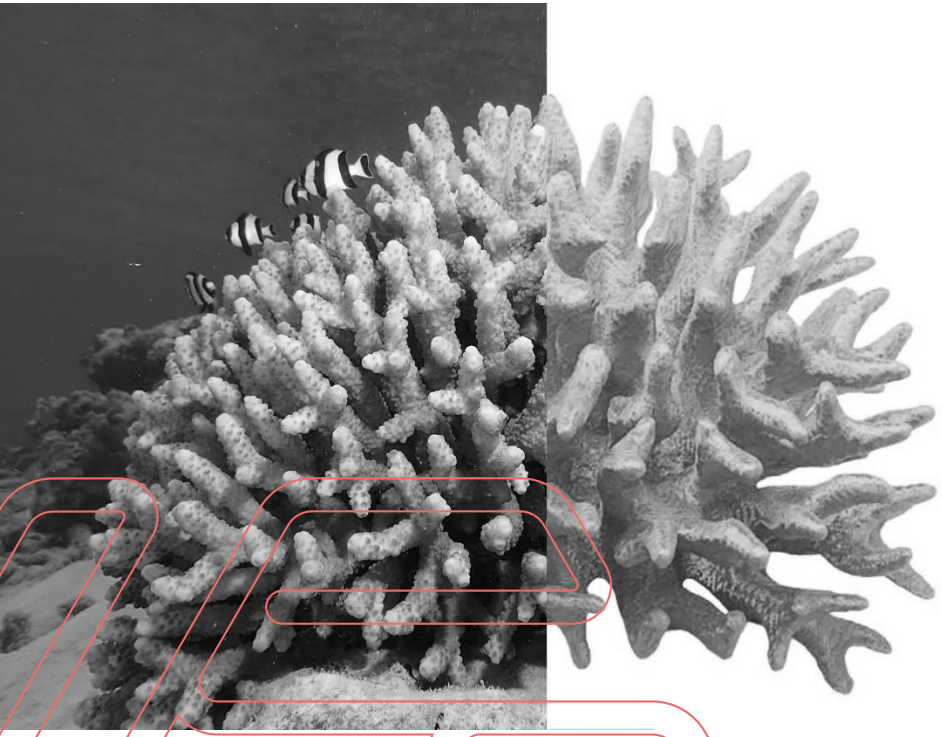


Immersion 5.0

Andrew Fitterer, Intel
Justin Weibel, Purdue University
Nathan Van Velson, ACT

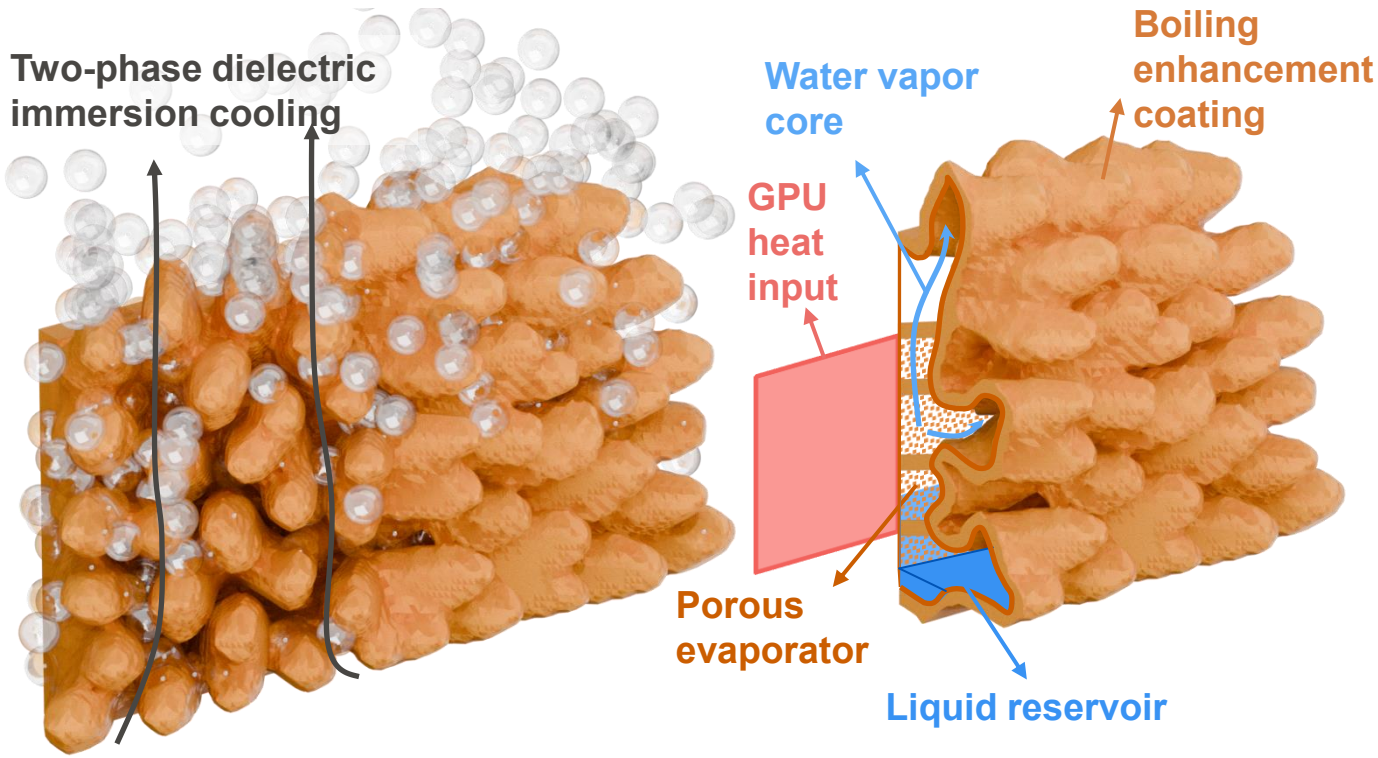
We are enabling a two-phase immersion cooling thermal solution for future high-power GPU / AI products using topology-optimized heatsinks with embedded spreaders.

