COOL INNOVATIONS

Next-Generation Thermal Management Materials for Emerging Technologies

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Analyst

AGENDA

01 **Unmet materials needs**

02 Cool innovations

03 Opportunities and outlook

ELECTRIFICATION

DIGITALIZATION

SUSTAINABILITY

Image sources: Pixabay, AP Newsroom

2024: EV FIRES IN SOUTH KOREA

South Korea urges automakers to disclose EV battery brands after fires

ELECTRIC VEHICLES

South Korea to certify EV batteries after blaze ignites fears

Seoul issues strict rules to protect industry it sees as a key driver of growth

Image source: Yonhap

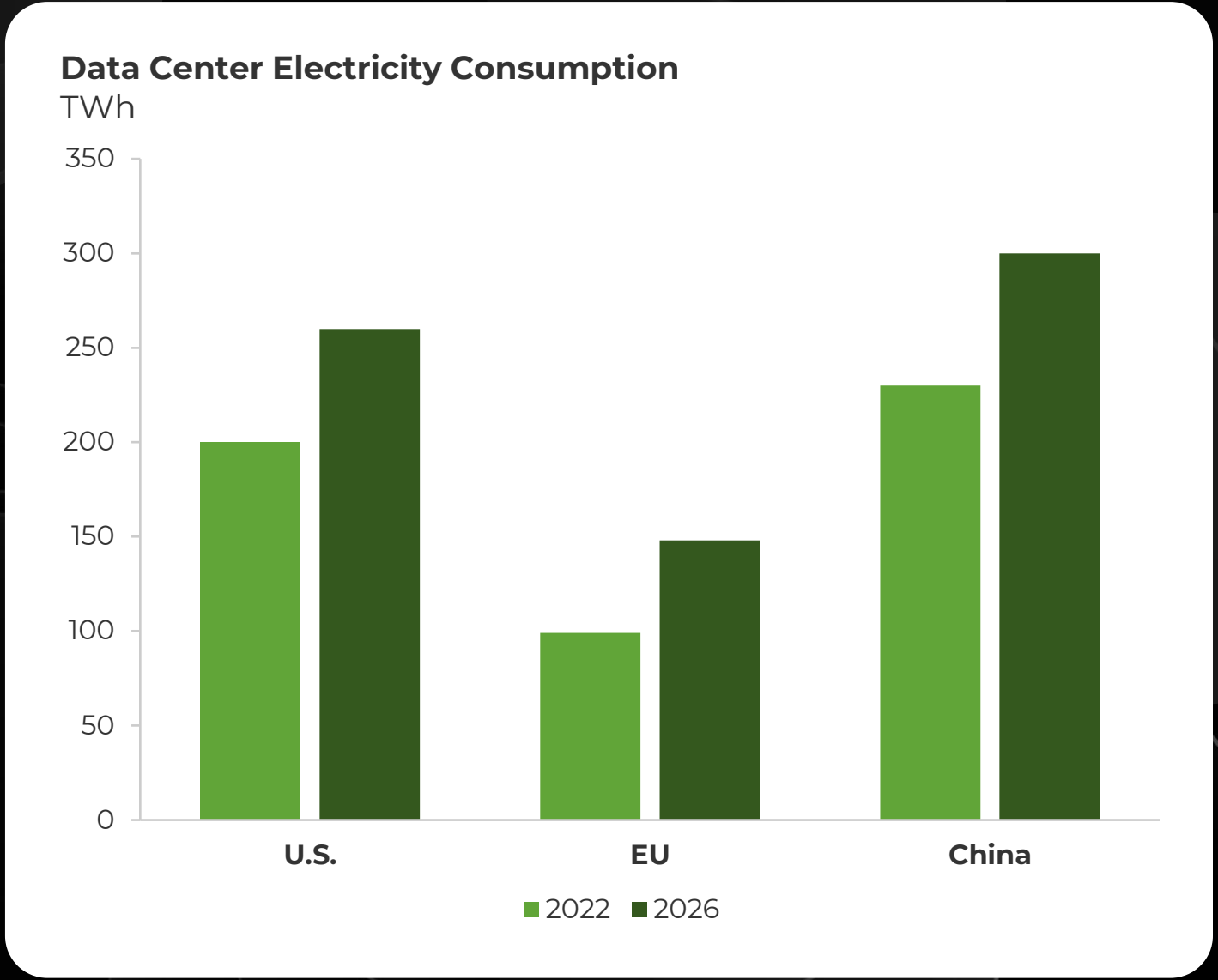
ELECTRIFICATION

DIGITALIZATION

SUSTAINABILITY

DATA CENTERS BOOM

