Cooling Environments





Immersion Project

[9046] Moving Beyond Interchangeability: Characterizing Esters among Coolants for Immersion

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OCP BRONZE™ Member

Chemistry Provides the Path to Coolant Standardization

PROBLEM



50+ IMMERSION COOLANTS

Many Products.
Difficult to Standardize.

SOLUTION

Classify By Chemistry

Fluorochemicals



- F

- Performance leader
- Premium cost: $$$$
- Sustainability & safety challenges

Engineered Esters



- COO -

- Value leader
- Moderate cost: $$
- Strongest sustainability & safety profile

Hydrocarbons



- CH_2 -

- Cost leader
- Lowest cost: $
- Broadly available

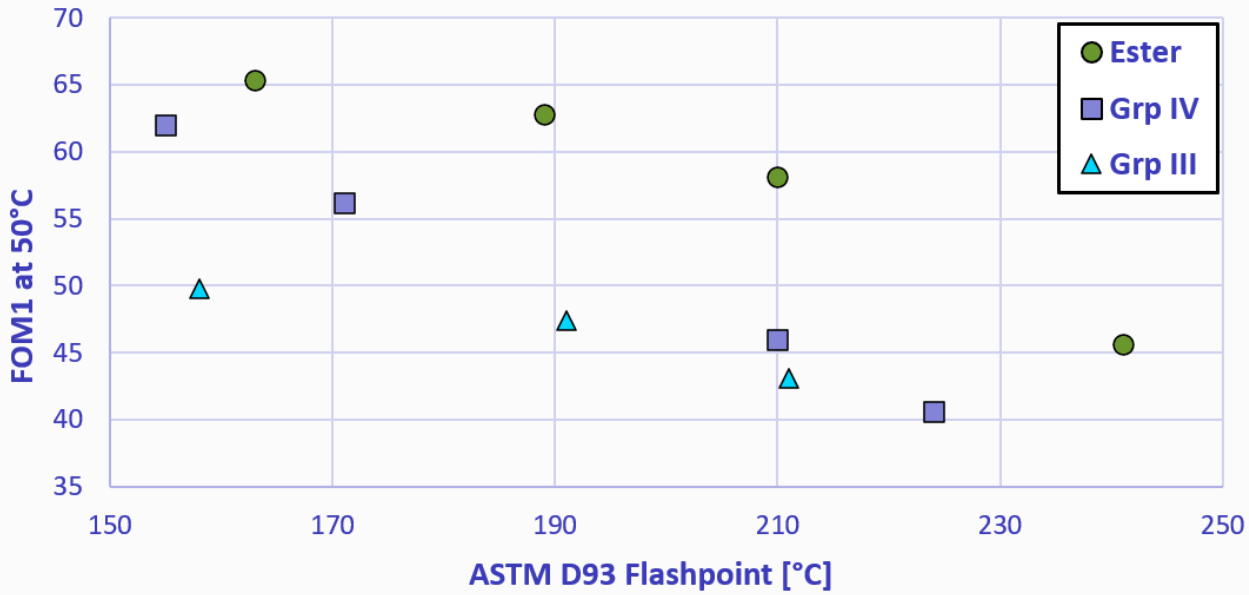
OUTCOME

Evidence-Based Framework

For Single-Phase Immersion Coolant Standardization & Selection

> PG25 may be PG25, but immersion coolants are not entirely interchangeable.
>
> Chemistry is the primary driver of coolant behavior and should be the basis for standardization.

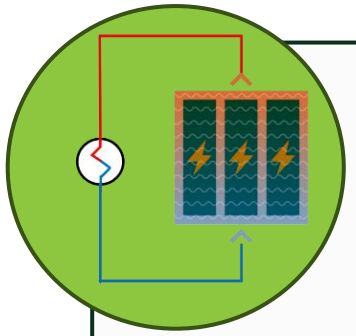
Fire Safety Must Be Evaluated Together with Cooling Performance



Low **viscosity** and high **density** are the key factors contributing to the difference between hydrocarbons and esters.

> Thermal performance metrics matter, but fire safety is paramount.
>
> Benchmarking against flash point enables a more comprehensive fluid evaluation.

