COOLERCHIPS - Cooling Compute Systems Efficiently, Anytime, Anywhere

-US leadership in high power chipsets cooling technology

Dr. Peter de Bock, Program Director ARPA-E
Dr. Jungho Kim, Program Director ARPA-E
Dr. Brent Ridley, Tech2Market Advisor ARPA-E

ARPA-E's Team Composition: COOLERCHIPS

Program Directors:
Manages program portfolio


Peter de Bock


Jungho Kim

Tech-to-Market Advisors:
market, strategy, business planning


Brent Ridley

Legal: *Assist with any legal questions*


Charles Conway


Geoff Goode

Tech SETAs: *Track technical status, advise, prepare quarterly feedback*


Vivien Lecoustre


Ashok Gidwani


Tom Bress


Nathan Kamphuis

PM SETAs: *Track project budget status, invoicing, award business related matters*


Moses Manning


Joey L'Etoile

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CHANGING WHAT'S POSSIBLE

Annual meeting agenda: If it works, will it matter

Day 1: Technology

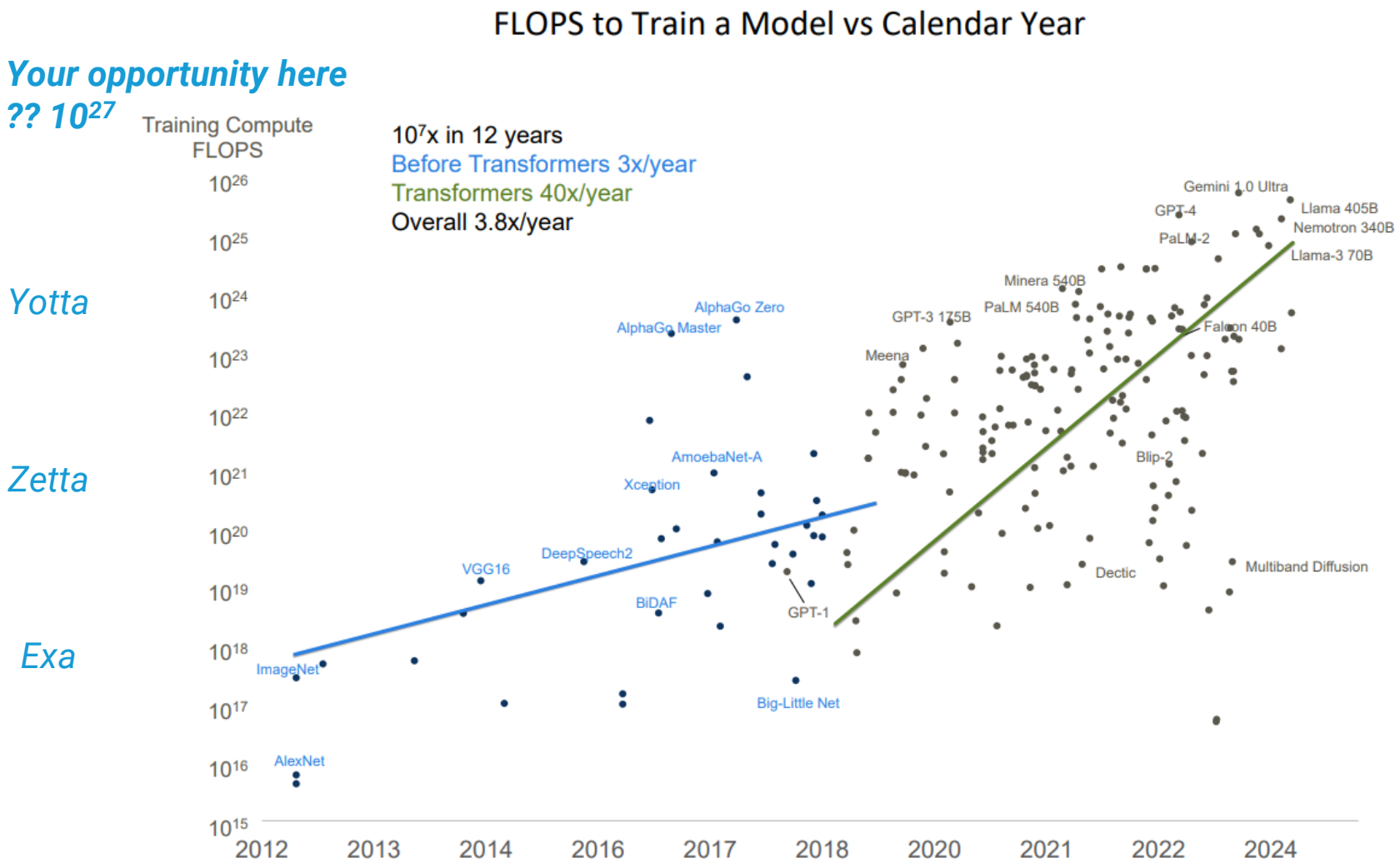
- Team updates
- Technical Keynotes
- Group Picture
- Poster session