Problem/Set up

- Chip and rack power densities are accelerating to support next-generation AI workloads, creating unprecedented thermal challenges.
- Legacy datacenter cooling infrastructure cannot scale quickly, and most deployments must adapt within existing facilities with long upgrade cycles.
- Two-phase immersion cooling has the potential to enable ultra-efficient thermal management for next-gen GPUs, but dielectric coolants have low critical heat flux that limits max powers.
- Our approach extends the viability of passive, two-phase immersion to cool GPUs up to 5 kW and beyond, enabling ultra-efficient future AI and HPC platforms.

Technology Description and Impact

KEY INNOVATIONS: TOPOLOGY OPTIMIZED TWO-PHASE IMMERSION COOLING VAPOR CHAMBER



- Two-phase immersion cooling enhanced by topology optimized vapor chamber heat spreader.
- Enables ultra-low resistance heat spreading to allow cooling of future high-power GPUs up to 5 kW.
- Passive operation drastically reduces cooling energy consumption compared to cold plate liquid cooling.

The Megawatt Rack (Tank)

Breakthrough in Heat Flux Management:

- Topology-optimized heatsinks with embedded vapor chambers allow localized heat spreading and efficient nucleate boiling, enabling up to 5 kW TDP.

Scalable Thermal Architecture:

- Design supports rack-level scaling from 160 kW today ➔ 1 MW by reducing per-device thermal bottlenecks.

Improved Energy Efficiency:

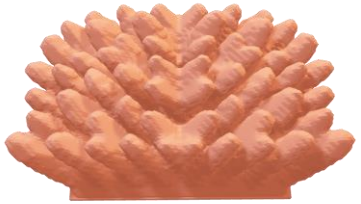
- Two-phase immersion with optimized heat sinks reduces pump power and potential elimination of chiller, improving PUE and lowering operational costs.

Future-Proof for AI/HPC Workloads:

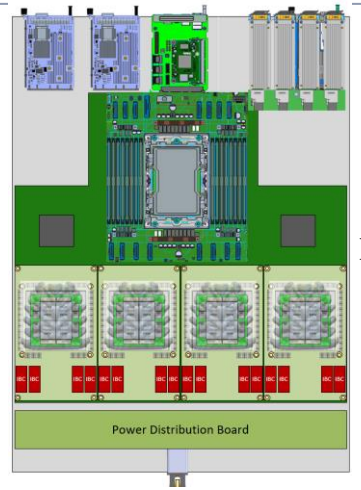
- Same data center thermal infrastructure can be reused for next-gen accelerators.

Enables Compact High-Density Racks:

- Efficient heat removal with temperature uniformity allows for higher compute density and increased efficiency/performance.

