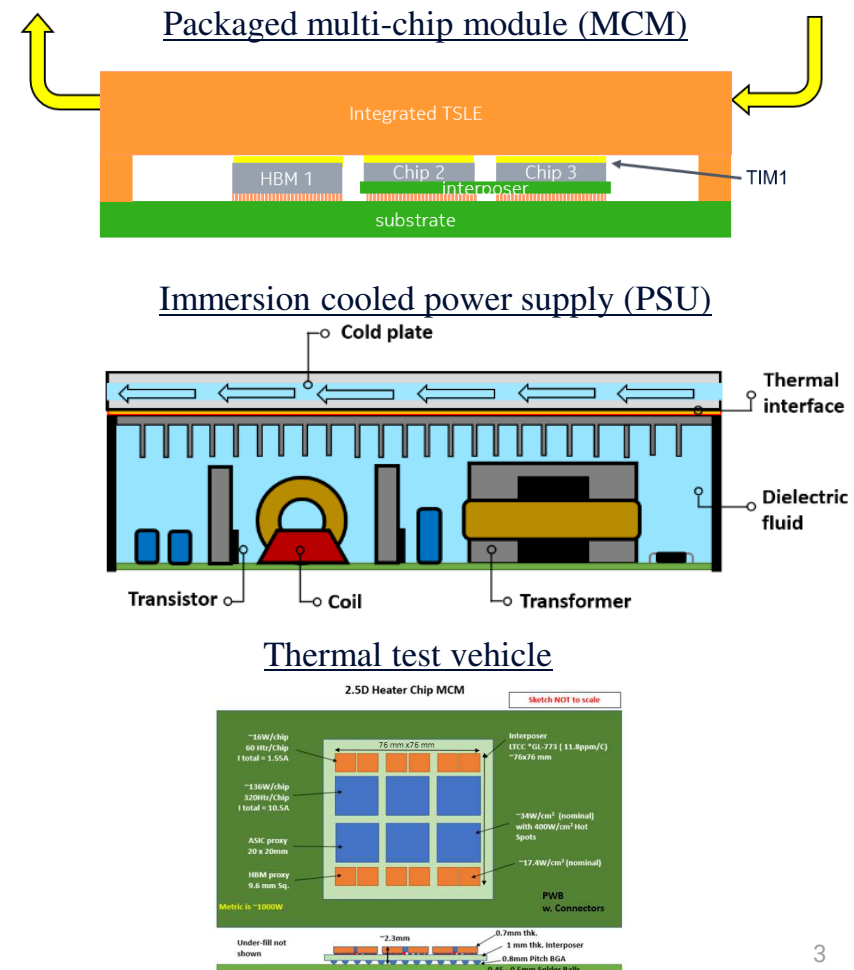
- Completely passive, self-regulating thermal management system based on two-phase thermosyphon and advanced integration

► *Potential impact:*

- Enable scale-able path to increased server heat densities while reducing TUE and reusing captured heat