Day 2: Making it matter

- Data Center Leaders
- Manufacturing
- Operators
- Maturation partners

WHERE ARE WE TODAY AND A FORWARD VIEW

You know when you are on the cutting edge when words to describe the size of the problem you are computing don't exist…



William Daly, NVIDIA, NASEM AI Workshop, 11/4/2024

Sector Growth and Chip Growth > kW

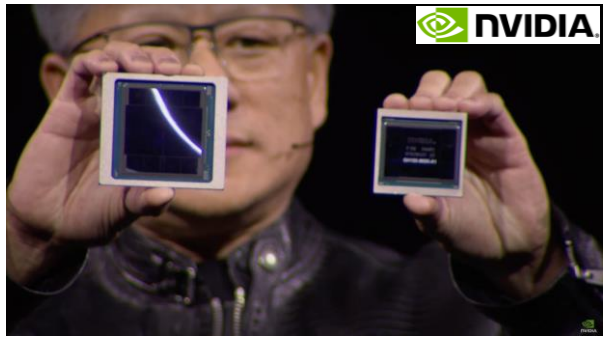
Insatiable demand for computing

ChatGPT/AI and solving large problems increasing global data center and high-density chipset demand

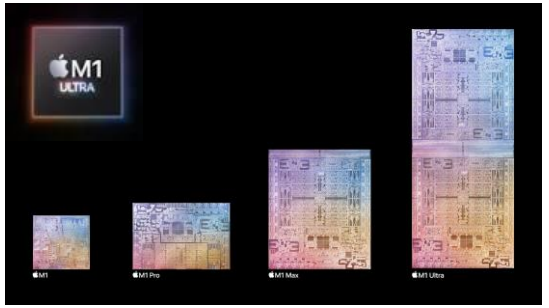
The rise of more powerful >1kW chipsets

eUAV is currently the limit of lithography as a result; chip are getting bigger and use more power

Consequence: More performance? More transistors.. Larger silicon, more power
Future? >1000W per chip

