Liquid Cooling: Drivers, timelines and a case for industry convergence on coolant temperatures
Liquid Cooling: Drivers, timelines and a case for industry convergence on coolant temperatures

Chris Malone
Datacenter Systems Engineer, Meta

OPEN POSSIBILITIES.
TL;DR

- Our industry is on a steady course to break the limits of heavily air-economized cooling, starting with ML Training chips and high-speed switch fabric ASICs. The solution is liquid cooling.
- Our industry (chipmakers, facility builders, operators) will benefit from converged liquid cooling practices, as we’ve done previously with economized datacenters.
- 30C coolant temperature is compatible with efficient data center design principles.
- We can probably stretch 30C through 2035, with industry investments around packaging, layout, and TIM improvement.
- 30C likely won’t last forever. Whatever forum & consensus we establish now can be used to better govern future changes, and rates of change.

OPEN POSSIBILITIES.
Sequence

Meta DC Operating Conditions
ML/Training Module Cooling Trends
Fabric Switch Cooling Trends
Challenge & Proposal
Supporting Material (if time available, or in Q&A)
Meta DC Operating Conditions
Our Datacenter Operating Conditions

Economization has worked very well for Meta for a decade

• Reference boundary conditions for hardware thermal design
  • Supply air temperature: 65°F to 85°F (18.3°C to 29.4°C)
  • Air-side deltaT: 22°F (12.2°C)
  • Altitude: Sea-level to 6000 ft

• Validation and deployment of IT gear
  • Thermal validation of hardware conducted up to 35°C (corner cases), with specific focus on operation at 30°C
  • Power and airflow requirements at 30°C used as reference for deployment (cluster planning)

~30°C is used as the nominal operating / ambient temperature for air-side economization.

(Charts in this deck with projections of air-cooling limits are based upon these conditions).
Chip, System, Rack, and Facility Designers:

If you design for air-side or water-side economized environments, our projections likely resemble yours.
The Emergence of Need for Liquid Cooling in ML

- Application Demand trendline is a *composite* of trends in chips / modules.
  - This includes estimated effective utilization of chips.*
- These are *per training module* estimates, not *per system*.
- TDP-only plotlines of specific chips / modules (not shown here) fall both above and below the Application Demand line.

- AALC - Air Assisted Liquid Cooling

* This varies some by architecture, data model, and software application.
The Bridge: Air Assisted Liquid Cooling (AALC)

Transitional solution to enable liquid cooling

- IT rack + Cooling Rack Bundle
- Enables liquid cooling in free air-cooled data centers

More info can be found at:
https://www.youtube.com/watch?v=S3hNlZGj4UM
The Limits of AALC as a Bridge

Likely good for 1 - 2 generations depending upon other optimizations (more on this, later)

- AALC - Air Assisted Liquid Cooling
- FWC - Facility Water Cooling
ASHRAE Describes Similar Challenges

A broad range of coolant temperatures, for a broad range of chip power levels and facility designs

This range of products, conditions, and coolant temperatures make it very difficult to optimize.

This affects performance, scale, and predictability.

OPEN POSSIBILITIES.
A Durable Thermal Interface Approach is Needed
What strikes the best balance of durability and efficiency, for new facilities and systems?

<table>
<thead>
<tr>
<th>Class</th>
<th>Typical Infrastructure Design</th>
<th>Facility Water Supply Temperature °C</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Primary Facilities</td>
<td>Secondary Facilities</td>
</tr>
<tr>
<td>W17</td>
<td>Chiller/Cooling Tower</td>
<td>Water-side economizer</td>
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<tr>
<td>W27</td>
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<td>Cooling Tower</td>
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<td>District heating system</td>
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Building a new facility with a goal to support emerging IT equipment for a decade, efficiently?

Which class should you choose?

OPEN POSSIBILITIES.
An Air & Liquid System Designed for 30°C

Air cooling only: 30°C is optimal
An Air & Liquid System Designed for 30°C

Air + Liquid Cooling: optimal in multiple aspects

- **At 30°C:**
  - Efficiency - PUE & WUE are manageable
  - Simplicity - Same primary loop supply for air & liquid
  - Durability - 30°C will be sufficient for many generations
ML/Training Module Cooling Trends
Assumptions We Make About Training Systems

Analysis based on UBB style 8x modules training system layout

Boundary:
• 8x OAMs per system
• PG25% based coolant
• AALC → coolant supply above 30°C (more on this, later)
• FWC → coolant supply at 30°C (more on this, later)

Package assumptions:
• Average ASIC die temp limit at 80 °C
• Improved HBM stack resistance
Many Points to Optimize in a Thermal Stack
Some optimizations addressable by HW system designers.

Thermal resistance stack (breakdown by %)

- ASIC
  - 10% HBM Stack
  - 27% Lid & TIM1
  - 24% ASIC Heat Crosstalk
  - 49% TIM2

- HBM
  - 7% HBM Stack
  - 3% Lid & TIM1
  - 3% ASIC Heat Crosstalk
  - 49% Coldplate
  - 39% Preheat

Hardware design optimization opportunity
Chipmakers and Packagers Can Make a Big Difference

Improvements here benefit whole industry, enhance potential of all coolant set points & thermal solutions

Thermal resistance stack
(breakdown by %)

- ASIC
- HBM

- HBM Stack
- Lid & TIM1
- ASIC Heat Crosstalk
- TIM2
- Coldplate
- Preheat

Chip & package optimization opportunity
ML Power Trend vs. Cooling Limits

Both AALC and FWC can be stretched with optimizations in the thermal stack.