The International Energy Agency's base scenario forecasts global electricity consumption to increase to over 800 TWh in 2026, up from 460 TWh in 2022. While the exact magnitude is uncertain, the upward trajectory of demand is undeniable. More than 50% of energy is consumed in cooling systems.



Source: The Economics of Low-Carbon Power for Data Centers

ELECTRIFICATION

DIGITALIZATION

SUSTAINABILITY

COOLANTS' ENVIRONMENTAL IMPACT

3M to Exit PFAS Manufacturing by the End of 2025

PFAS ban would render systems unsafe

25th May 2023

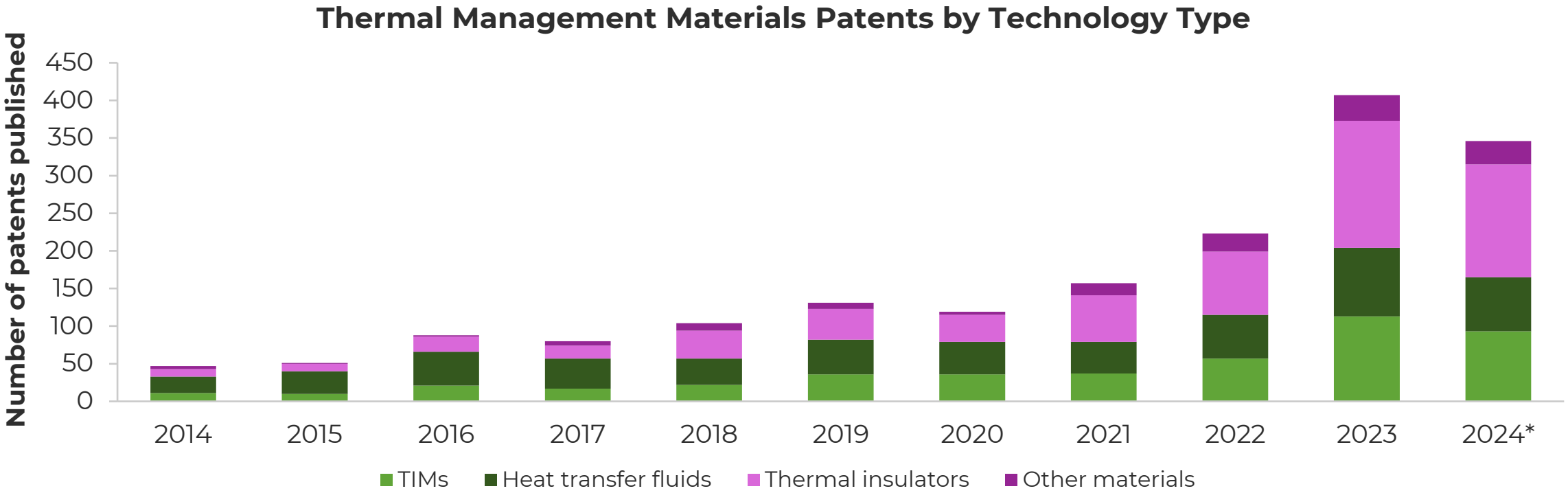
ELECTRIFICATION

DIGITALIZATION

SUSTAINABILITY

PATENT TRENDS

Innovations in thermal interface materials (TIMs) and insulators are accelerating