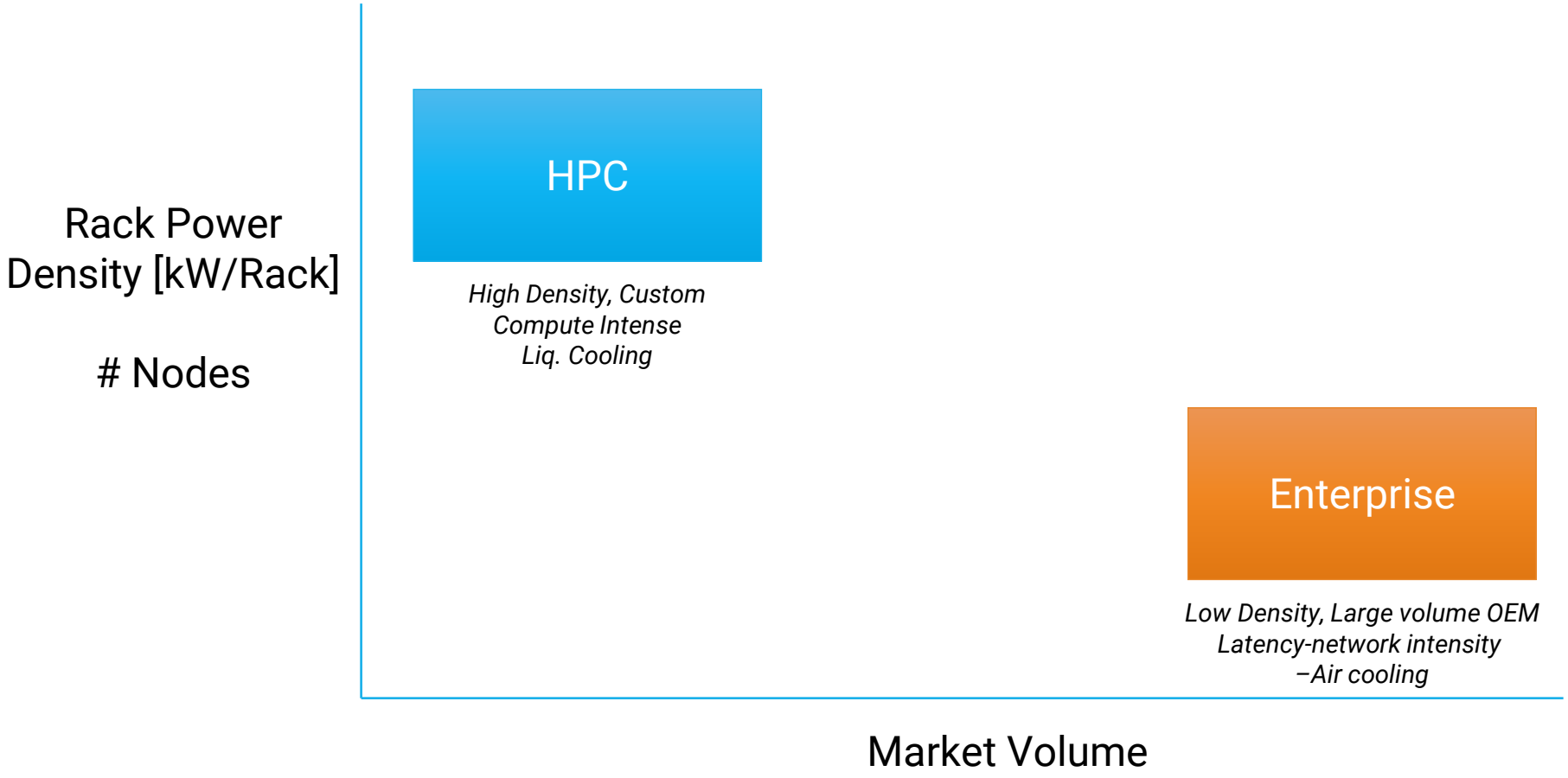


Nvidia co-founder and CEO Jensen Huang held up the new Blackwell GPU chip, left, to compare to its predecessor, H100, "Hopper."

