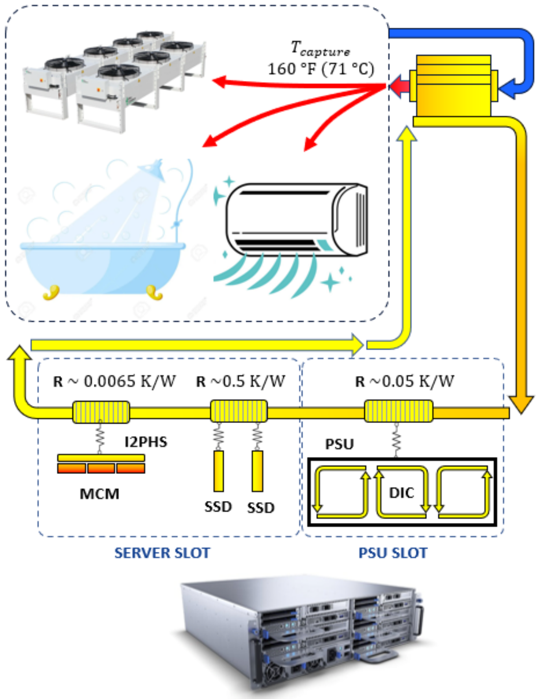
Delivering energy and exergy efficiency in the converged 5G RAN/EDGE compute network

Todd Salamon (PI), 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.



Total Project Cost:	$2.78M
Length	36 mo.

COOLERCHIPS Kickoff Meeting
October 18 & 19, 2023

Brief COOLERCHIPS Project Overview

Fed. funding:	$2.78M
Length	36 mo.

Team member	Location	Role in project, core competencies
Nokia Bell Labs (NBL)	Murray Hill, NJ	**Role:** System and component development **Core competencies:** two-phase heat transfer; advanced packaging and integration; system-level testing
University of Illinois (UIUC)	Urbana-Champaign, IL	**Role:** Enhancing component-level liquid cooling **Core competencies:** heat transfer; surface enhancement techniques for improved flow boiling; immersion cooling

Context/history of the project

- **How project came together:** Leverage NBL's and UIUC's core competencies to develop a high-performance thermal management system for edge computing applications
- **Enabling features:** Completely passive, self-regulating thermal management system based on two-phase thermosyphon and advanced integration
- **Bigger vision:** Enable scalable path to increased heat server heat densities while reducing TUE and reusing captured heat
- **Goal/success criterion:** Demonstrate heat capture ≥ 160 °F (~71 °C) and reuse with 3X to 4X increase in server heat density