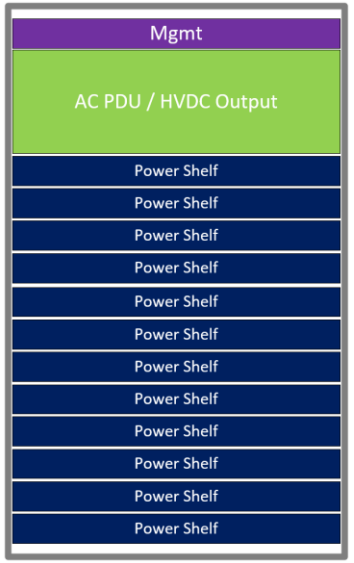


5kW+ GPU/ASIC TO-Heatsink

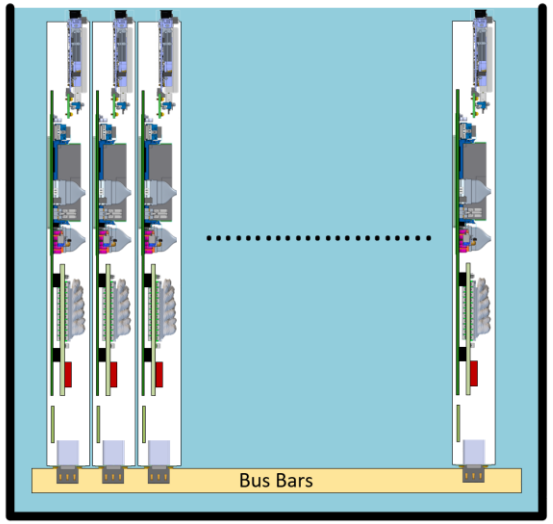


High Power Density Compute Blade

Side-Car Power Rack

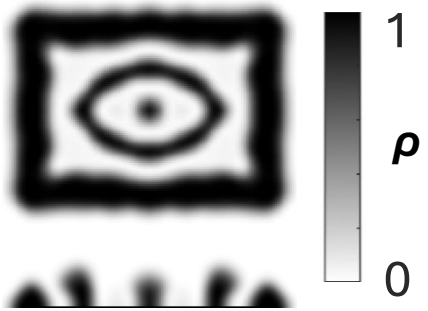


Tank/Condensers Sized for 500 kW - 1MW Total IT Power

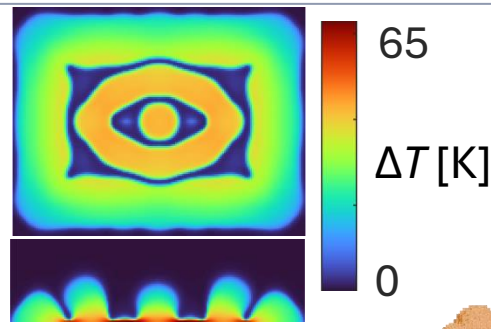


Topology Optimization Workflow

Discretized physical density $\boldsymbol{\rho}$



Solve temperature $\boldsymbol{T}$



Initialization



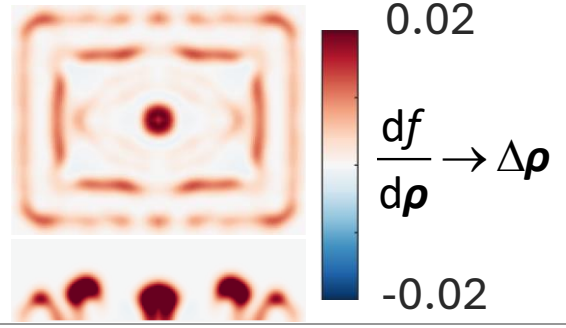
Intermediate Design

Heat Transfer Analysis

Iterations

Sensitivity Analysis

Update design based on the sensitivity of objective to $\boldsymbol{\rho}$



Final Design

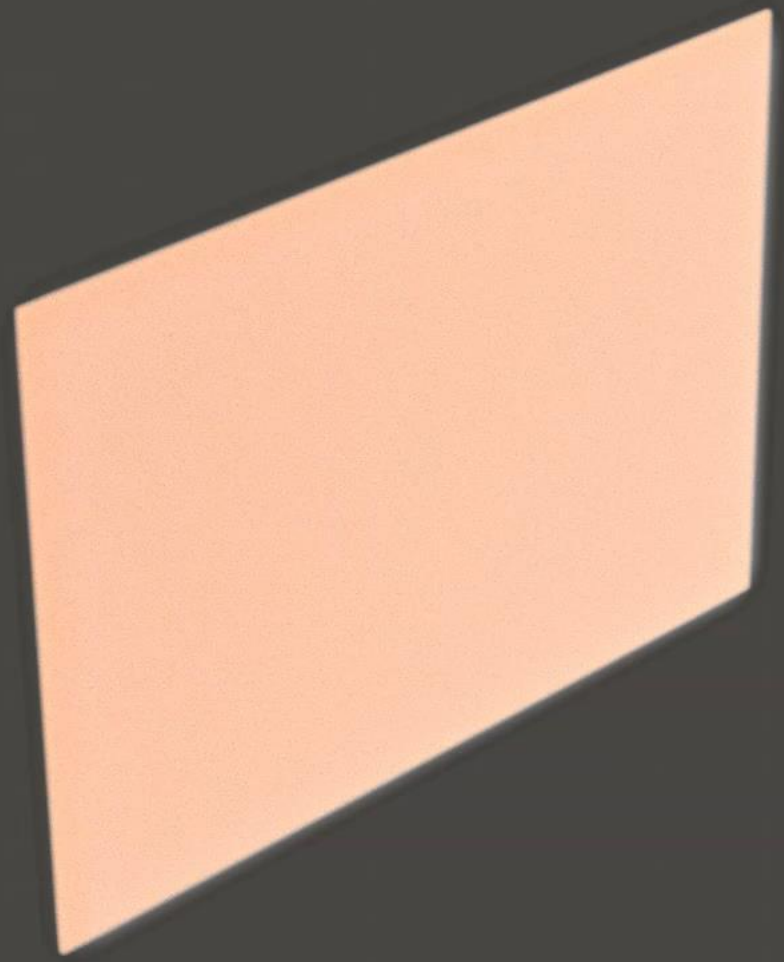


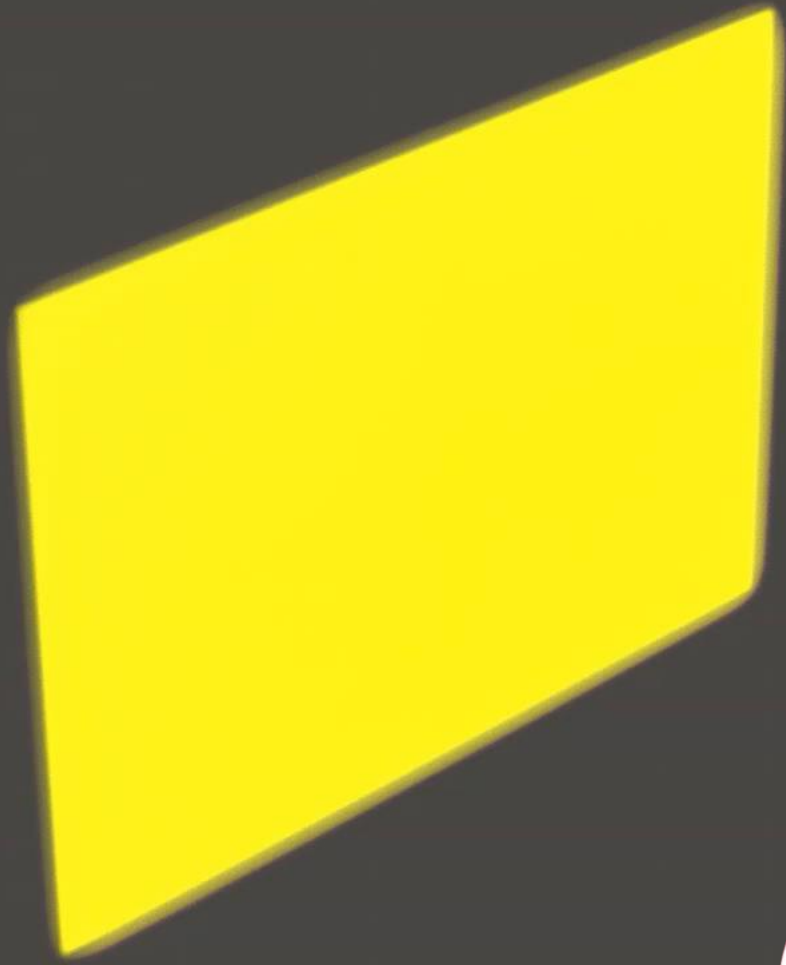
Optimization target

$$f = \gamma \int_{\Omega_{heater}} T d\Omega / Q_{heater} + (1-\gamma) \int_{\Omega} \bar{\rho} d\Omega / |\Omega|$$

Topology optimization formulations

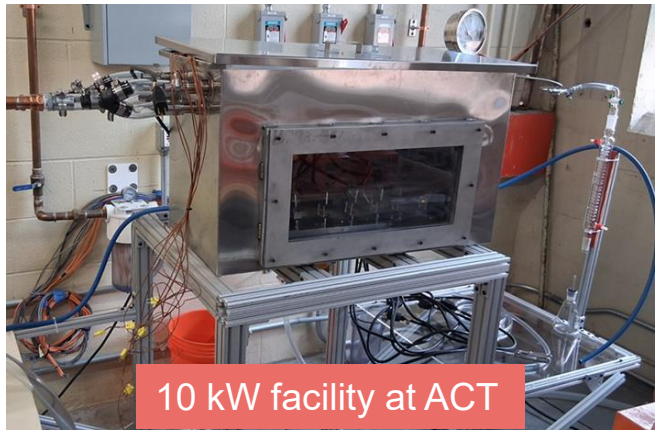
min.:	$f(\boldsymbol{\rho},\boldsymbol{T})$	f: Target function
s.t.:	$\boldsymbol{g}(\boldsymbol{\rho},\boldsymbol{T})=0$	$\boldsymbol{g}$: Governing eq.
:	$0 \le \boldsymbol{\rho} \le 1$	$\boldsymbol{\rho}$: Physical density
		$\boldsymbol{T}$: Temperature