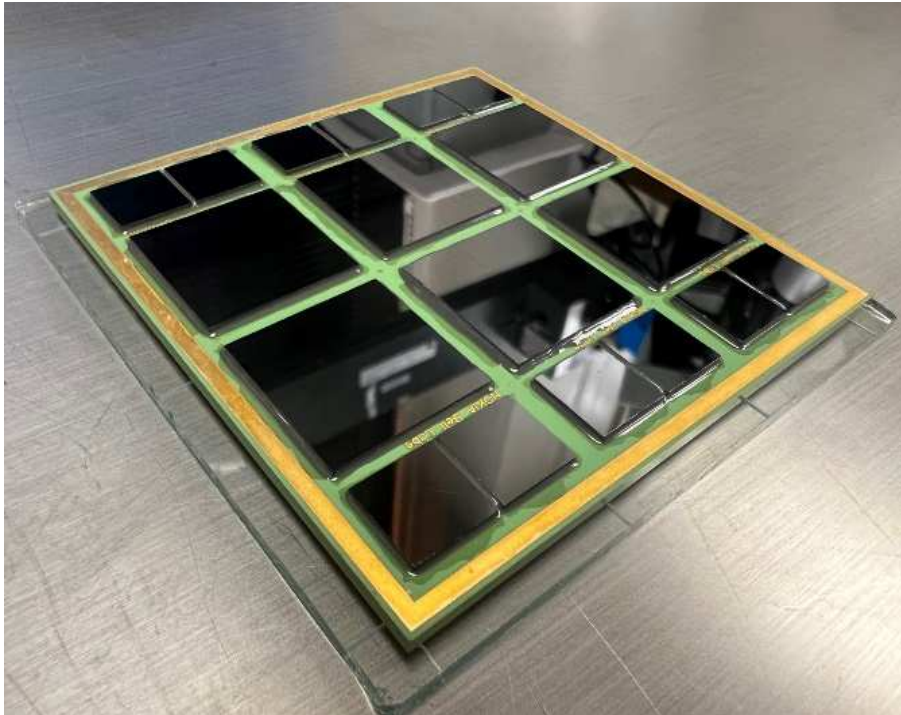
► *Key features:*

- Low thermal resistance evaporators allow cooling of high-power GPUs
- Passive nature of system reduces up-front cost, improves system reliability and reduces energy footprint



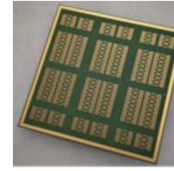
Multi-chip module TTV

Thermal Test Vehicle (2400 W)