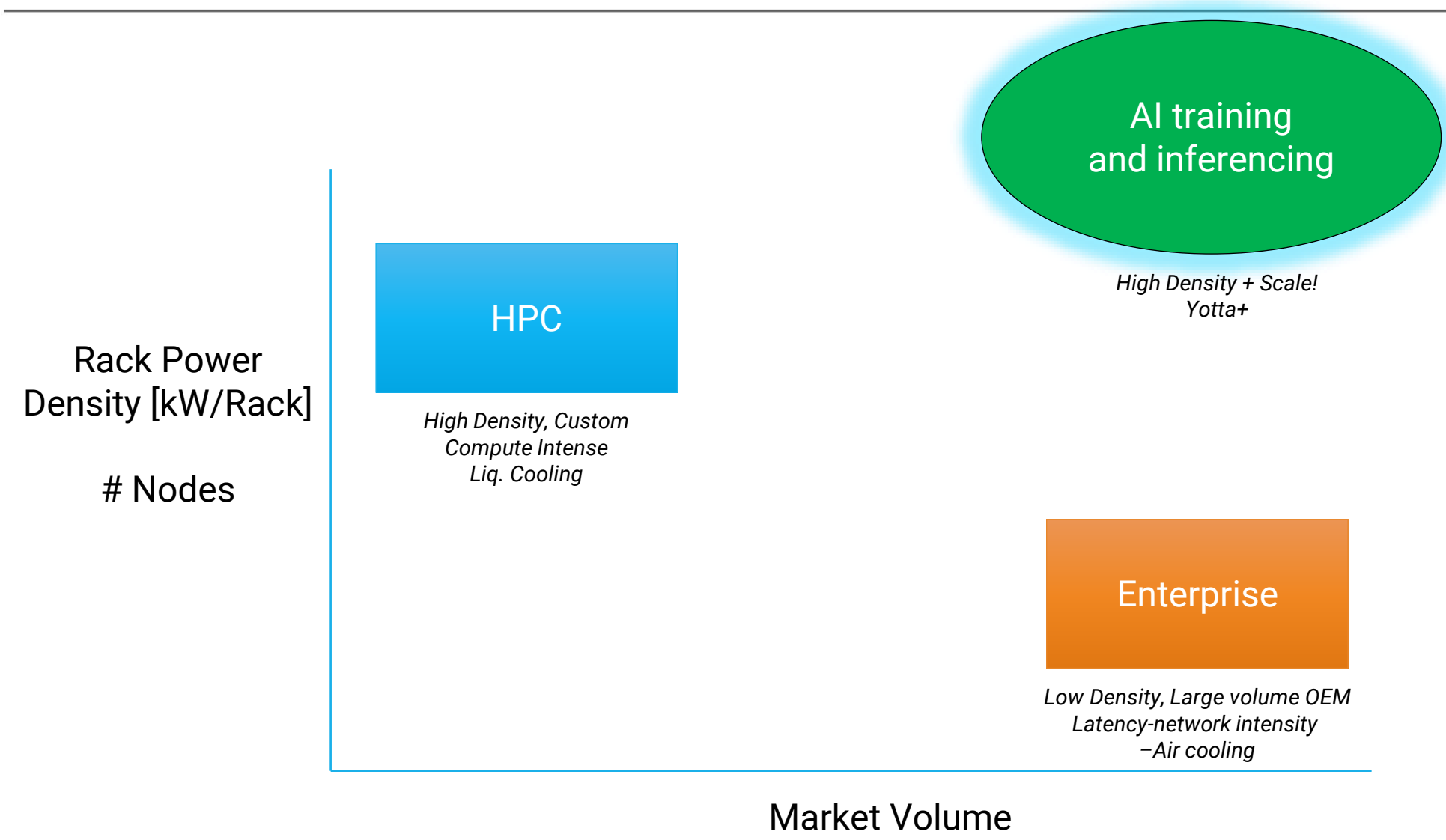


https://www.apple.com/newsroom/2022/03/apple-unveils-m1-ultra-the-worlds-most-powerful-chip-for-a-personal-computer/

Compute landscape is changing



AI is realizing a new scale of computing – ask to DOE 120GW+



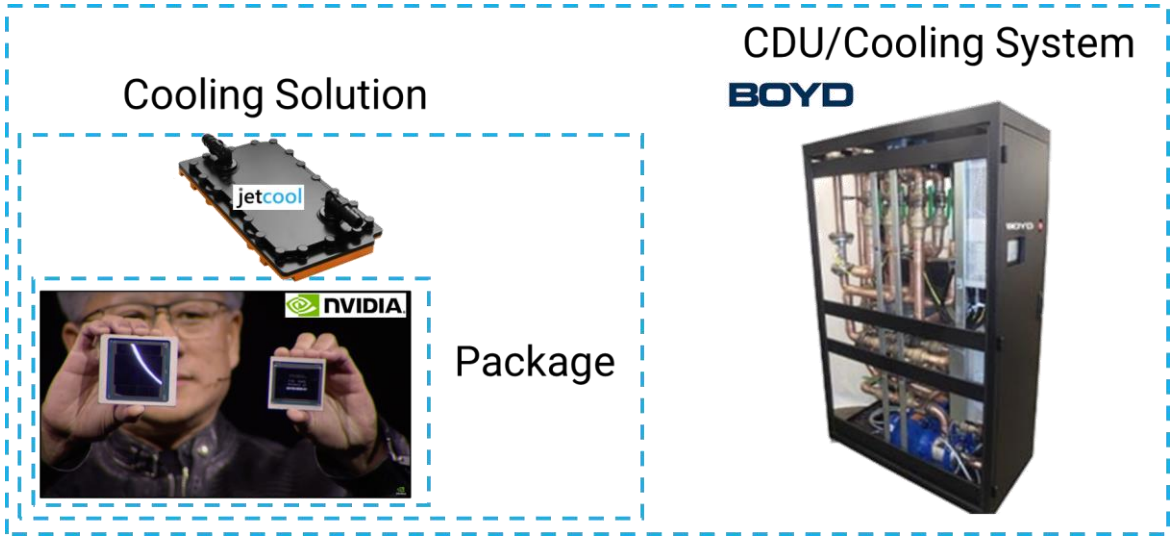
Computing at scale requires Extreme Performance & Availability

https://www.flyawaydesigns.com/blogs/news/product-review-the-best-way-to-get-your-toddler-to-sleep-on-the-plane

Airplanes – 50+ years record of **bringing people home safely**

Design for 1/1E-9 hrs. safety.

Is Tier 3, 99.982% availability still enough?



with 100,000 compute nodes – how do we get to >1E-6-1E9 reliability for computing. **Bring servers home safely(to end of their economic life)!**