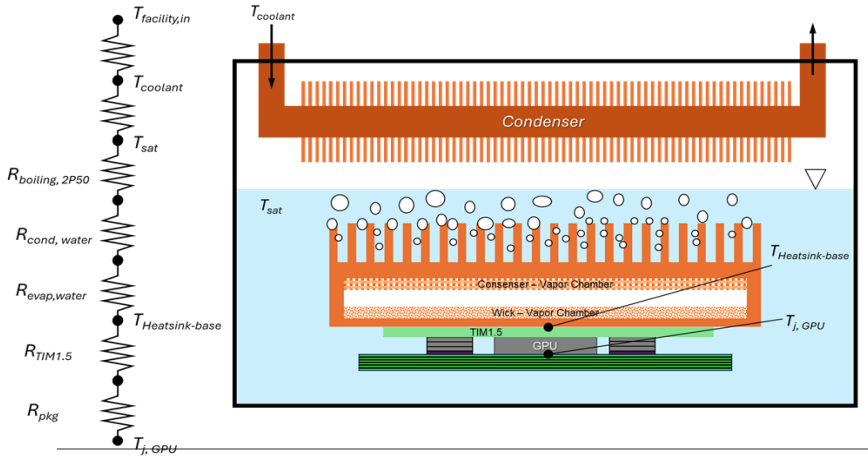


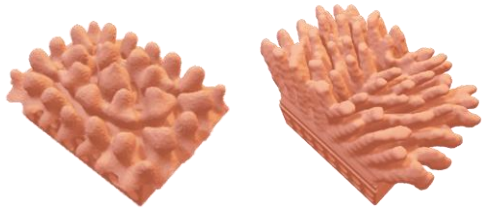


System Integration Results and Midterm Milestone

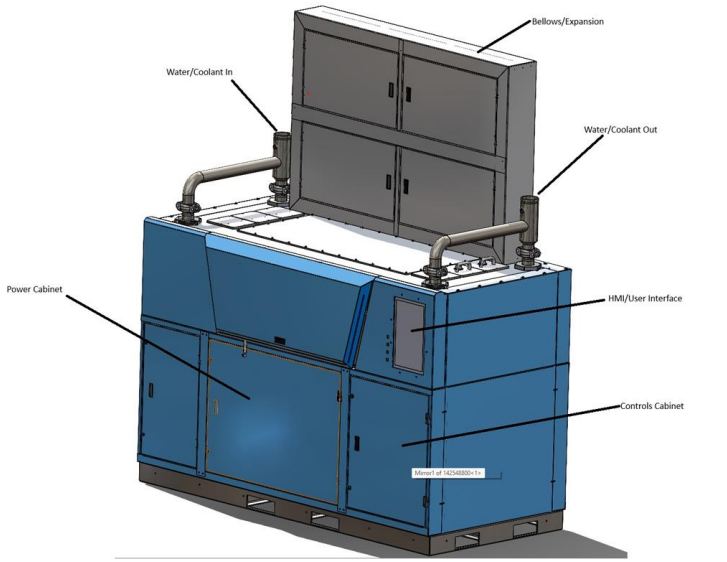
- 10 kW immersion tank fabricated and tested and available for characterization of heat spreaders at ACT.
- 160 kW immersion tank under development with Modine for system level testing.
- Analysis of thermal resistance network shows solid TO heat spreader designs meet midterm milestone targets, with clear pathway to final milestone targets, for 2 kW and 5 kW TDPs.