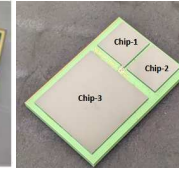


Hot spots up to 460 W/cm²

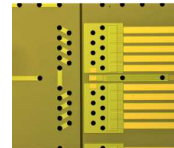
Interposer



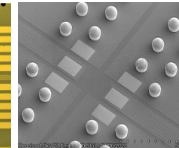
X1 module



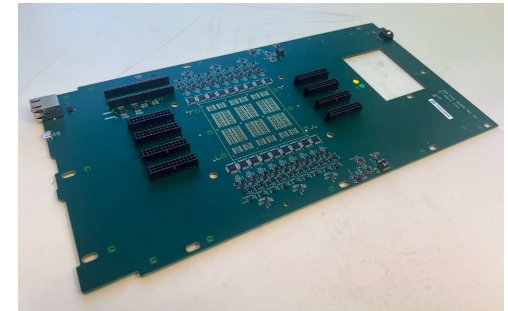
Heater & RTD on logic die



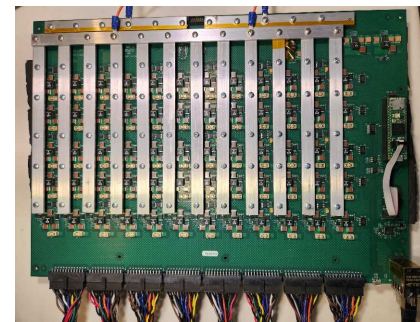
Copper pillar bumps



Host PCB



Power delivery board

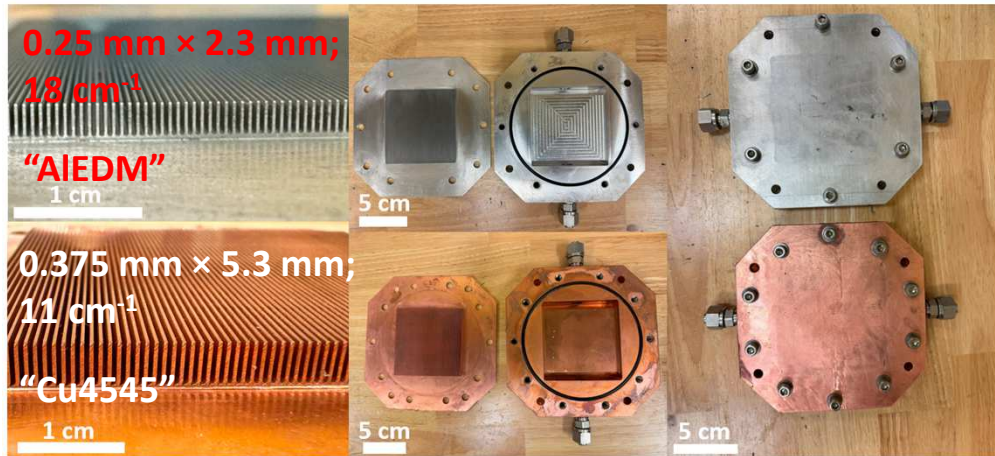


TTV on Host PCB

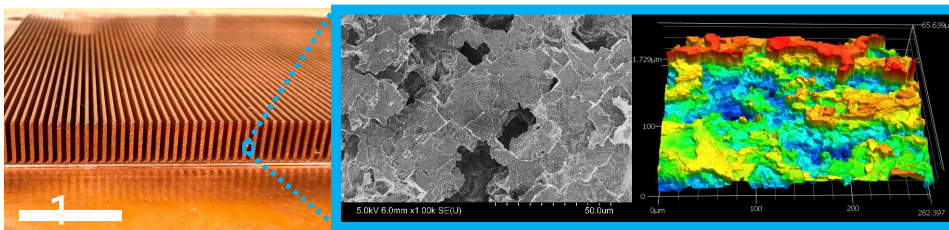


Surface-enhanced evaporators

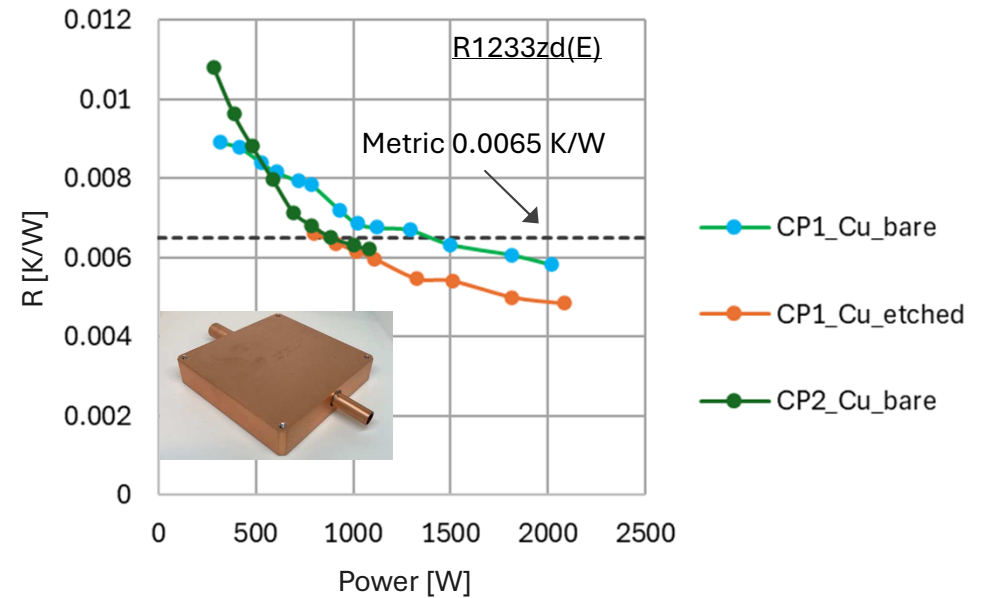
Aluminum and copper modular cold plate designs