Evaluation of Cooling Performance in Application



Natural convection test rig

500 W per server

20L of fluid per cassette

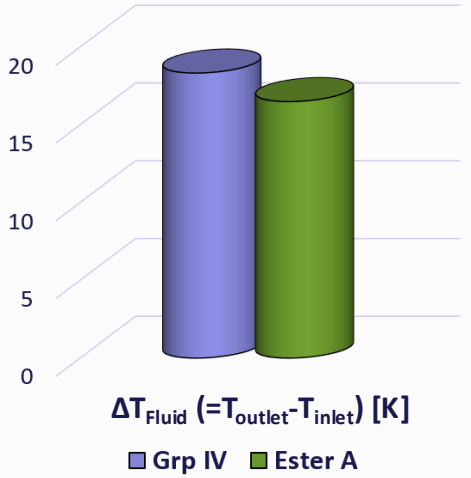
Cooling water temperature controlled by thermostat

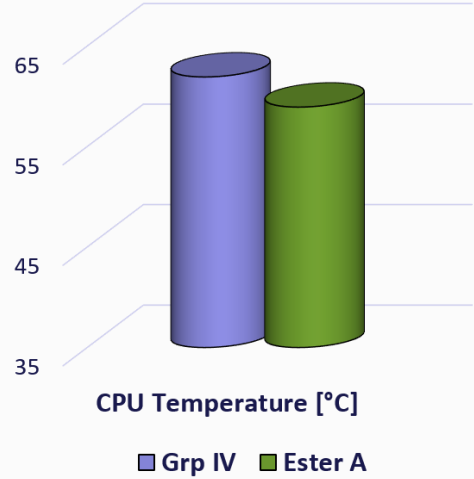




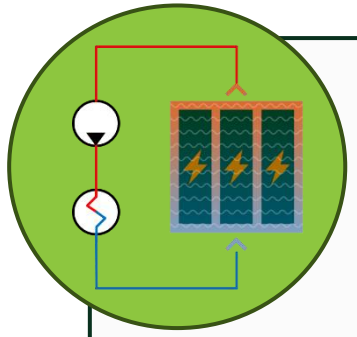
Both fluids have comparable flashpoint at the lower end of the OCP specification, low viscosity and high FOM1.

	Grp IV	Ester A
ASTM D93 flashpoint [°C]	155	160
Kinematic viscosity at 40°C [cSt]	5.2	4.5
FOM1	62	65