CHANGING WHAT'S POSSIBLE

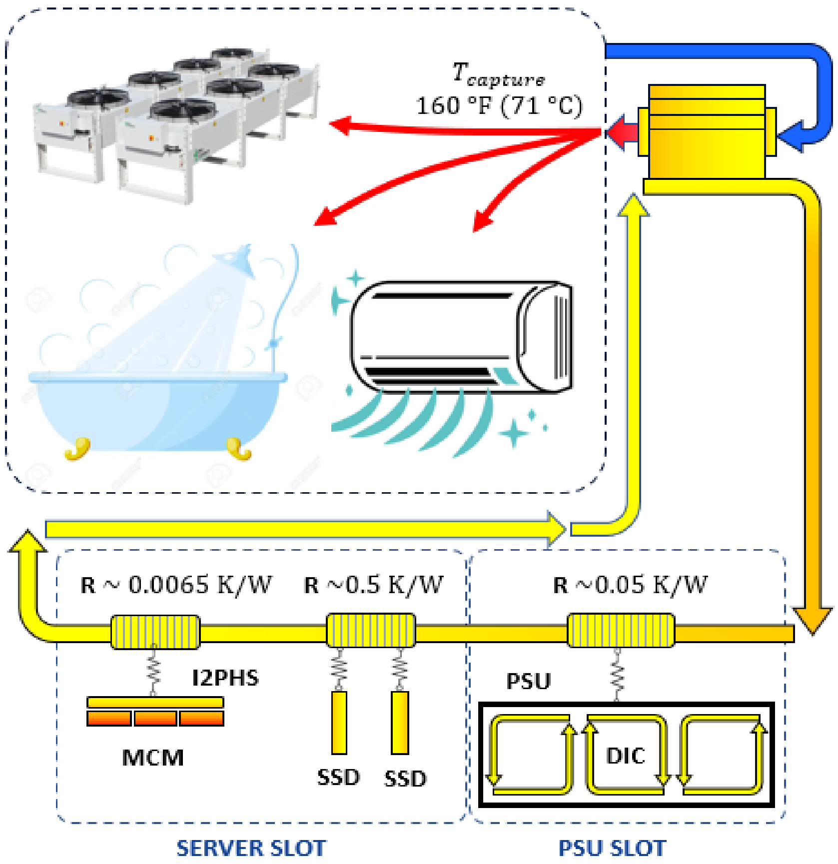
Concept Detail

- **Our innovation:** Passive system with highly-integrated liquid cooling
- **Key performance metrics:**

Metric	State of the Art	Proposed	Unit
Heat capture temperature, $T_{capture}$	~15 (~59)	> 71.1 (160)	°C (°F)
Compute node heat density[1], Q'''_{server}	~96	≥ 274	kW/m^3
Heat capture efficiency, $\eta_{capture}$	>90	> 90	%
DC TUE ($\equiv P_{total} / P_{IT}$)	1.4	≤ 1.09	-
DC WUE ($\equiv$ DC water usage / P_{IT})	1.8	0	$L.kWh^{-1}$
Chip cooler performance, $R_{chip\text{-}to\text{-}cooler}$	0.015	0.0065	$C.W^{-1}$

- **Technology commercialization routes:** Develop supply chain leveraging licensing, partnering / spin-out and In-house offering
- **Simulation tool:**
  - Utilizing in-house two-phase thermo-fluidic simulation tool
  - Enhancements for 3D heat spreading, plenum effects, and system simulation
- **Thermal test vehicle:** 1000 W multi-chip module (MCM)

System architecture



[1] $$Q'''_{server} \equiv \frac{P_{server}}{V_{server}} = \frac{P_{IT} + P_{PSU} + P_{Cool}}{V_{server}}$$

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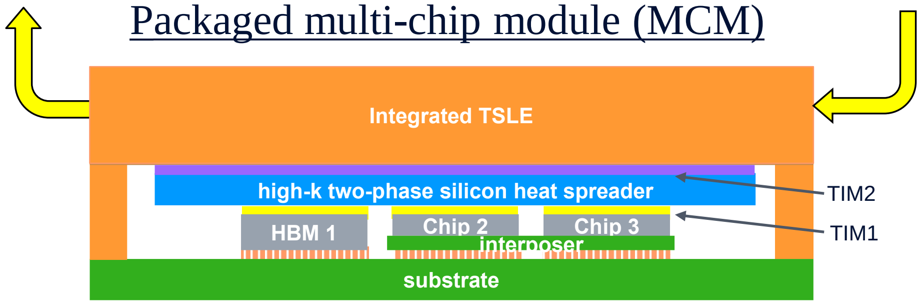
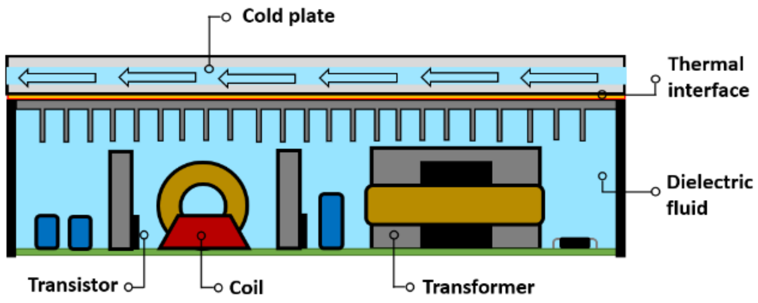
Packaged multi-chip module (MCM)



Immersion cooled power supply (PSU)