SEM and confocal microscopy images of etched copper surface

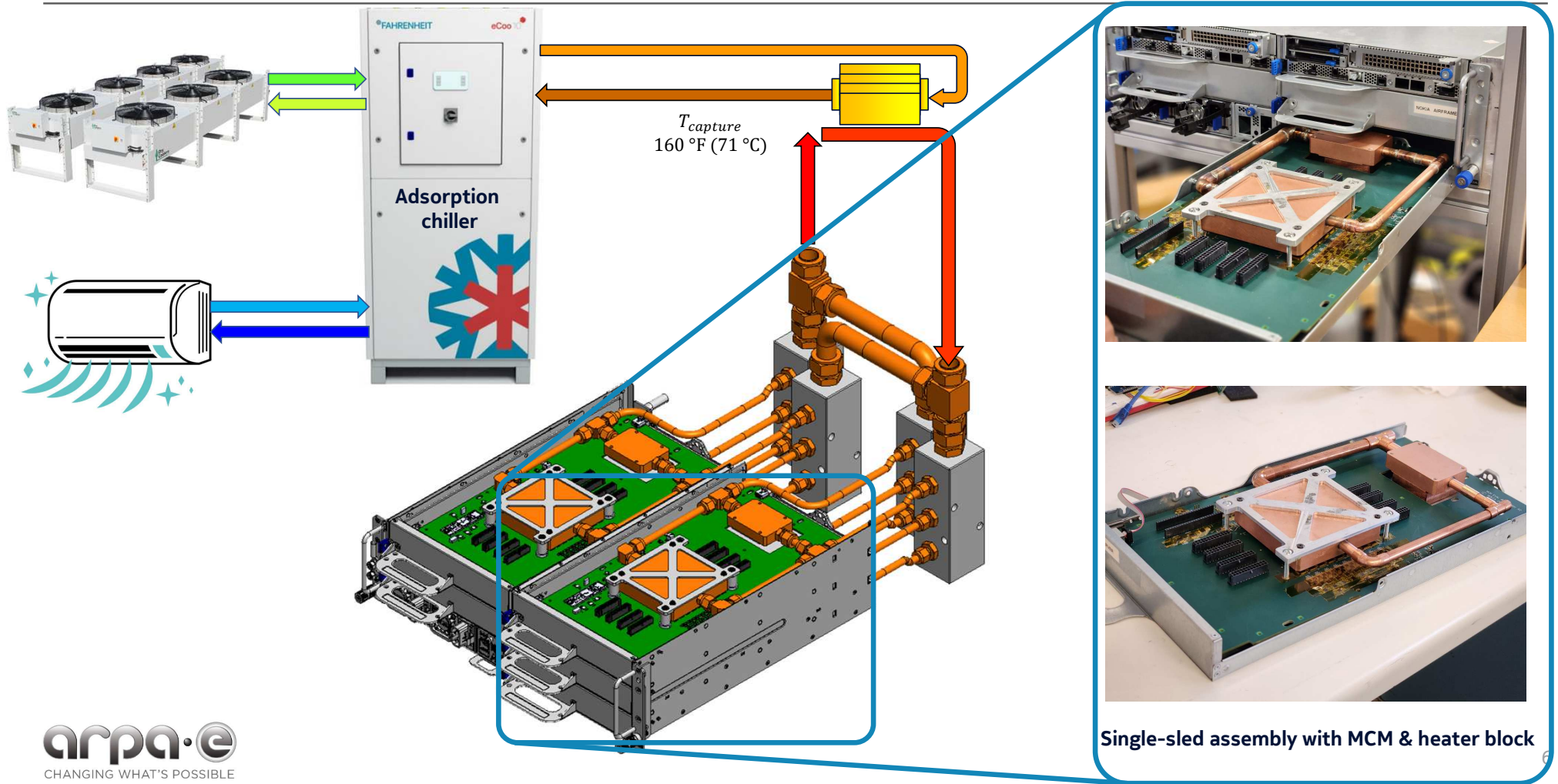


Evaporator thermal resistance versus power



- Evaporator pressure drops in the 2 – 2.5 kPa for design power of 1000 W

What Is Next: System-level proof of concept

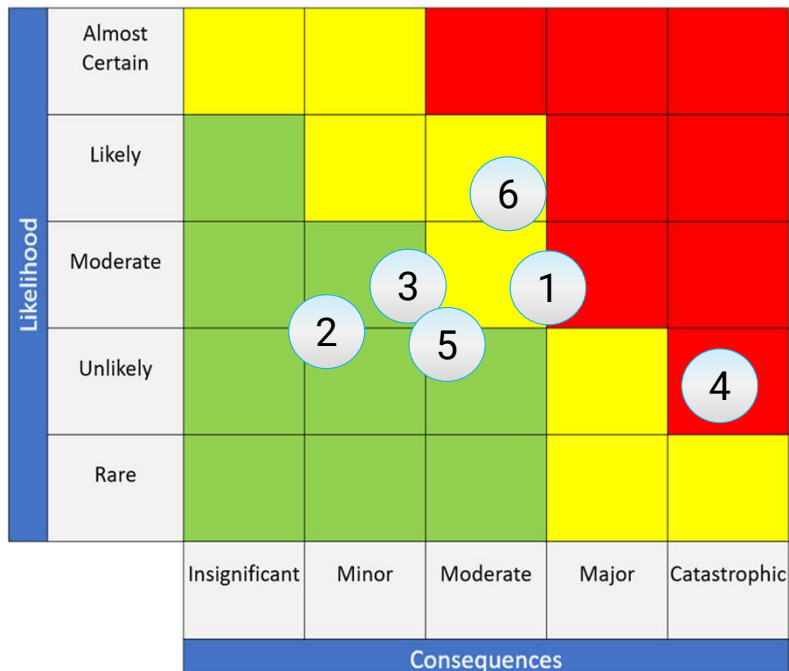


Timetable of milestone activities

Tasks \ Timeline	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
1. System requirements												
2. Thermal test vehicle												
3. In-package heat spreader												
4. Enhanced 2P evaporator												
5. PSU and SSD cooling												
6. Two-phase test beds												
7. System level demo												
8. Tech-to-Market												

System Reliability

Risk likelihood and consequence



Risk and mitigation approach

Risk	#	Mitigation
Thermomechanical stress	1	Compliant, high-performance TIMs
Heat capture efficiency	2	Target highest power components
Surface-enhanced evaporator performance	3	Filtering, reliability testing of surface enhancements
System thermofluidic reliability	4	Filtering, reliable connectors, pressure-tested components, non-condensable gases
Sliding interface reliability	5	Rigorous compliance testing
Immersion-cooled PSU reliability	6	Compatible materials, stable fluids, consistent heat removal