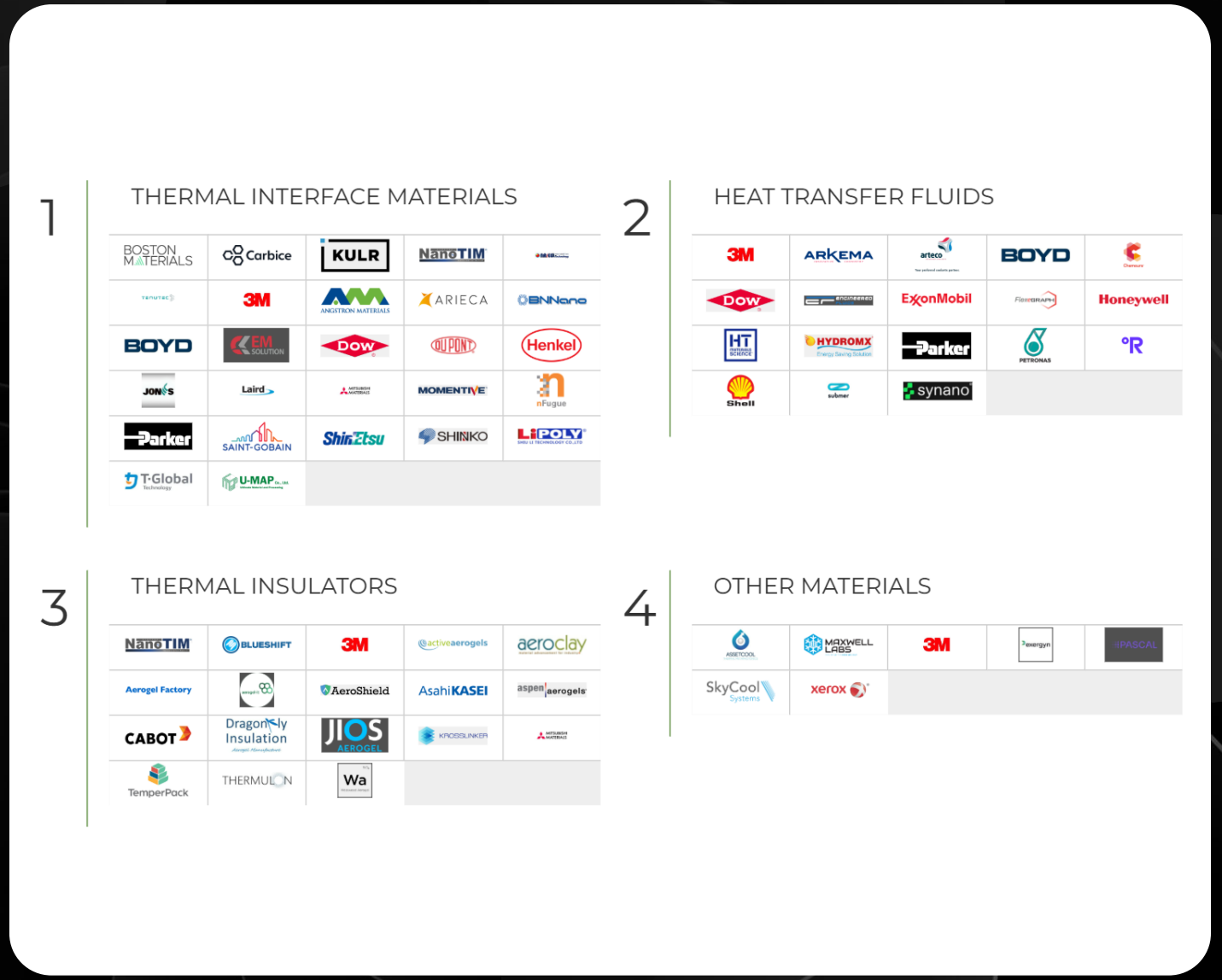


Source: Patent Trends: Thermal management materials

TECHNOLOGY LANDSCAPE

Four categories with distinct characteristics

- TIMs