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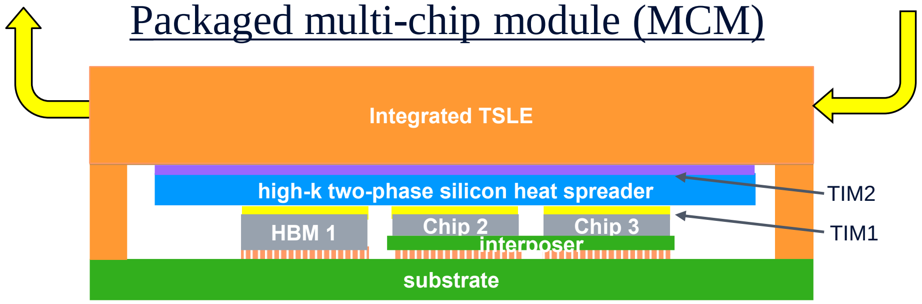

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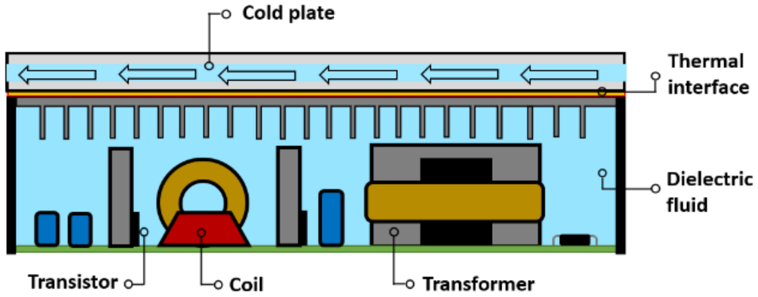
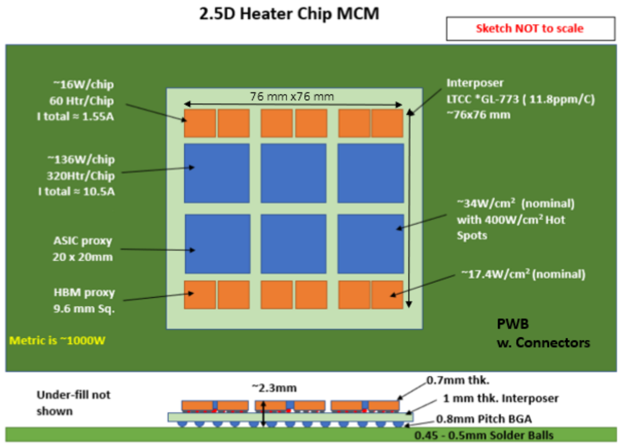