Confirmation of Test Results With Active Circulation



Active fluid circulation

35L of coolant

Up to **4L/m** flow rate

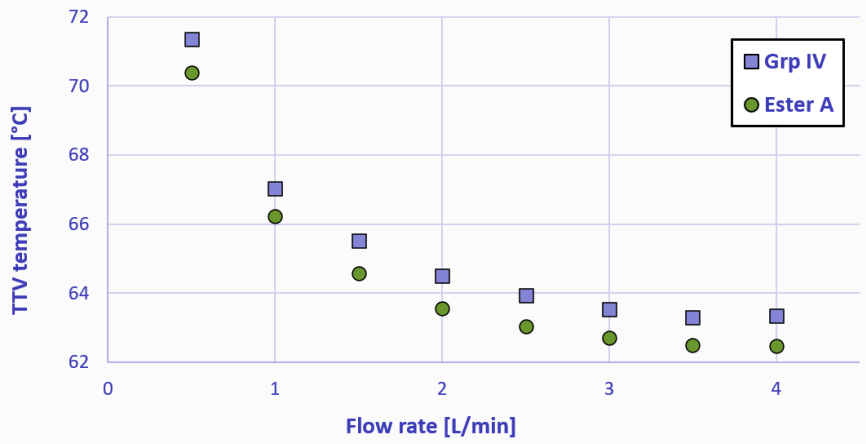
Server + TTV* to simulate a GPU

Fluid inlet-temperature controlled



*TTV: thermal test vehicle

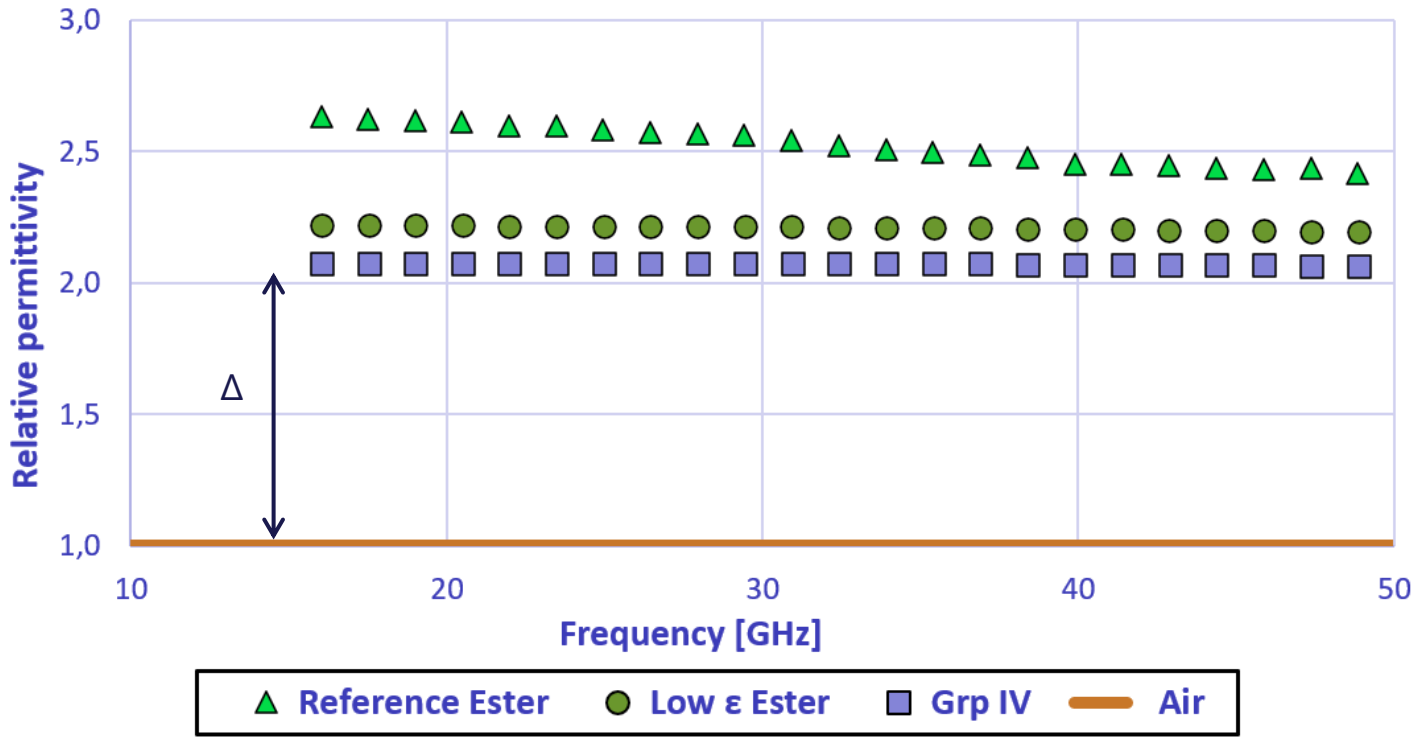
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Good correlation of temperatures from both test rigs with FOM1 over a broad range of viscosities from 4-30 cSt.

To fully utilize the potential of a fluid, the equipment must be adjusted to its properties.

Esters Show Distinct Dielectric Behavior



> Relative permittivity of esters is close to hydrocarbons in the relevant GHz range.
>
> Next industry challenge: move from air to immersion-proof interconnect designs.

- Signal transmission is influenced by interactions with the surrounding medium: air vs. liquid.
- Ester groups have a dipole moment that aligns with an electric field, increasing relative permittivity.
- At **high frequencies**, dipoles cannot reorient fast enough, reducing their contribution to relative permittivity.

Dielectric-Safety Performance & Moisture 1

Why Moisture Limits Differ Between Fluid Chemistries

Dielectric performance is more closely related to **relative moisture saturation** than absolute water content.