- Heat transfer fluids
- Thermal insulators
- Other materials



Source: Technology Landscape: Thermal management materials

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02 | **Cool innovations**

03 | Opportunities and disruptors

TIMs

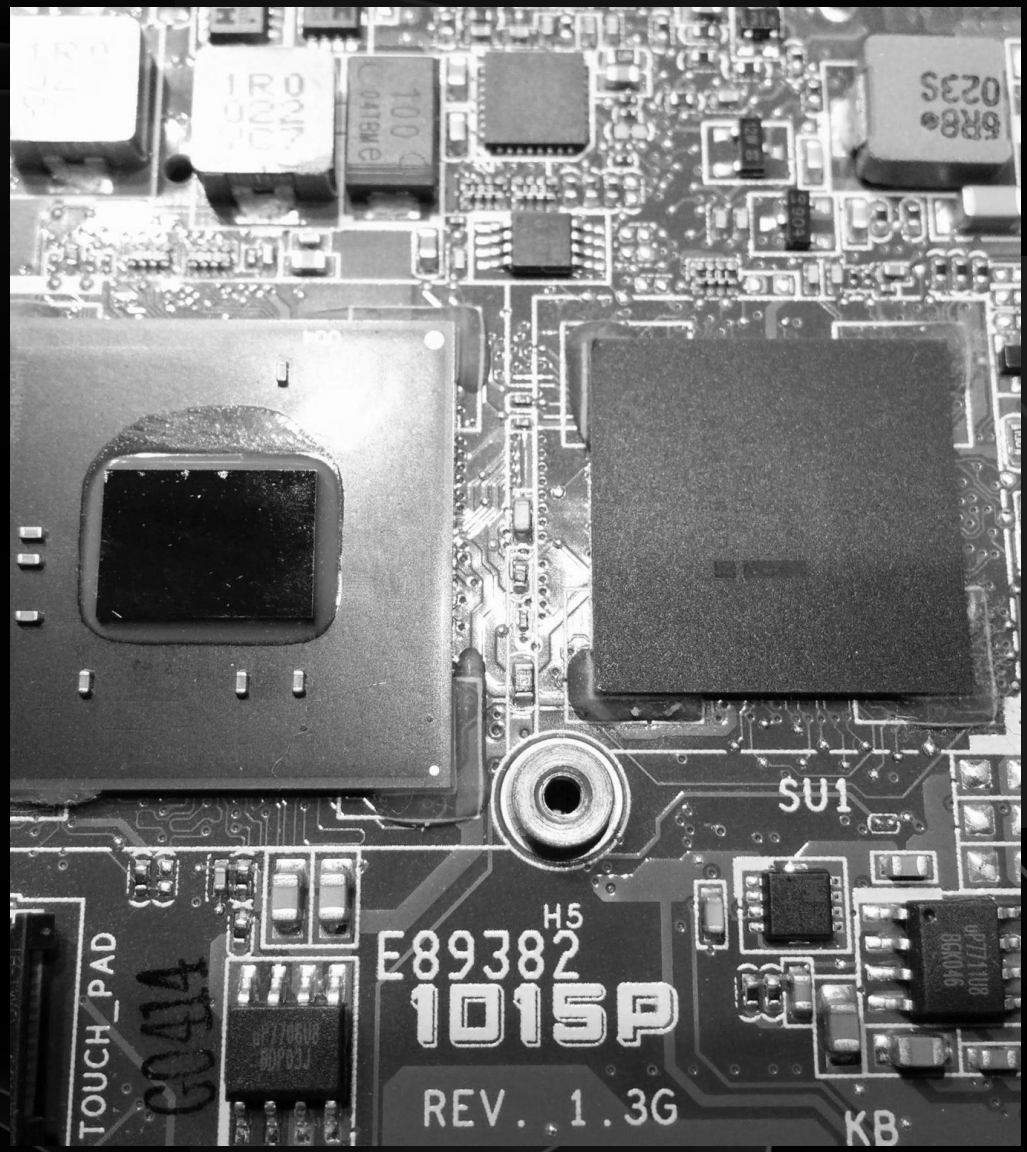
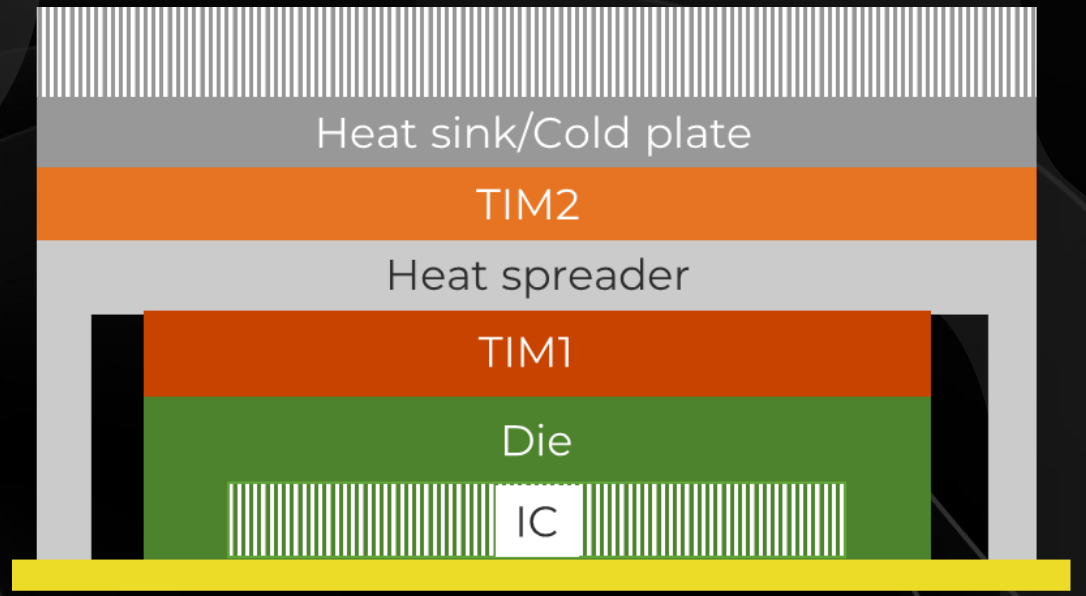
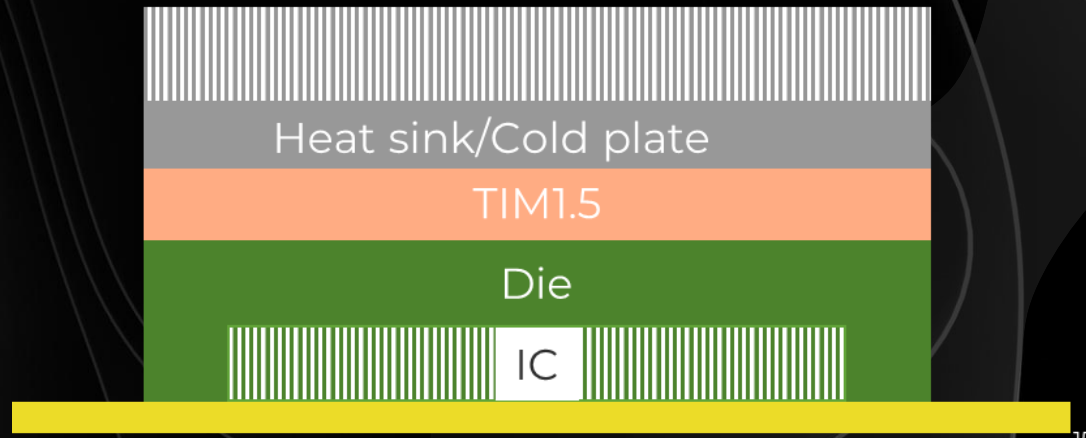