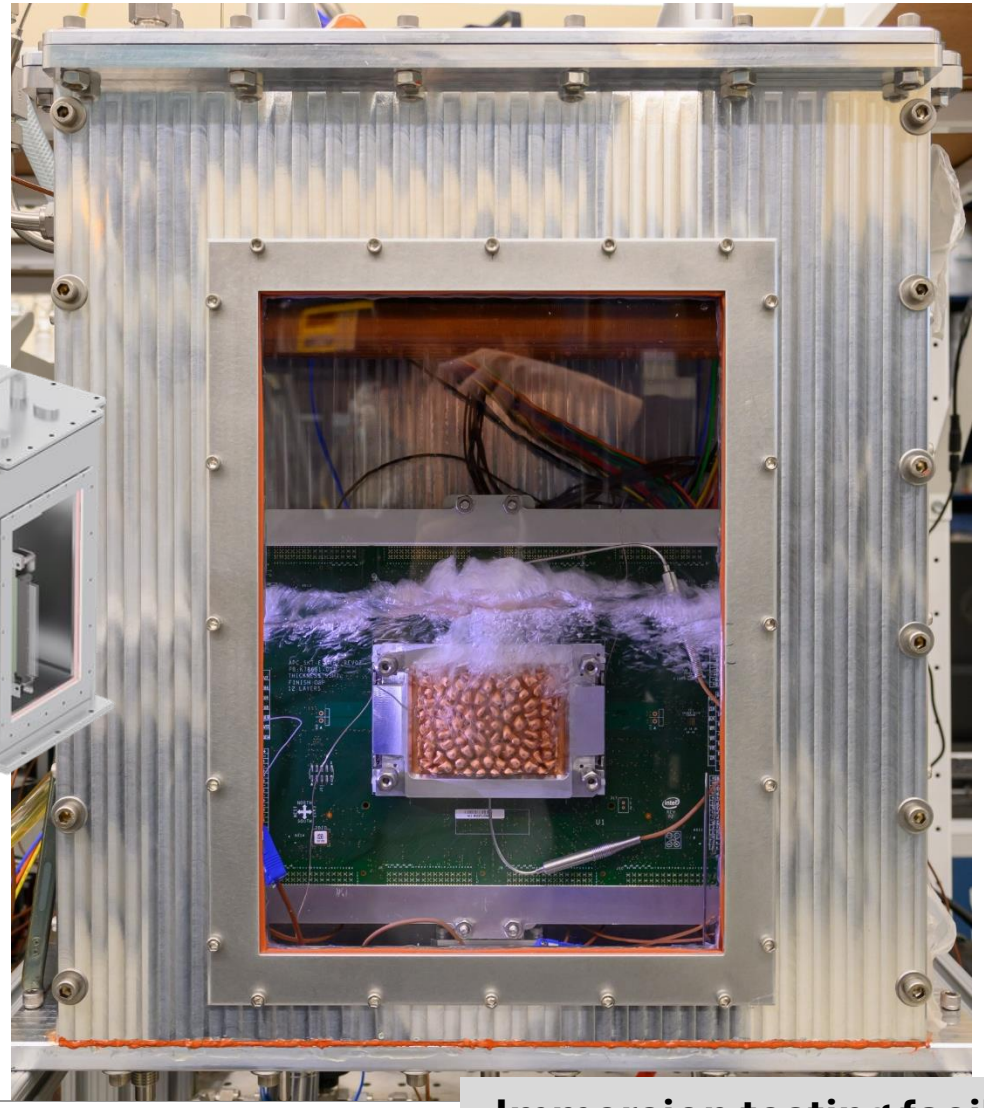


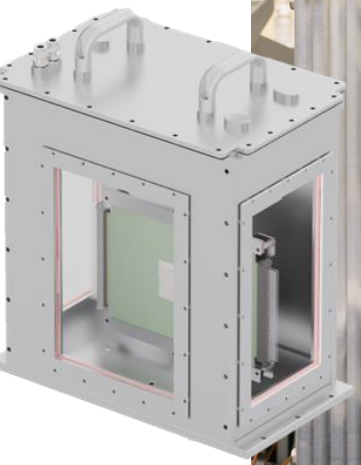
Thermal Resistance	2 kW - Solid	5 kW – Vapor Chamber
Heat spreader	0.0065 K/W	0.005 K/W
Total System	0.015 K/W	0.01 K/W