No catastrophic failure mode allowed

COOLERCHIPS INTRODUCTION

ARPA-E Workshop COOLERCHIPS

Keeping the Status-Quo…

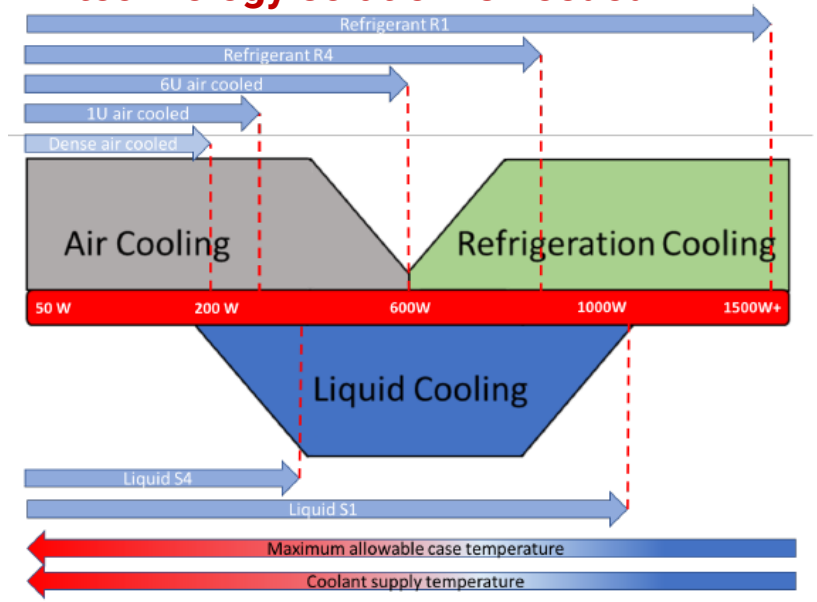
Without ARPA-e intervention, the industry **will prefer simple, well understood cooling methods** (keep refrigerated air for as long as possible) even if they use large amounts of energy

- There was a prominent view that energy efficiency is less important than **uptime**. *"Energy is Cheap!"*
- ***"Net zero matters, not energy efficiency"***
  – Poll B response (offset with renewables)
- ***"One only goes to liquid or two-phase if they have to"***
  – Poll B response

… Will only scale so much

The power density is trending up. The case temperature is trending down. These two trends in combination will **significantly increase the required energy to cool**.

- ***"Average power density of 2030 Rack will be 100-200 kW"***
  – Poll B Response
- **A technology solution is needed**



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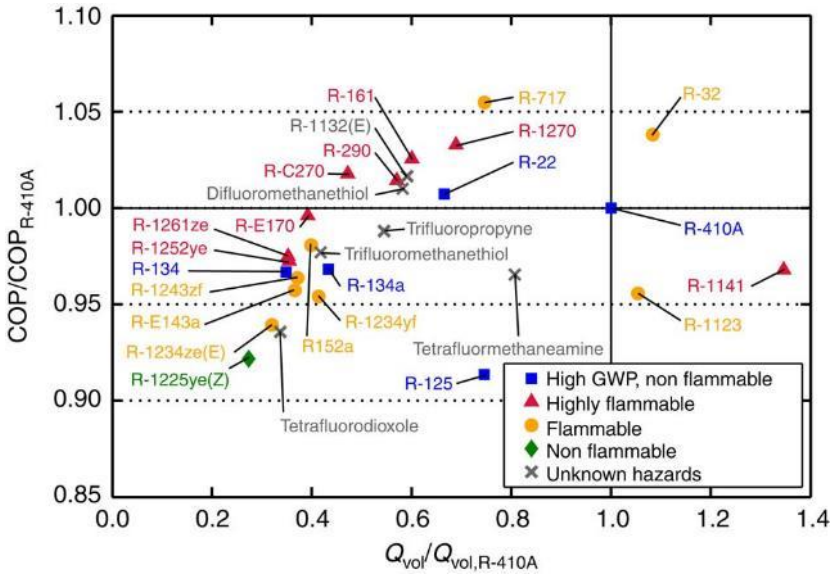
CHANGING WHAT'S POSSIBLE

New Technology Concepts Have Emerged to Re-Imagine Cooling

Variety of complementary technology paths and philosophies exist to **re-imagine cooling of electronics** and achieve **a leap in performance**…. …while still achieving solutions with high potential **uptime** and similar **cost**.

Advancing Dielectric Coolants and technology solutions

(program req: GWP<10, OHP) PFas



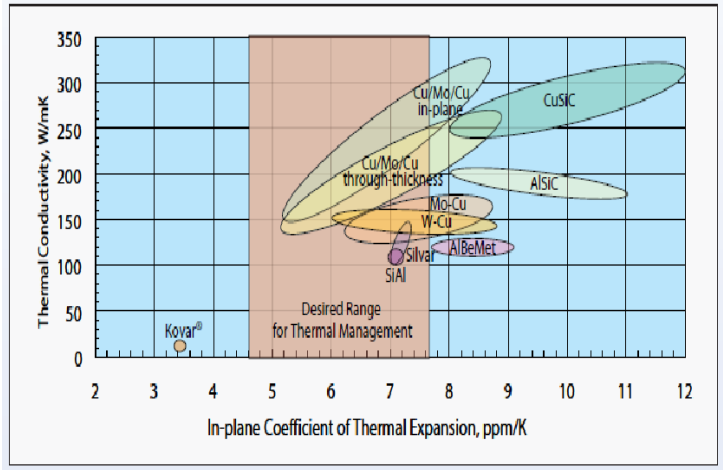
Fluids or coatings that allow for efficient heat transfer of electronics i.e. Immersion 2.0