Mineral Oil

Water Content at 50% of Saturation Limit

20 – 40 ppm

0% 50% 100%

Dry Saturation Limit

50% Relative Saturation = Similar Moisture Stress

↓

Similar DBV Response

Hydrocarbon Fluid

Water Content at 50% of Saturation Limit

40 – 80 ppm

0% 50% 100%

Dry Saturation Limit

50% Relative Saturation = Similar Moisture Stress

↓

Similar DBV Response

Ester Fluid

Water Content at 50% of Saturation Limit

400 – 800 ppm

0% 50% 100%

Dry Saturation Limit

50% Relative Saturation = Similar Moisture Stress

↓

Similar DBV Response

Same Relative Saturation = Similar Moisture Stress = Similar DBV Response

KEY FACTS

- Water solubility differs significantly between fluid chemistries
- The same ppm value can represent different moisture conditions
- Breakdown voltage decreases as relative saturation increases
- Moisture limits are chemistry-dependent, not universal

Compare Relative Saturation, Not Just Water Content

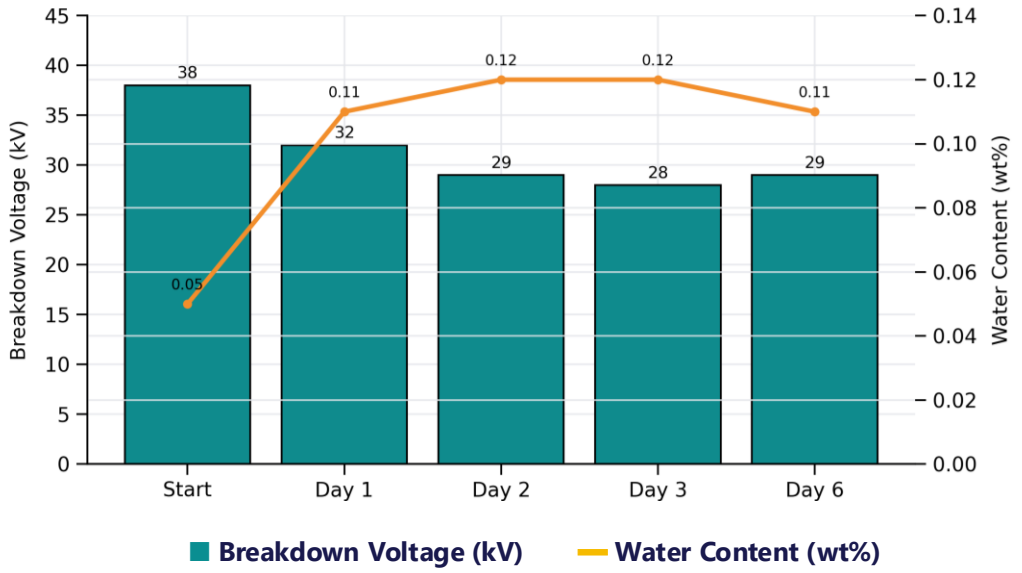
Focus on relative saturation to ensure accurate dielectric-safety assessments across different fluids.

Dielectric-Safety Performance & Moisture 2

Laboratory Stress Test: Dielectric Stability Following Forced Moisture Exposure Under a Worst-Case Humidity Scenario

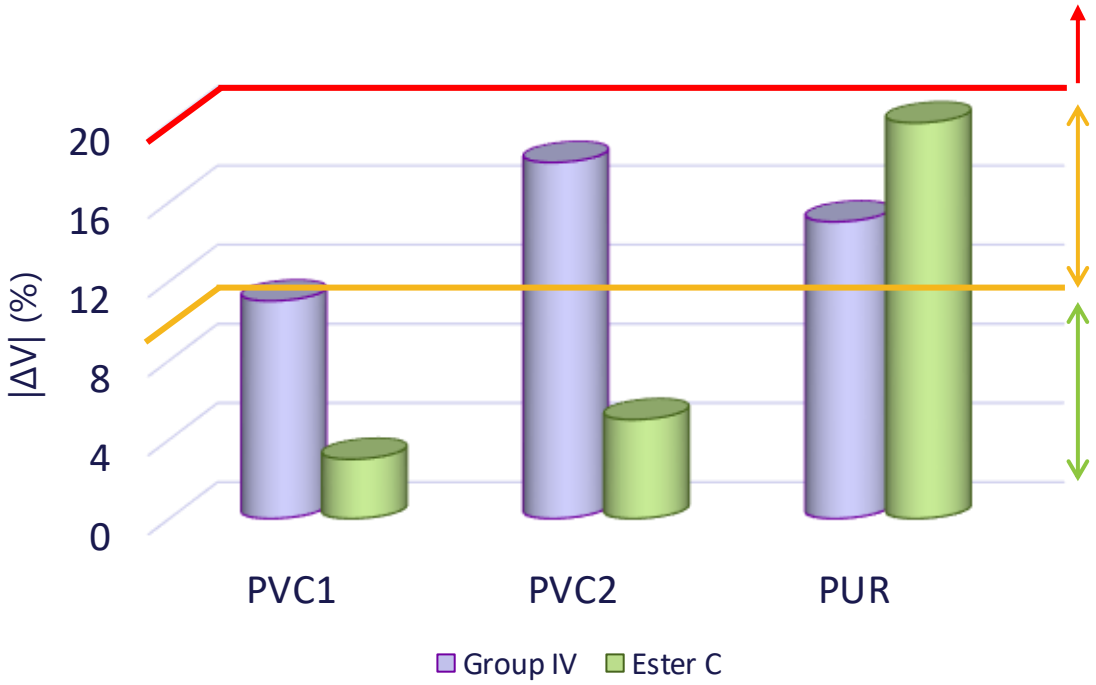
- Exposure at ambient temperature for 6 Days
- Water content increased initially, stabilizing at ~0.11–0.12% to the maximum saturation limit.
- Acid number remained constant, indicating no significant hydrolysis.
- Volume resistivity and dissipation factor showed only minor changes despite moisture saturation, indicating stable dielectric performance.