Thermal test vehicle



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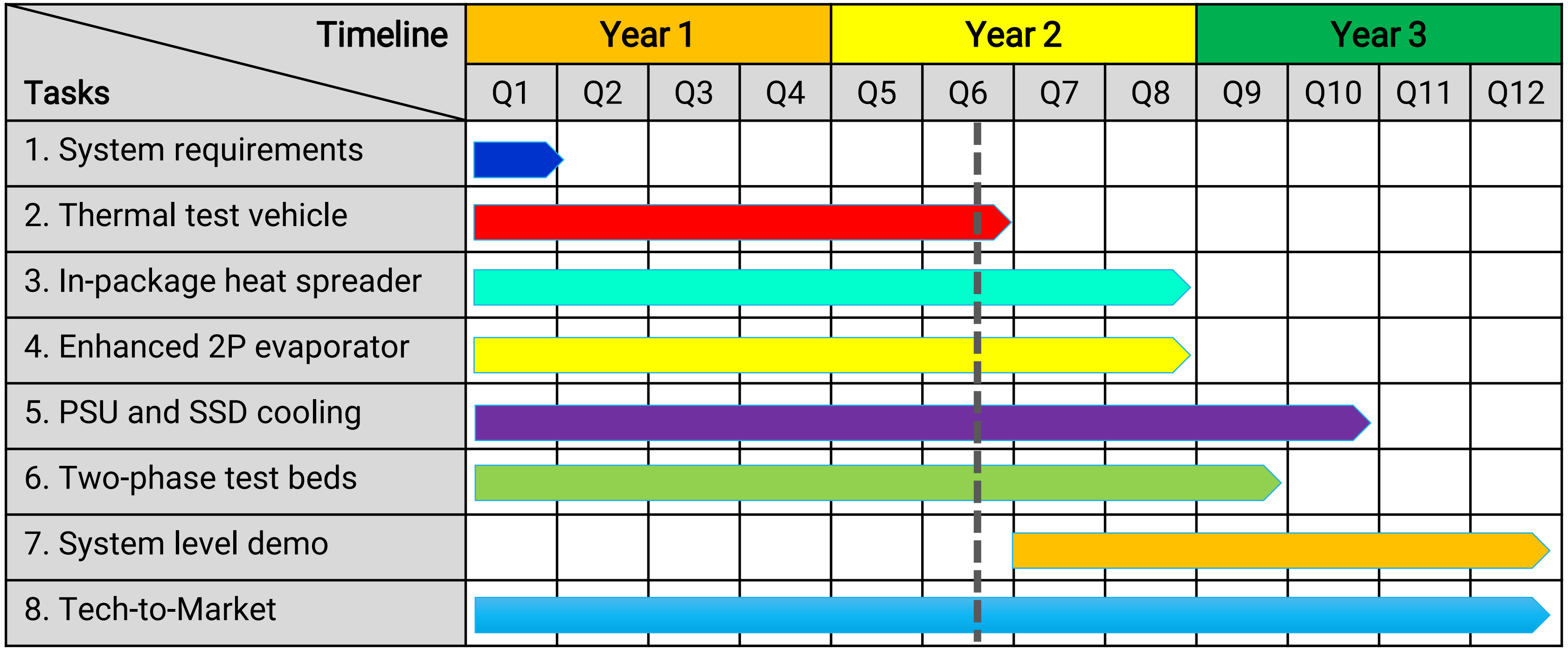
Task Outline & Technical Objectives

- *Primary tasks*



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	■	■	■	■	■	■	■	■	■	■	■	■

- *Major project targets and deliverables*