When we design Fluids in 3D…. Heat Transfer Coefficient ↑↑

-Single Phase 5.0
-Two-Phase 5.0
-Immersion 5.0
-Passive Devices 5.0
-Air impingement 5.0

But make it reliable!

Exploring different materials for cooling helps TIM



i.e. Additive or cast CTE-matched, high thermal conductivity ceramics like ALN, SiC, AlSiC For coldplates of the future

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McLinden, M., Brown, J., Brignoli, R. et al. Limited options for low-global-warming-potential refrigerants. Nat Commun 8, 14476 (2017).

Bukhari, Mohabattul & Hashmi, M.s.J. & Brabazon, Dermot. (2012). Evaluation on Metal Matrix Composite of CuSiC as Candidate for Thermal Management Materials in Electronics Packaging.

COOLERCHIPS™

Cooling **O**perations **O**ptimized for **L**eaps in **E**nergy, **R**eliability, and **C**arbon **H**yperefficiency for **I**nformation **P**rocessing **S**ystems

U.S. Department of Energy Announces $40 Million for More Efficient Cooling for Data Centers

15 Projects Will Develop High Performance Cooling Systems to Create More Energy Efficient Data Centers that Reduce Carbon Emissions and Mitigate Climate Change

05/09/2023

*"Climate change, including severe weather events, threatens the functionality of data centers that are critical to connecting computing and network infrastructure that power our everyday lives," said **U.S. Secretary of Energy Jennifer M. Granholm.** "DOE is funding projects that will ensure the continued operation of these facilities while reducing the associated carbon emissions to beat climate change and reach our clean energy future."*

Program Structure

Technical Scope A: Secondary Loop

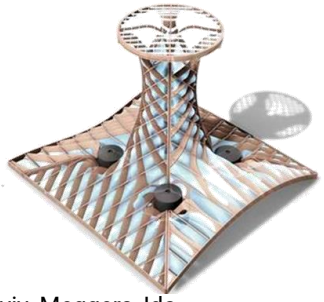
Chip (and other devices) surface to facility supply by any means, but meeting potential program technical, operational and cost requirements

- DLC 5.0, immersion 5.0, advanced next gen concepts.

Technical Scope B: Secondary + Primary loop

System-level approach, “All-in-One” Edge data center

- Self contained, locate anywhere
- EDGE / low latency
- Minimal/no water
- High compute density



Aviv, Meggers, Ida
https://www.holcimfoundation.org/projects/hydroculus-cooling

Scope C: Tools for modeling of system Energy, CO2 footprint, reliability and Cost

Scope D: Testing Infrastructure

Timeframe 2023-2026 POC: peter.debock@hq.doe.gov

PROGRAM TARGETS AND TIMELINE

Category A chip to supply

Table 2: Target ambient conditions

Dry bulb temperature	40°C
Relative humidity	60%
Atmospheric pressure	101.3 kPa

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Table 4: Technical Category A Targets

Thermal Resistance, chip-to-coolant	• ≤ 0.01 K/W
Power Consumption	• Total cooling power of secondary loop including all ancillary equipment (CDUs, pumps, heat exchangers, etc.) ≤ 3% IT load (estimated by testing) • Total cooling power to reject all heat to ambient ≤ 5% IT load (estimated by simulation) at the ambient conditions specified in **Table 2**. In the case that any water evaporation is used; this must be reported in liters/kWh.
Power Density	• Power density ≥ 80 kW/m^3 ○ Includes volume of any balance of plant (CDUs, pumps, heat exchangers) that is either inside the rack or as stand-alone unit simplified as bounding box encompassing the outer dimensions of the system ○ Minimal partial rack power of > 10 kW
Coolant Environmental impact	• Coolant Global Warming Potential (GWP) < 10 • Coolant Ozone Depletion Potential (ODP) = 0
Reliability	• Use System Reliability modeling to project path to system availability of >99.982% (equivalent to Tier3 Uptime[7])
IT equipment replacement cycles	• IT equipment replacement cycles equivalent or longer than baseline
Cost	• Applicants are to present a high-level analysis demonstrating how the proposed cooling solution will be economically competitive compared to state-of-the-art ○ System model showing path to total system payback of 7 years ○ System model showing path to total system IRR ≥ 10%