Image source: superuser

UNMET NEEDS

- Target markets: Electronics
- High thermal conductivity and low thermal resistance at the contact surface
- High out of plane thermal conductivity and shape conformity
- Excellent electric insulation





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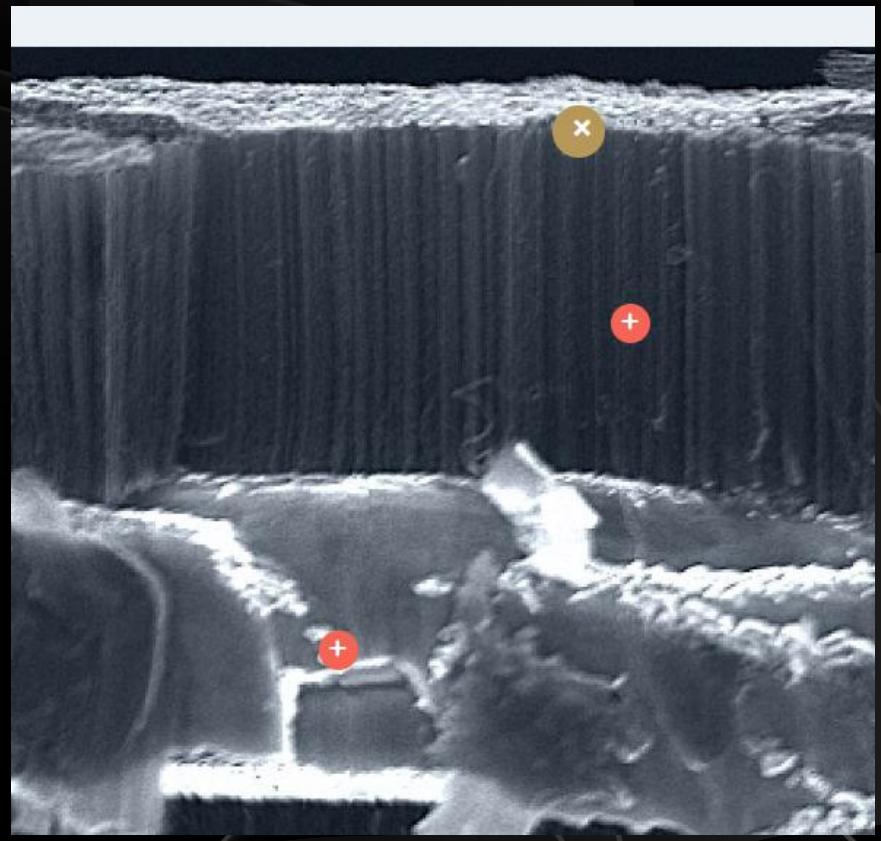
STATE OF THE ART: TIMs

	Thermal grease Thermally conductive pastes	**Carbon-based TIMs** Graphite and carbon black TIMs	**Nano TIMs** TIMs containing nanomaterials	**Metal-based TIMs** Liquid metals-based TIMs	**Phase-change materials (PCMs)** PCM-based TIMs
Stage of development	Scale	Scale	Introduction	Scale	Scale
Thermal conductivity (W/mK)	4.1–15	3–15	5–100	16–73	1.5–10
Thermal resistance ($C.cm^2/W$)	0.32–1.94	0.6–2	0.001–0.6	0.065–0.65	0.25–0.39
Operating range (°C)	100–130	350–400	200–300	150–200	125–150
Cost	USD 4,000/kg	USD 1–USD 5/pc	USD 10–USD 50/pc	USD 10–USD 20/syringe	USD 1–USD 50/pc
Ease of use	Med	High	High	Low	High
Lux Recommendation	Ignore	Ignore	Engage	Monitor	Engage

CARBICE'S ICEPADS

Carbon nanotube-based materials for TIMs

- Carbice produces vertically aligned nanotubes
- Out-of-plane thermal conductivity is 12 W/mK
- Thermal resistance is as low as 0.08 cm^2K/W
- The nano-tubes are flexible and accommodate shape changes at the contact surfaces



LUX TAKE

Startups have focused on improving the effective nanoscale additives through structured arrangements with keen focus on reducing thermal resistance at contact surfaces.