- AALC serves as transitional solution in air-cooled facilities.
- 30 °C facility water can support future ML demand over 5~10 years, and sustainable if package/cooling technology further advance.

- AALC - Air Assisted Liquid Cooling
- FWC - Facility Water Cooling

* This varies some by architecture, data model, and software application.
Fabric Switch Cooling Trends
This is not just an ML Problem
Impact of stretching air cooling for NW chips

2021 - 2.8 kg

2025 - 3.7 kg
Challenge: Lack of community alignment

Current situation with facility water supply temperature

- Range is too wide. Difficult to optimize.
- No concrete boundary conditions to plan / constrain range of optimization. Applies to facility, system, chip thermal sol’n.
- Mature, efficient (PUE and WUE) cooling paradigms for ~30°C air.
- Same paradigms durable with facility water at ~30°C ranges.

Narrow the range. Benefit from common investment in...

- Infrastructure Design
- Chip design, packaging, thermal solution
- Component/Platform Solution
- Material/Coolant Standards and Supply
- Streamlined design/validation/manufacturing & quality standards

ASHRAE Environmental Specification for Liquid Cooling:

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Proposal

Better harmonize efforts across OCP to narrow down the boundary

• What supply temperature?
  • 30C liquid & air systems maintains PUE & WUE efficiencies + a durable entry point for liquid cooling
• What HW cooling technology to expect, for chipmakers and IT equipment designers?
  • 30C coolant temps can buy time for further optimization of TIMs, packaging, layout
  • Optimizations at the chip level can, in turn, extend the life of 30C-based facilities
    • Likely stretches air-cooled system viability for more mainstream applications

Lay a foundation to address key areas and gaps.

• How should the chip/platform evolve to maintain continuous perf growth along with efficiency and sustainability improvements?
• How can we reduce the ambiguities/uncertainties for every community member?
Call to Action

• Let’s converge as an industry on a facility water temperature. How about 30C?
  • If not 30C, bring your data and your rationale. You might have a better approach.

• If we can agree on 30C, let’s invest in an ecosystem (from chip to data center) that leverages our infrastructure investment for as long as possible without sacrificing efficiency or performance.

• Let’s form an industry community to amplify this approach
  • Large scale operators, chip suppliers, and facility builders should converge and partner with other industry standards groups (e.g., ASHRAE) for broader influence.
Call to Action

Want to get involved?

• How to get involved - Meta POCs
  • OAI Group Lead [Meta] - Whitney Zhao, whitneyzhao@fb.com,
  • OAI Cooling Lead [Meta] - Cheng Chen, chengchen@fb.com
  • Meta Thermal Lead - John Fernandes, jfer@fb.com

• OAI Group:
  • Where to find additional information: https://www.opencompute.org/wiki/Server/OAI
  • Mailing list: https://ocp-all.groups.io/g/OCP-OAI

• OCP Rack & Power - https://www.opencompute.org/projects/rack-and-power
• OCP Advanced Cooling Solution - https://www.opencompute.org/wiki/Rack_%26_Power/Advanced_Cooling_Solutions
Supporting Material
Fabric Switch Cooling Trends
This is not just an ML Problem
Can Stretch Air Further with Single Chips, Big Heatsinks

2021 - 2.8 kg

2025 - 3.7 kg
Fabric Switch ASICs. Power Efficient vs. Modular.

The most *power efficient* switch ASICs break free-air-economized limits faster.

- **Pluggable optics** (less power efficient)
  - Separate cooling solutions for optics and switch ASIC
  - Air-cooling of pluggable optics still the preferred approach

- **Near/co-packaged optics** (more power efficient)
  - Combined cooling solution for ASIC and optics assembly
Switch ASIC only

Power trends and cooling limits

- Heat sink solution (in a 4RU chassis) influenced by weight, airflow, fan power and noise limitations
- Cold plate solution should enable long-term support for future switch ASIC packages, but does not alleviate air-cooling concerns for pluggable optics
- System-level cooling (25% PGW mixture)
  - For Air-assisted liquid cooling, coolant supplied at 40°C
  - For Facility Water cooling, coolant supplied at 30°C
  - Coolant side $\Delta T = 10°C$
Co-packaged optics assembly (Switch ASIC + OMs)

Power trends and cooling limits

- Heat sink solution limited by cooling capacity (in addition to factors outlined in the last slide)
- Cold plate solutions may cover us to 3900W. Power-efficiency of direct drive may enable support further out than projected by XSR optimized.

- System-level cooling (25% PGW mixture)
  - For Air-assisted liquid cooling, coolant supplied at 40°C
  - For Facility Water cooling, coolant supplied at 30°C
  - Coolant side $\Delta T = 10°C$

30C FWS implementation has potential to support 10+ years of hardware deployments.
Thank you!