Ready for high power: 1000 W chip coolant only 10°C below chip surface

Energy Efficient: True cooling power (no fans included like PUE) <3% secondary loop <5% data center level even in extreme hot/humid environment (so that a single design can be deployed anywhere)

Ready for high density: Compute rack and CDU 80kW/m3 is approximately ~ > 3kW/U or >126kW/42Urack

Reliability: System reliability engineering to equal or exceed air cooling reliability

Economical: Beat or exceed current air cooled payback and IRR business case

All metrics must be met in a single design

Category B modular data centers

Table 2: Target ambient conditions

Dry bulb temperature	40°C
Relative humidity	60%
Atmospheric pressure	101.3 kPa

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Table 5: Technical Category B Targets

Power Density	• The compute power density of the entire modular datacenter, including the power functional block, the IT space functional block, and cooling functional block should be equal or greater than 20 kW/m^3
System Volume	• Not to exceed shipping volume of an ISO 40 shipping container
Ambient Conditions	• See **Table 2** • Compatible to operate in outdoor environment • Do not assume a water supply is available
Power Consumption	• Total cooling power to reject heat to ambient including all ancillary equipment (CDUs, pumps, etc.) ≤ 5% IT load (evaluated by testing) for any ambient conditions within the specified range. • Minimum compute power of 100 kW
Coolant Environmental impact	• Coolant Global Warming Potential (GWP) < 10 • Coolant Ozone Depletion Potential (ODP) = 0
Reliability	• Use system reliability modeling to project path to system availability of > 99.982% (equivalent to Tier3 Uptime)
IT equipment replacement cycles	• IT equipment replacement cycles equivalent or longer than baseline

Cost	• Applications are to present in their application a high-level analysis how the proposed cooling solution will be economically competitive compared to state-of-the-art
	  ○ System model showing path to total system payback of 7 years
	  ○ System model showing path to total system IRR ≥ 10%

Ready for high density: 20kW/m3 is approximately ~ > 1MW/ISO40 container

Energy Efficient: True cooling power (no fans included like PUE<5% at modular data center level even in extreme hot/humid environment (so that a single design can be deployed anywhere)

Reliability: System reliability engineering to equal or exceed air cooling reliability

Economical: Beat or exceed current air cooled payback and IRR business case

All metrics must be met in a single design

Category C tools innovation D testing & facilities

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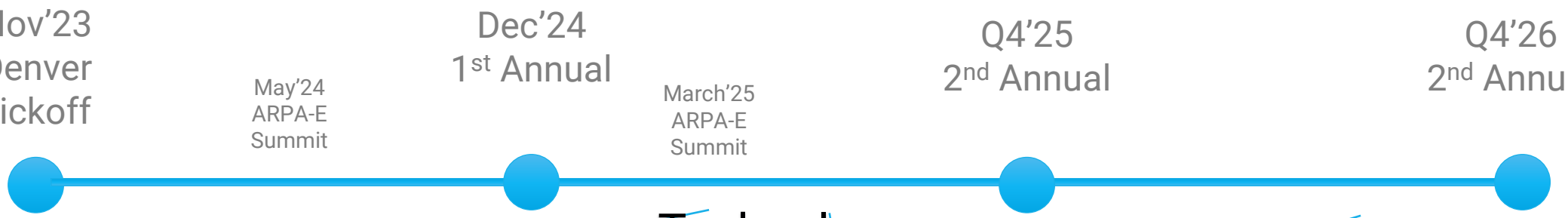
Table 6: Technical Category C Requirements

Team Requirements	• Demonstrated expertise in developing stand-alone or modular modeling software, software integration, energy modeling, reliability modeling and data center cost estimation
Code Requirements	• The software shall be able to model both traditional data centers and modular EDGE data centers (must support both Technical Category A and Technical Category B data centers) ○ Include base library of common cooling components with reasonable default values for all parameters (pipes, fittings, turns, pumps, heat exchangers, etc.) ○ Graphical user interface for building the data center model
	○ Code shall allow the modeled data center to be placed in any climate zone, and shall allow the user to specify average climate conditions or to upload hourly climate conditions ○ Energy, reliability, and cost analyses will be run using a common system model ○ Code shall estimate operational CO_2 emissions using national average or local carbon emission factors ○ Extensible: users shall be able to build custom component modules that will interface with the larger model ○ Well-documented API ○ Code shall estimate both CAPEX and OPEX of the simulated data center ○ Open-source (true open source preferred, no licensing fees necessary to run the software)
Release Schedule	• Software will be made available to the Technical Category A and B performers every 6 months as stand-alone software or as a modular add-on to common additional software that must be generally available to any users of the model for the duration of the program ○ The first released version at 6 months will have basic functionality of energy, reliability, CO_2 footprint, and cost analysis modeling capability, and it is anticipated that subsequent versions will have increased fidelity and capability updates in each of these areas based on further development and community input
Support	• Team will support a call with all Technical Category A and Technical Category B performers teams and collect input on how to further increase the functionality of the software every quarter • Team will provide user documentation to Technical Category A and Technical Category B performers with every software release and provide consulting on an as needed basis