Carbice

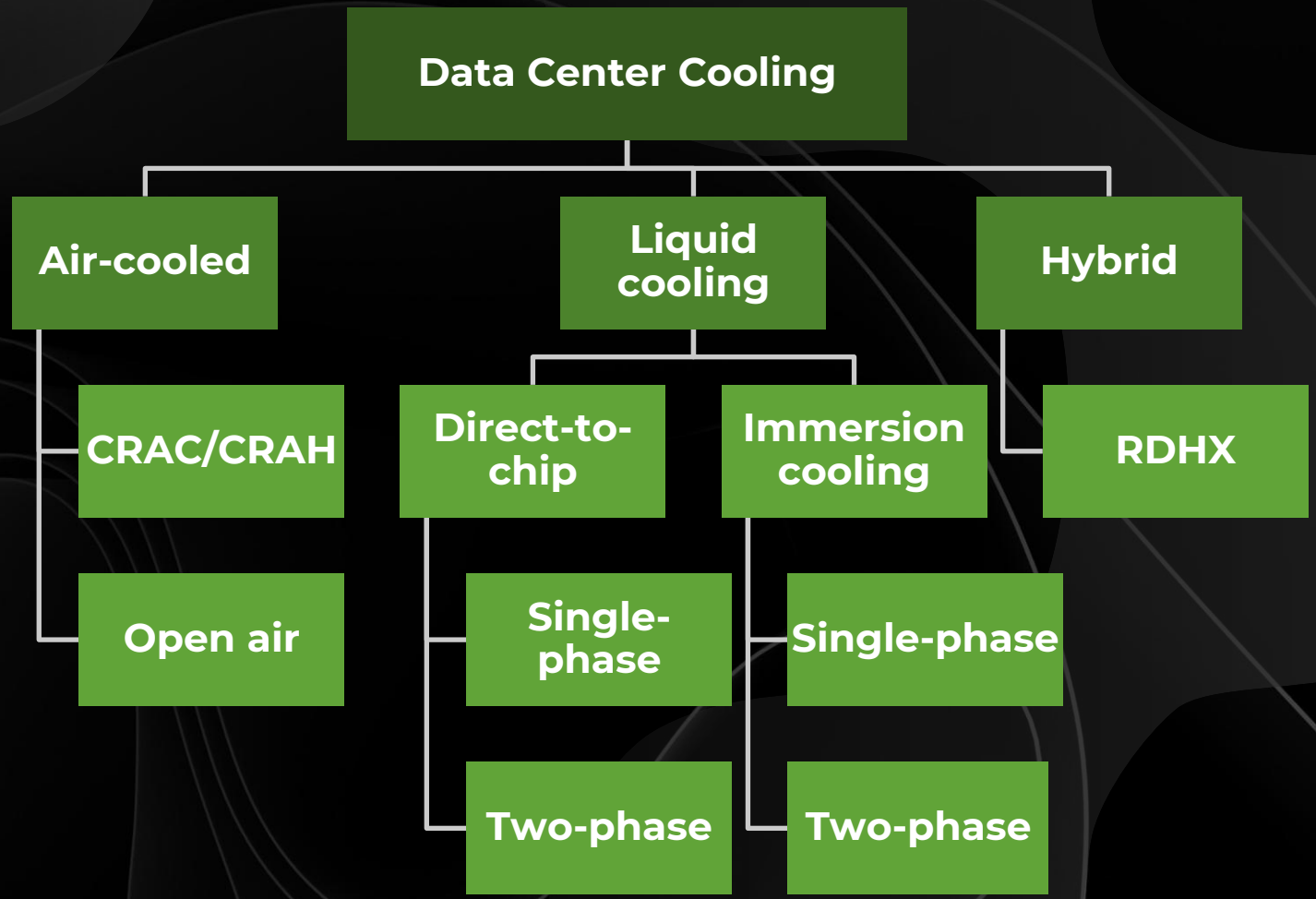
Image source: Carbice

HEAT TRANSFER FLUIDS (HTFs)

Image source: Thermtest Instruments

UNMET NEEDS

- Target market: Data center liquid cooling
- High thermal conductivity, high dielectric properties and low viscosity
- Low environmental impact
- High reliability