  - 1000 W MCM thermal test vehicle
  - Surface enhanced two-phase evaporator with $R_{\text{chip-to-cooler}} \leq 0.0065$ C/W
  - Overall system demonstration

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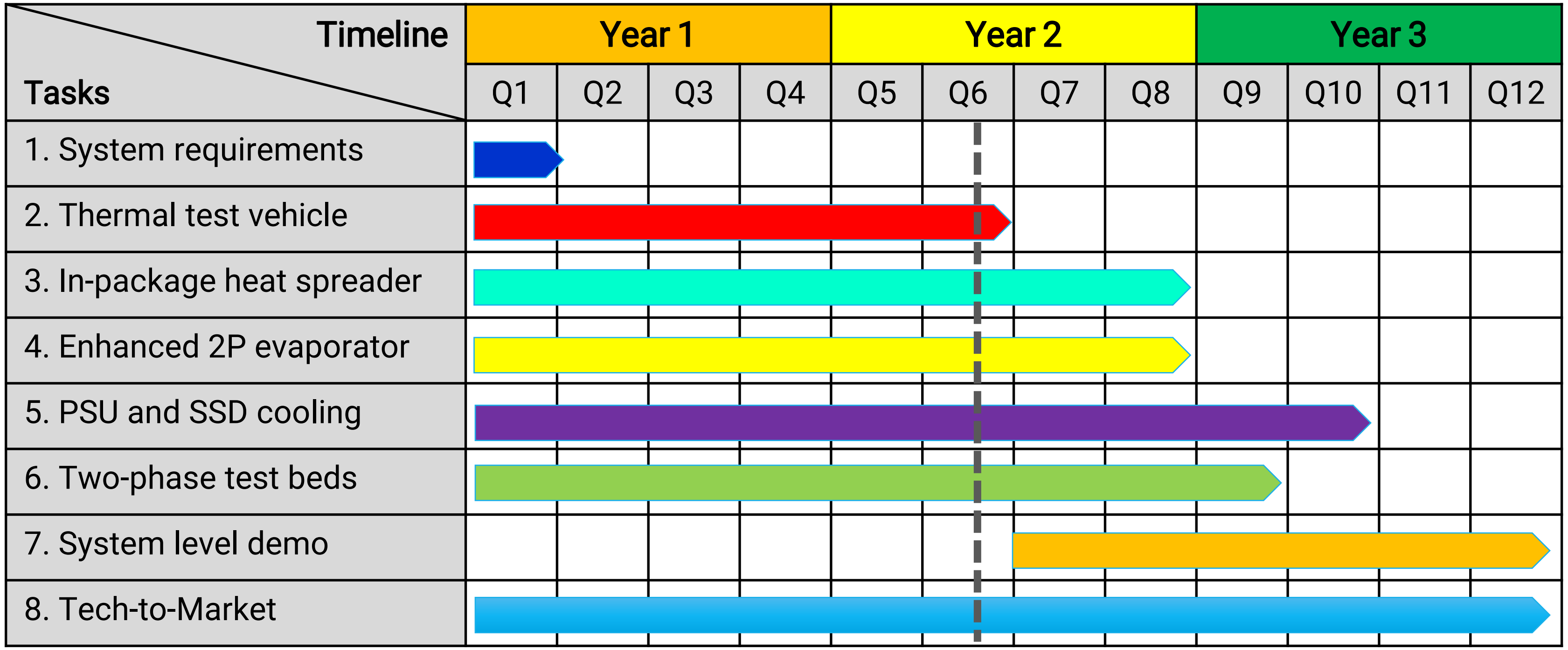