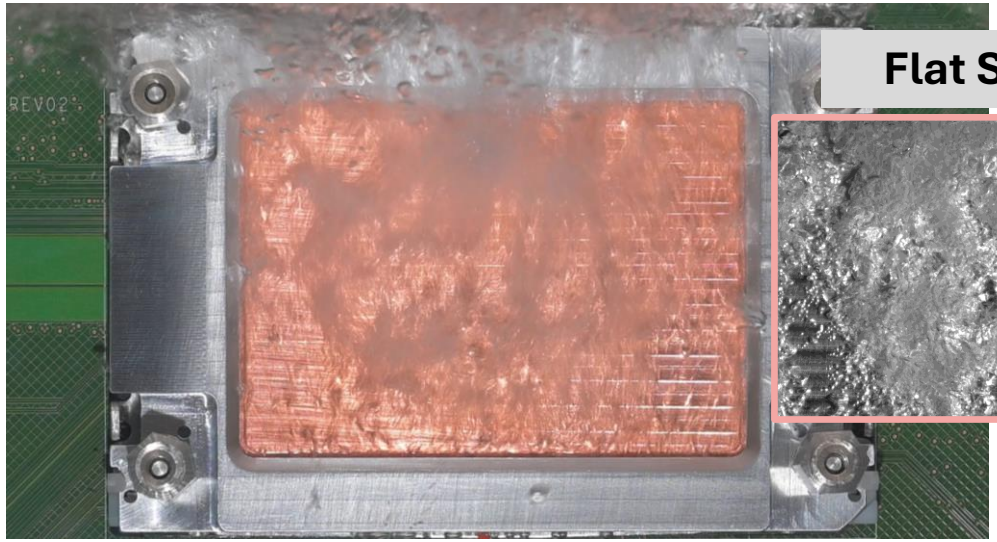


160 kW facility under development

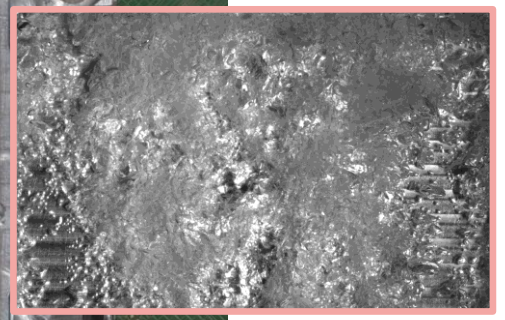
Technology Demonstration Testing

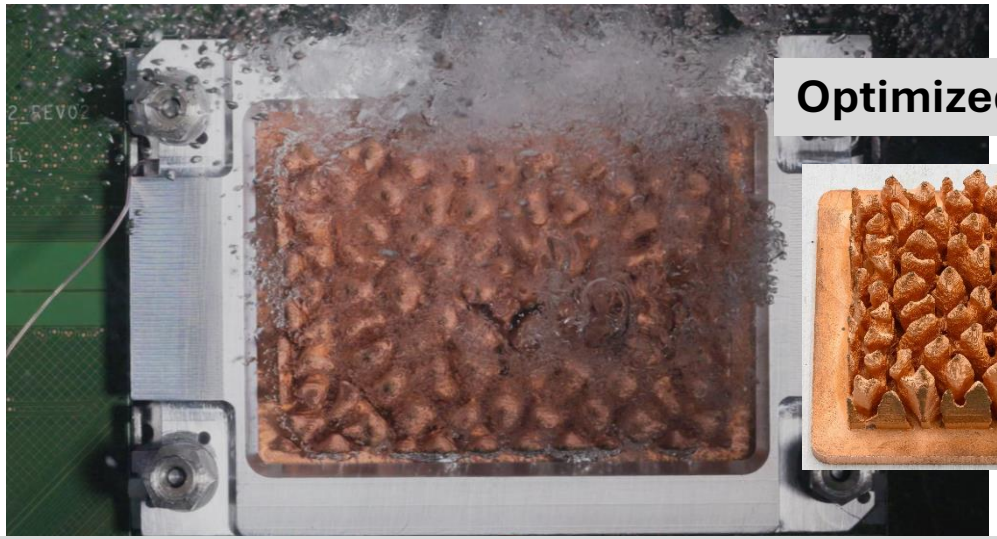






Flat Surface





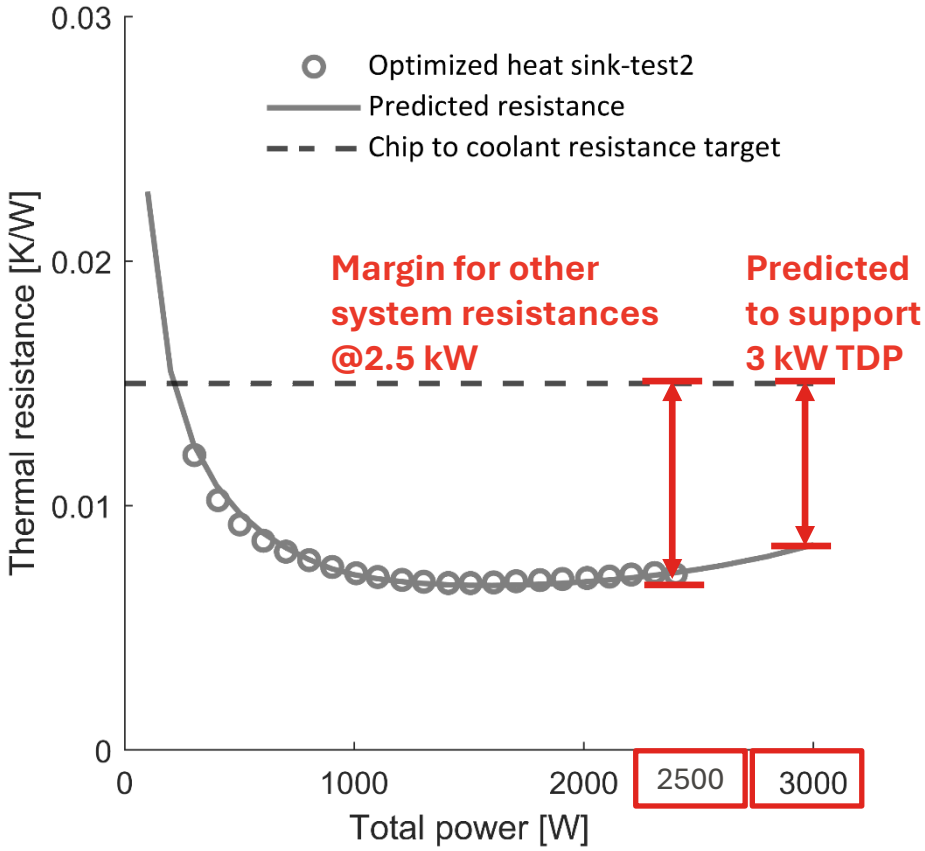
Optimized Heat Sink

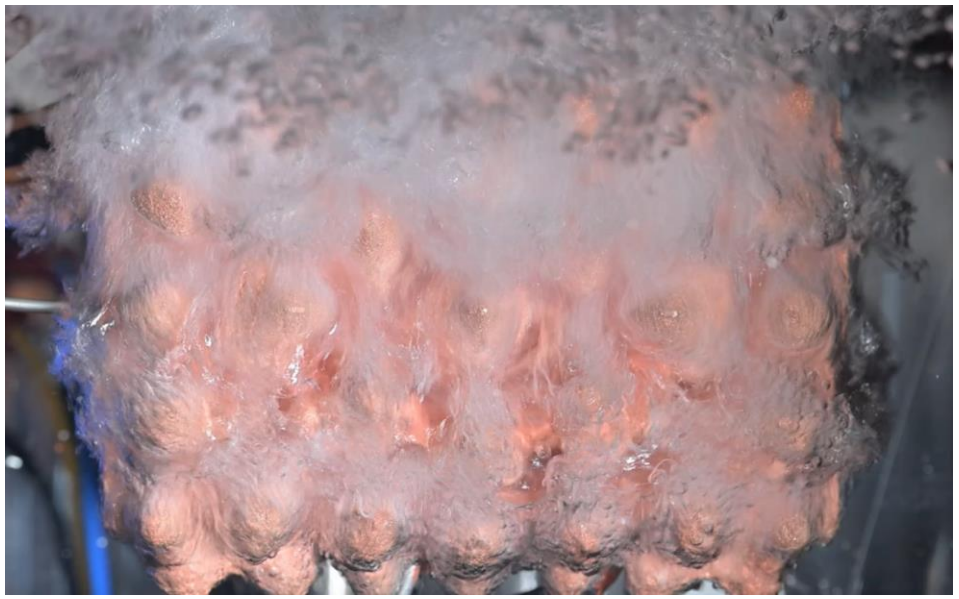


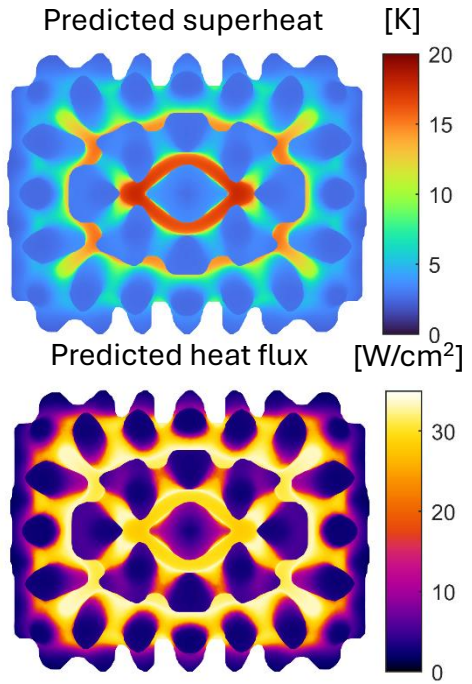
Immersion testing facility established at Purdue and reliability testing for boiling enhancement coatings and heat sinks completed using Intel TTV