Technology-to-Market Approach and Update

- ▶ *What's your team plan to commercialize your technology developed via the COOLERCHIPS program?*
 1. Licensing
 2. Partnering / spin-out
- ▶ *What are the anticipated first markets? What are the market requirements in terms of cost and performance?*
 - Targeting larger-scale data centers with focus on AI/ML workloads.
 - Total cost of ownership (TCO) less than air- and single-phase liquid cooling. Performance allowing significant rack (>100 kW) and site densification.
- ▶ *TCO analysis for 1.3 MW data center with 125 kW racks in St. Petersburg / Clearwater, Florida¹*

	Case 1: Single-phase DTC	Case 2: Two-phase thermosyphon DTC	% reduction for Case 2
PUE	1.22	1.12	-8.2%
Initial capital cost	\$4,117,977	\$2,487,852	-39.6%
Total lifetime energy cost	\$4,243,388	\$2,377,002	-44.0%
Total lifetime maintenance cost	\$767,936	\$597,379	-22.2%
Total lifetime cost	\$9,129,300	\$5,462,233	-40.2%
NPV cost [\$]	\$7,549,603	\$4,525,803	-40.0%

¹ TCO Analysis Tool version 4, The Green Grid (2023)

Key finding – elimination of CDUs and increased chilled water temperature (110 °F vs 86 °F) result in significant capital cost (-39.6%) and energy (-44.0%) savings.