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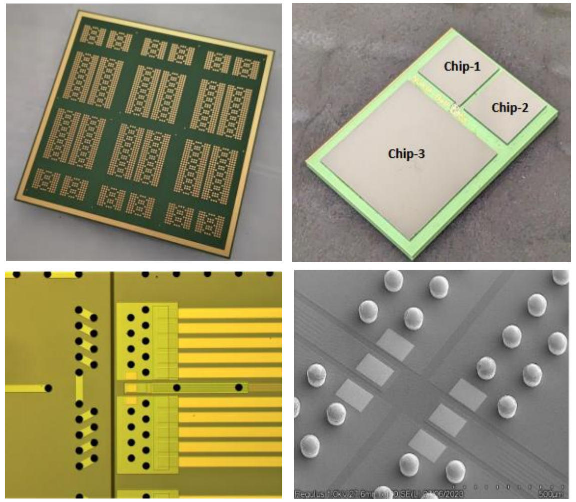
Images of MCM components



CHANGING WHAT'S POSSIBLE

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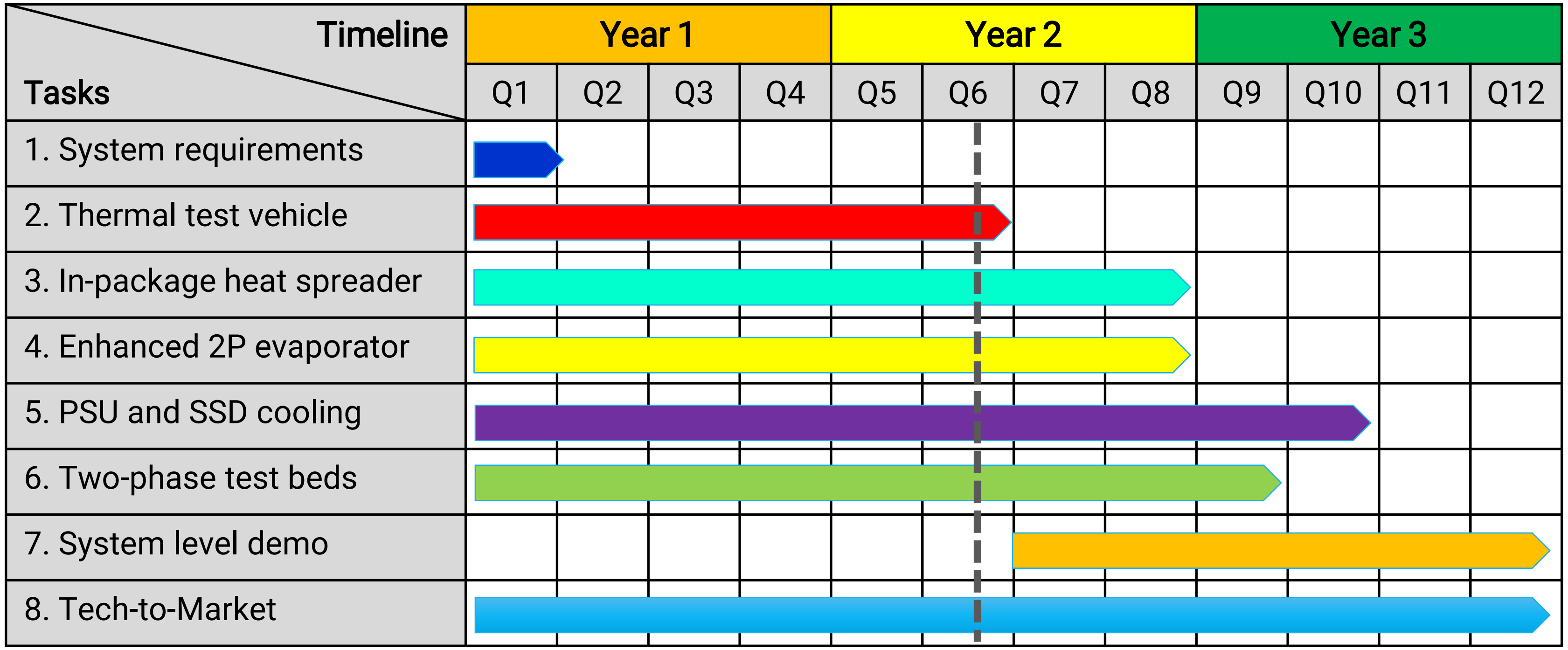