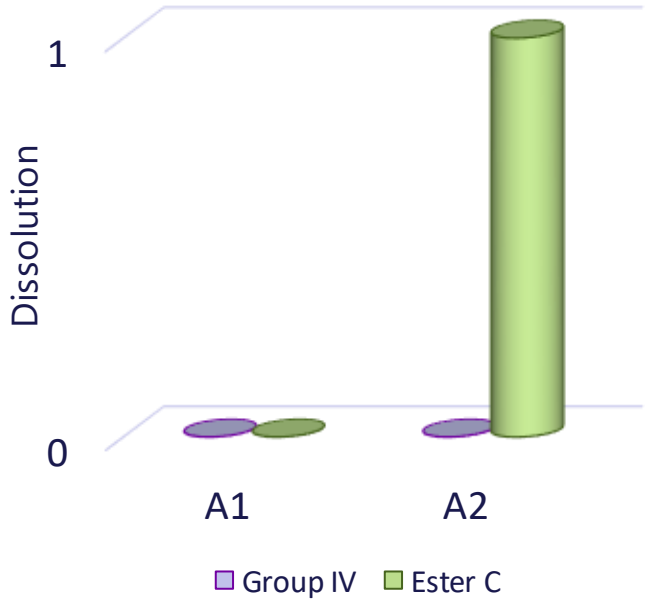
Ester B: Water Uptake and Dielectric Performance Under Forced Extreme Humidity Exposure



Understanding Chemistry Facilitates Material Review

OCP Material Compatibility guidelines (80°C, 336 hours)





For Ester C: polyvinyl chloride (PVC), adhesive A1 > polyurethane rubber (PUR), adhesive A2.

1. Esters provide molecular design flexibility, enabling compatibility with legacy server materials.
2. Materials can demonstrate compatibility across both Group IV and ester chemistries.

> Material compatibility follows chemistry, not product name.
>
> Esters can be tailored at the molecular level for compatibility with key ITE components.
>
> Advocating for OCP 'Engineered Esters' Material Compatibility Data Sheet.

Sustainability & Safe Handling

Chemistry-driven standardization simplifies deployment across regions and life cycles.

Regulatory

- Supports compliance with existing EHS frameworks.
- Reduces complexity associated with region-specific environmental requirements.

Operational

Supports common handling, storage and transport practices.

Fully miscible with hydrocarbon fluids, simplifying transition and maintenance.

Sustainability

- Engineered esters are readily biodegradable.
- Engineered esters has a low environmental persistence.

Standarization

Sustainability metrics can be standardized through:

- Biodegradability
- Toxicity
- Handling classification
- Life-cycle methodologies

Building a Standardization Framework

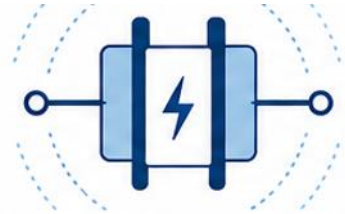
Standardization requires understanding which properties are chemistry-dependent and defining test methods and acceptance criteria for each of them.