Concept Validation

TOPOLOGY OPTIMIZED HEAT SINK VALIDATED TO SUPPORT UP TO 3 KW TDP







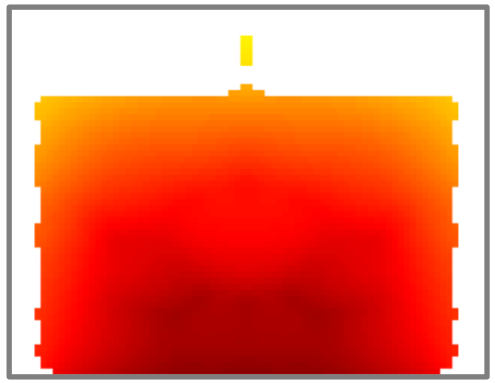
Boiling on topology optimized solid copper heat sink (shown operating at 2400 W) meets program milestones on path to overall system thermal resistance targets

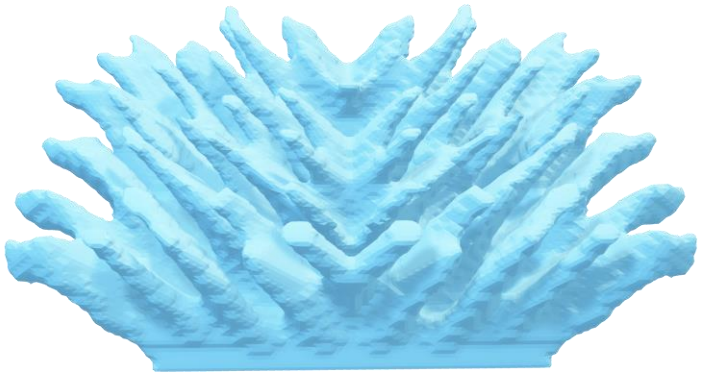
Vapor Chamber Design Progress

TOPOLOGY OPTIMIZED VAPOR CHAMBER PREDICT TO SUPPORT 5 KW @ < 0.01 K/W

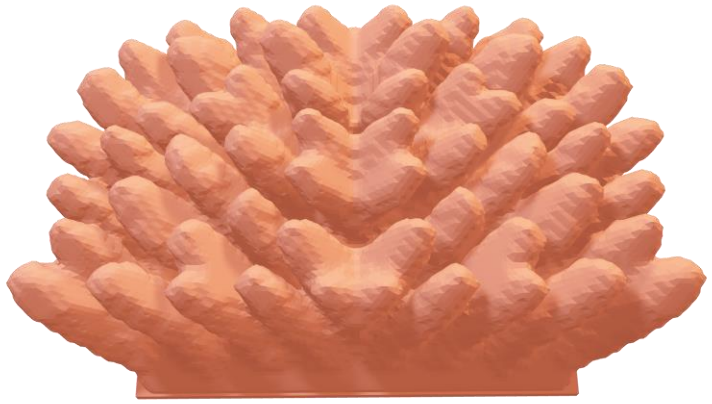








Internal Vapor Core Visualization



Vapor Chamber Design

Additively Manufactured Vapor Chamber Shells (before support structure removal)