Publications and Conference Presentations

1. Talk entitled “**Single-Phase and Two-Phase Liquid Immersion Cooling of Data Center Power Supply Units for Heat Capture**” by A. Qiu *et al.*, presented at the **ASME Summer Heat Transfer Conference (SHTC 2023)** in Washington, DC, July 10-12, 2023.
2. Talk entitled “**Two-Phase Cold Plate Evaporator Designs for High Power Dissipation**” by David Apigo *et al.*, presented at **ASME InterPACK 2023** in San Diego, CA, October 24-26, 2023.
3. Talk entitled “**Dynamical System Analysis of an Oscillating Heat Pipe to Guide Sustained Oscillations**” by Rishav Roy *et al.*, presented at **ASME InterPACK 2023** in San Diego, CA, October 24-26, 2023.
4. Talk entitled “**Single-Phase and Two-Phase Liquid Immersion Cooling of Data Center Power Supply Units for Heat Capture**” by Haoyun Qiu *et al.*, presented at **ASME InterPACK 2023** in San Diego, CA, October 24-26, 2023.
- ★ 5. Paper entitled “**An Integrated Simulation Framework for Thermal-Mechanical Performance Analysis of Two-phase Microchannel Evaporators**” by Sarwesh Parbat *et al.*, presented at **ITherm 2024** in Denver, CO, May 28-31, 2024.
6. Paper entitled “**Dependence of Oscillation Frequencies on Operating Conditions in an Oscillating Heat Pipe**” by Rishav Roy *et al.*, presented at **ITherm 2024** in Denver, CO, May 28-31, 2024.
7. Paper entitled “**Experimental investigation of the heat spreading performance of oscillating heat pipes for electronics cooling applications**” by Syed Faisal *et al.*, presented at **ITherm 2024** in Denver, CO, May 28-31, 2024.
8. Paper entitled “**Single-Phase and Two-Phase Liquid Immersion Cooling of Data Center Power Supply Units for Heat Capture**” by Haoyun Qiu *et al.*, presented at **ITherm 2024** in Denver, CO, May 28-31, 2024.
9. Paper entitled “**Surface-Enhanced Two-Phase Cold Plate Designs for High Power Dissipation in Data Centers**” by Haoyun Qiu *et al.*, presented at **ITherm 2024** in Denver, CO, May 28-31, 2024.
10. Invited panelist (Todd Salamon) for “**Two-phase Cooling of Electronics Panel**” hosted by Dr. John Thome, **ITherm 2024** in Denver, CO, May 28-31, 2024.
11. Paper entitled “**High Power Thermal Test Vehicle with 2-Phase Cooling for AI Datacenters, 5G RAN, and EDGE Compute Nodes**” by Yang Liu *et al.*, presented at **ECTC 2024** in Denver, CO, May 28-31, 2024.

Funding, Partnerships, Advisors

- ▶ *Please list any anticipated needs following the completion of the COOLERCHIPS award.*
 - Partner to work with to license and/or further develop the technology

Team

Team member	Contact	Role in project, core competencies
	Todd Salamon todd.salamon@nokia-bell-labs.com	Role: System and component development Core competencies: two-phase heat transfer; advanced packaging and integration; system-level testing
	Nenad Miljkovic nmiljkov@illinois.edu	Role: Enhancing component-level liquid cooling Core competencies: heat transfer; surface enhancement techniques for improved flow boiling; immersion cooling
	Jiu Xu jiu.xu@meta.com	Role: T2M Analysis and Commercial Implementation



David Apigo (NBL)



Manohar Bongarala (NBL)



Mark Earnshaw (NBL)



Syed Faisal (NBL)



Vivek Garimella (UIUC)



Pouya Kabirzadeh (UIUC)



Yang Liu (NBL)



Nenad Miljkovic (UIUC)



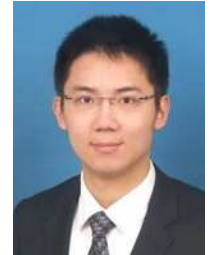
Aaron Qiu (UIUC)



Rishav Roy (NBL)



Todd Salamon (NBL)



Jiu Xu (Meta)