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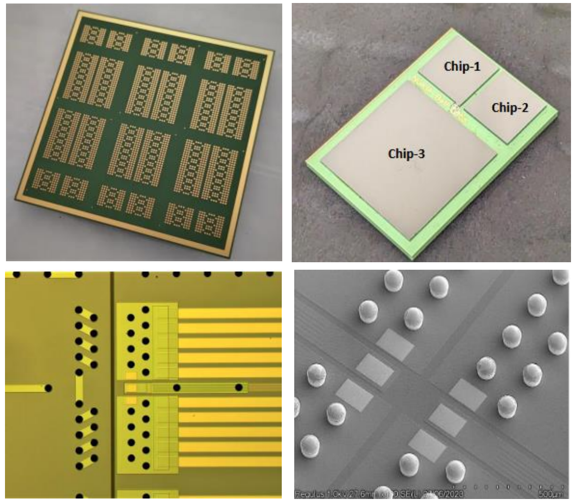
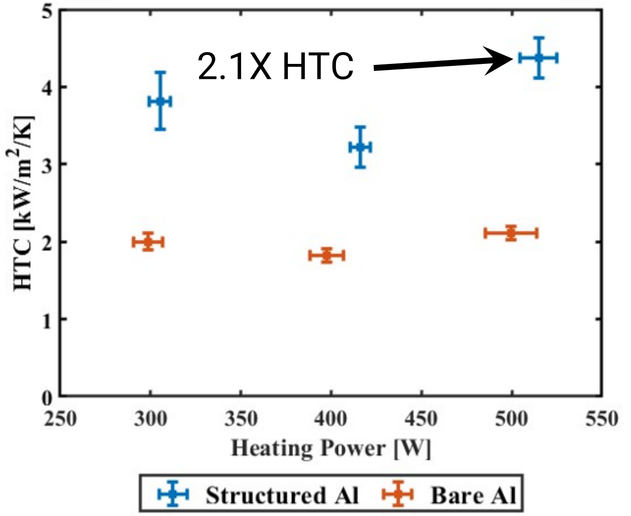
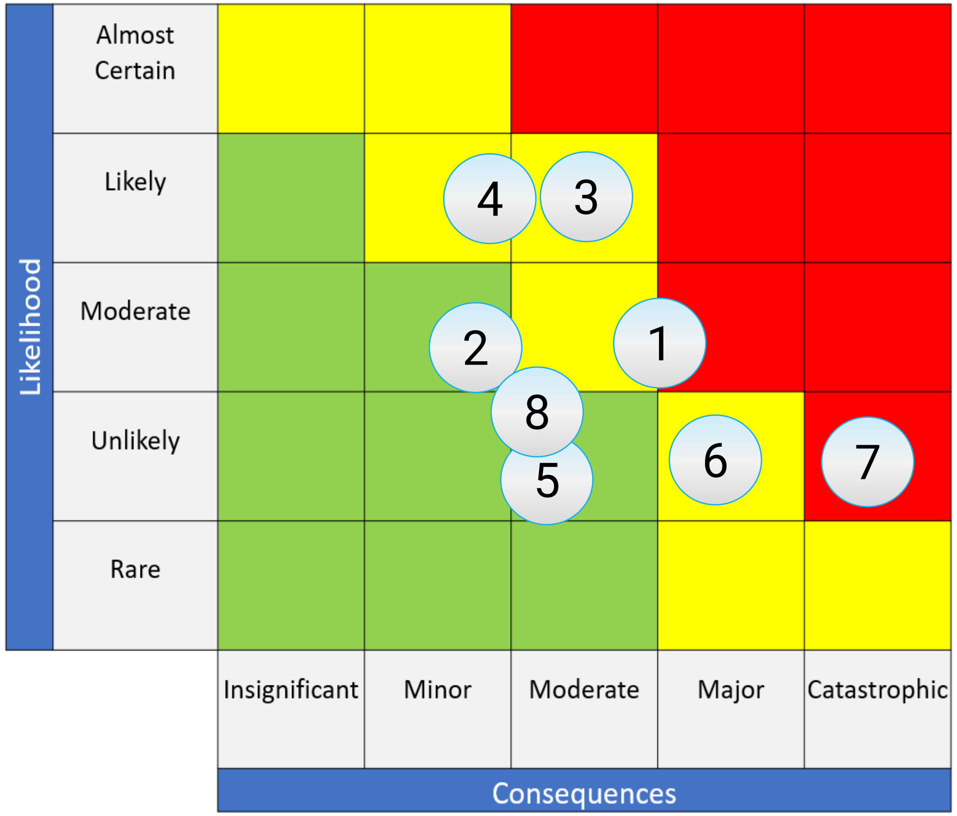


Enhanced evaporator performance



Challenges and Risks

Primary technical and commercialization risks



Risk Status

Risk	#
Thermomechanical stress	1
Heat capture efficiency	2
2P IHS integration	3
Evaporator performance	4
MCM test bed	5
TCO advantage	6
System thermofluidic reliability	7
Sliding interface reliability	8

Technology-to-Market Approach

- *What is our commercialization plan?* Develop supply chain to support edge computing application
  - Licensing
  - Partnering / spin-out
  - In-house development and offering
- *How will it lead to further follow-on investment?*
  - Stakeholders will provide additional development resources to commercialize
- *What are the anticipated first markets? What are the market requirements in terms of cost and performance?*
  - Targeting EDGE DC market. Total cost of ownership (TCO) less than air- and single-phase liquid cooling. Performance allowing significant rack (>100 kW) and site densification.
- *What are the anticipated long-term markets? What are the market requirements in terms of cost and performance?*
  - Long-term market would target larger-scale data centers. Total cost of ownership (TCO) less than air- and single-phase liquid cooling. Performance allowing significant rack (>100 kW) and site densification.

CHANGING WHAT'S POSSIBLE

Needs and Potential Partnerships

- *Please list any additional current needs for your project: resources, expertise, etc.*
  - Thermofluidic modeling and simulation of two-phase flow (potential for partnering / collaboration)
    - Example areas: Component modeling (e.g., heat exchangers, condensers, etc.), model validation, system simulation, device modeling (e.g., oscillating heat pipes)
  - Discussions with large-scale data center operators on cooling system requirements, operational considerations, etc.
- *Please list any anticipated needs following the completion of the award*

Q & A

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https://arpa-e.energy.gov