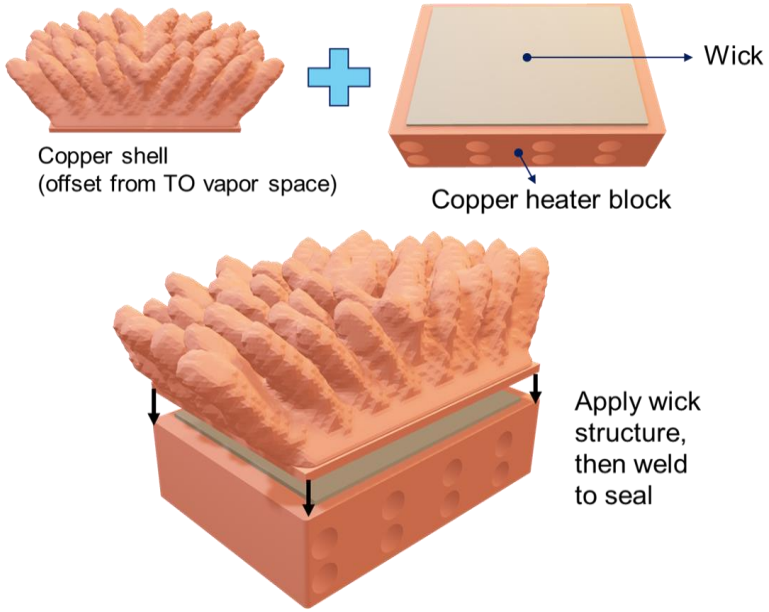


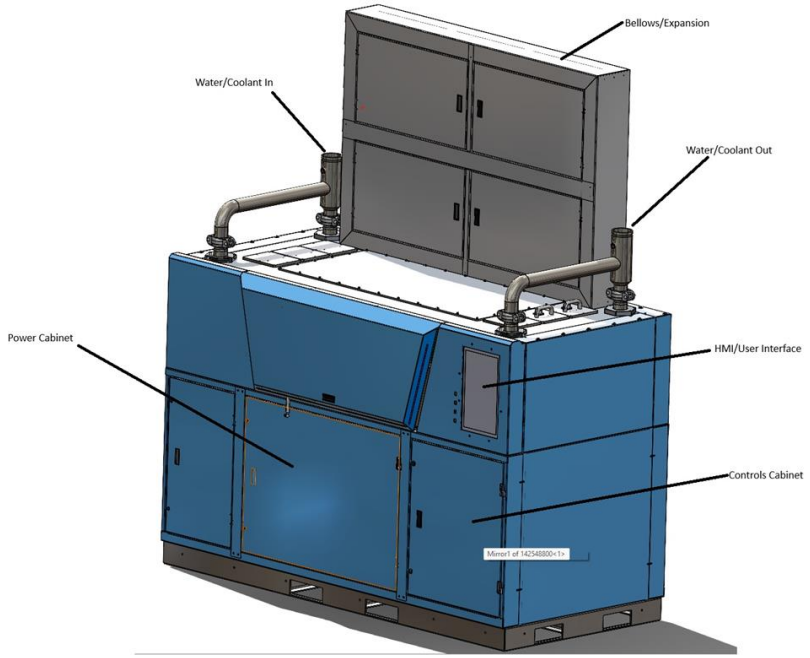
SS Test Print

Cu Test Print

What is Next: Detail of Upcoming Tasks

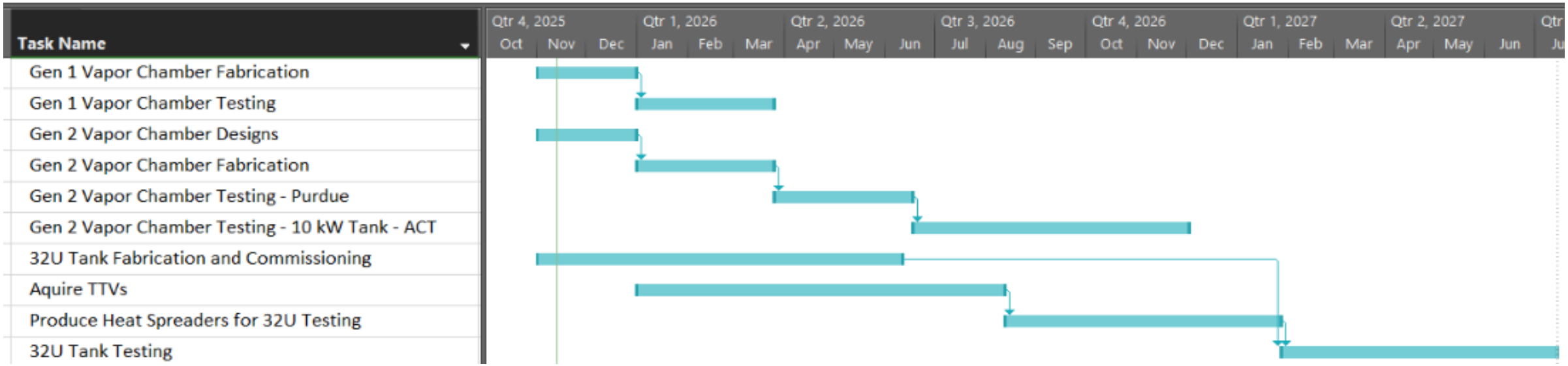
- Manufacturing and assembly of first generation (Gen1) vapor chamber (VC) heat sinks.
- VC-embedded heat sink testing to feedback into VC model & optimization framework.
- Manufacture and test Gen2 vapor chamber designs.
- 160 kW immersion tank to be completed in Q1 ’26. Integration with ACT facilities (electrical, facility coolant).
- 5kW TTV systems (proxy for future GPU servers) are installed in our 160kW tank for heatsink performance testing.





What is Next: Timetable

- Manufacturing & testing iterations of vapor chamber (VC) heat sinks.
- Testing the VC heat sinks in 10-kW tank.
- Manufacturing and testing for 160kW tank.
- Produce heatsinks for TTVs and test in 32U Tank.



System Reliability

Interaction	Failure Modes	Severity	Occurrence	Mitigation
Die ↔ Vapor Chamber	Capillary limit exceeded → vapor chamber evaporator dry-out	9	5	Design for operation at 5 kW based on wick capillary pressure and permeability; multiple liquid return paths from condenser to minimize wicking distances against gravity
Boiling Surface ↔ Fluid	Exceed CHF on the external surface of the vapor chamber leads to film boiling	10	4	Use of boiling enhancement coating and CHF factory of safety in optimization
Vapor Management ↔ Condenser	Condenser flooding; NCG layer blocking condenser	8	6	Adequately sizing condenser coils; bellows vapor management system
Fluid ↔ Material Compatibility/ Chemistry	Organic leaching / plasticizer release	8	5	Tighten AML; vendor certs; soak tests at temp; Immersion fluid filtration
Condenser ↔ Facility Water	Water-side fouling / biofilm	9	5	Finer filtration; oversized condenser; Fluid additives

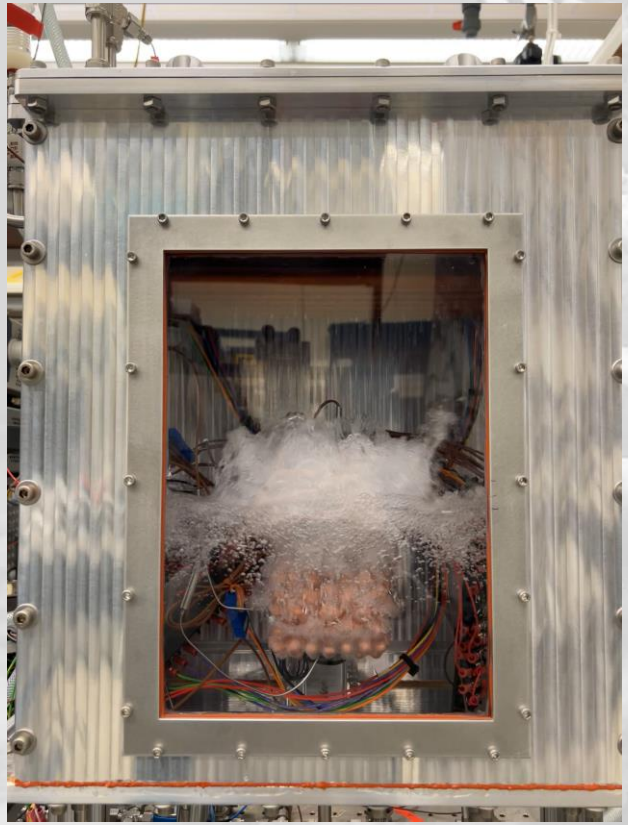
- Demonstration testing has substantially de-risked concerns related to the power dissipation limits, as well as correlation between models and measurement data.
- Boiling enhancement coatings have proven stable viable reliability testing, as well as after application to complex structures.
- No unexpected material compatibility issues have arisen.

Needs/The Ask: Funding, Partnerships, Advisors

- Partners interested in completing a post-project or concurrent MW rack (tank) demonstration

Immersion 5.0

We are enabling a two-phase immersion cooling thermal solution for future high-power graphics/ AI products using topology-optimized heatsinks with embedded spreaders



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