Thermal performance & fire safety



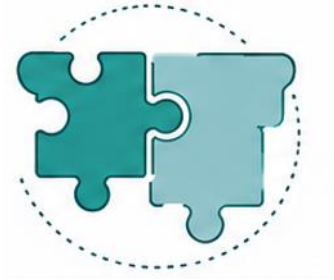
Safe operation in immersion environment

Dielectric performance



Signal transmission
Moisture management

Compatibility



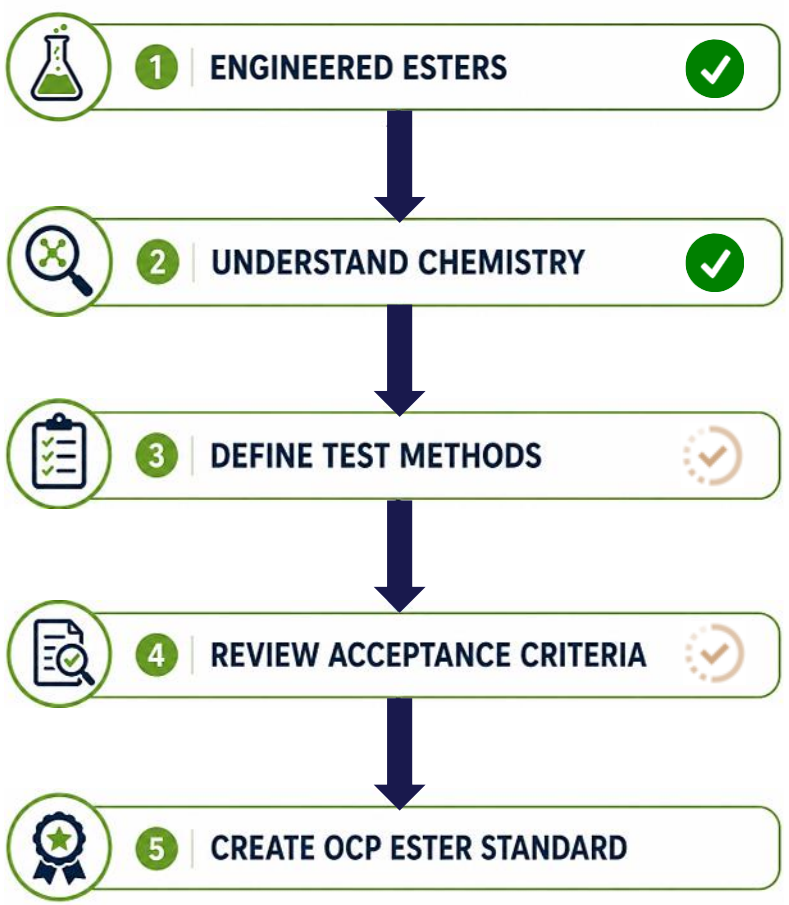
Material-liquid interactions

Sustainability & safe handling



Environmental impact and safe handling through full product life cycle

Building a Standardization Framework



Proven Today	Points of Attention
Thermal performance & fire safety *Low-viscosity esters can match Group IV cooling performance while maintaining high flash point.*	*Standardization of thermal performance test method to ensure comparability.*
Relative permittivity *Ester dielectric behavior is predictable and converges toward hydrocarbons at GHz frequencies.*	*Moving from air towards immersion-proof interconnect design.*
Hygroscopicity *Moisture limits are chemistry-dependent, not universal.*	*Method to saturate coolants with water missing*
Sustainability & handling *Esters offer strong environmental and safety credentials.*	*Selection of vapor pressure method for esters.*
Compatibility *Compatibility is chemistry-dependent and can be engineered through molecular design.*	*Material selection guidelines per chemistry class for ITE.*

Call to Action

- Problem to solve
  - Let's create evidence-based standardization for engineered esters in single-phase immersion cooling.

    Let’s build on the transformer industry's 40+ years of expertise in dealing with various fluid chemistries.

- Get involved


Immersion Project


Fluids Committee


ITE Committee


Reliability Committee


Solutions Committee


Challenges

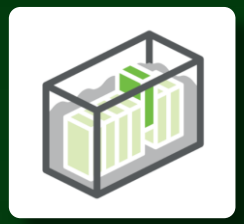

Industry Liaison Team

- Where to find additional information?
  - Evonik *Immersion Cooling Solutions*
  - Oleon *Server Immersion Cooling | Oleon*
  - Perstorp *Thermal management fluids*

Thank You!

Cooling Environments





Immersion Project