Table 7: Technical Category D Requirements

Team Requirements	• Track record in testing and evaluating data center equipment • Expertise in energy consumption testing and measurement of data center equipment and cooling equipment • Expertise in reliability testing of data center equipment and cooling equipment
Facility requirements	• Technical category D-A: ○ Provide power to the servers at a minimum of 200 kW ○ Heat rejection capability at a minimum of 200 kW at heat rejection temperatures that can be set from 40°C up to 80°C in increments ○ Team shall measure the cooling power consumption of Technical Category A performers teams as a fraction of IT load ○ 4" diameter primary cooling loop supply connections. • Technical category D-B: ○ Capability of powering and testing of standalone modular EDGE data center units up to 1.5 MW ○ Measurement of the power used by the cooling system as a fraction of the IT load ○ Internal measurements of power and temperatures through a standardized interface ○ Environmental testing of Technical Category B technologies may include simulated environments as well as outdoor testing ○ Reliability testing shall be performed for both Technical Category A and Technical Category B technologies up to 1000 hours ○ Available space to test between 5 to 10 ISO 40 footprint modular data centers
Test Objectives	• Team will be responsible for developing testing development plans, standardizing the protocols, interfaces, and facilities for testing the technologies produced by the Technical Category A and Technical Category B teams
Support	• Team will support Technical Category A and Technical Category B teams • Team will work with performers to advise on testing of Technical Category A and Technical Category B technologies

Program Timeline - Focus



Technology on **server**

Go-No/Go: Key Component de-risking, Single Server Prototype & reliability system model	**Experimental Validation at server level and models at rack and full system level at power density ≥80kW/m³ and ambient conditions specified in Table 2 of the FOA that:** • **Thermal Performance: Experimental validation that the developed system can achieve an interim thermal resistance of ≤0.015 K/W and path presented to meet ≤ 0.01 K/W FOA target.** • **Energy: Experimental validation that secondary cooling loop power can meet < 3% IT load and model that overall system can meet < 5% IT load for system meeting.** • **System Availability: Established availability system model. Availability system model projecting > 95% system availability per annum for economic life period of system as is and path on how to achieve > 99.982% availability at end of project.** • **Availability Physics: Availability pareto chart. Identify top 5 interactions that are availability system bottlenecks. Physics of failure modes identified and relevant parameters (i.e. activation energy or other) experimentally validated with > 100 hours of testing.**

Technology on **rack**

Detailed Design Review full performance targets	**Detailed design review showing through modeling that the key components meet the following performance targets listed below:** **1. Thermal Resistance, chip surface-to-facility coolant, of ≤ 0.01 K/W Total cooling power of secondary loop including all ancillary equipment (CDUs, pumps, heat exchangers, etc.) ≤ 3.00 % IT load and total cooling power to reject all heat to ambient ≤ 5.00 % IT load (estimated by simulation) (at power density ≥ 80kW/m³ and ambient conditions specified in Table 2).** **2. Economic model showing path to system payback of <1 year.** **Reliability system model demonstrating path to 99.982% system reliability (potentially, via simulations from Cat C model)**

Annual meeting agenda: If it works, will it matter

Day 1: Technology

- Team updates
- Technical Keynotes
- Group Picture
- Poster session

COOLERCHIPS is not only about heat transfer, it's a cooling system program

Day 2: Making it matter

- Data Center Leaders
- Manufacturing
- Operators
- Maturation partners

Do you know where you need to end to raise investment? What is success? What is your target?

LOOKING FORWARD

"The electric light bulb did not come from the continuous improvement of candles." (Oren Harari)

- Be inspired,.. Inspire your team
- This is a dynamic industry – connect & learn
- Think about the system – what are you not good at?
- What will an operator think about your technology?
- What value do you deliver to the data center?
- ARPA-E efforts are unique: Use COOLERCHIPS community

It is our privilege to work with you. Thank you.

U.S. DEPARTMENT OF ENERGY

https://arpa-e.energy.gov