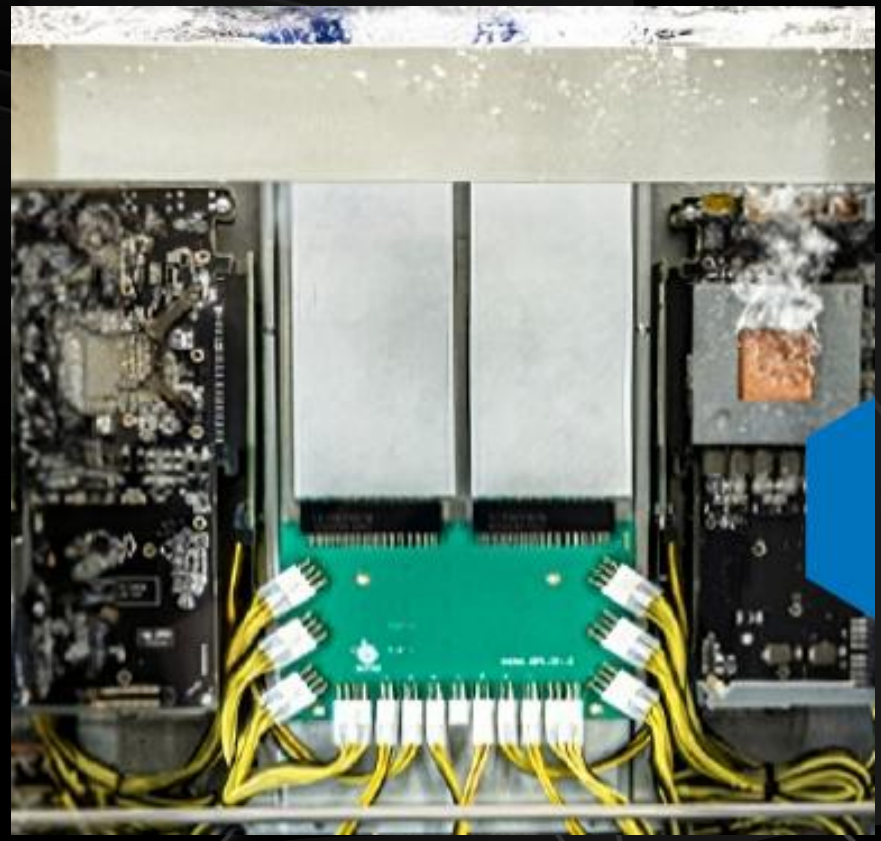
STATE OF THE ART: HTFs

	Water-glycol Any ratio	2-phase liquids 2-phase liquids for cooling	Synthetic DE fluids Derived non-HC sources	Nanofluids HTFs with nanoscale additives
Thermal conductivity (W/mK)	0.25–0.58	0.05–0.08	0.12–0.2	0.6–1.52
Specific heat capacity (J/kgK)	2,500–4,200	1,000–2,000	2,000–2,300	2,500–4,200
Dielectric constant	40–80	1.8-1	2–2.1	2.4–80
Viscosity (cP)	1–5	0.4–2	0.45–50	1–10
Max operating temp (ºC)	120–140	135–200	150–250	120–150
Cost (USD/lt)	1–4	70–140	10–15	20–150
Environmental impact	Low	High	Low	Med
Ease of use	High	Med	High	Med
Lux Recommendation	Ignore	Engage	Engage	Monitor

3M'S REPLACEMENT

Opteon HTF for immersion cooling

- Commonly used HTFs: 3M's Novec and Fluroinert will not be available after 2025 due to PFAS concerns.
- Chemours worked with Liquidstack to develop an alternative – Opteon (GWP ~148).
- 2-phase (2P) liquid immersion cooling has the PUE in the range of 1.07–1.15 depending on the geography



LUX TAKE

Despite the best PUE, 2P immersion cooling still faces adoption barriers due to maintenance and expertise requirements. In the near term direct-to-chip with single- and two-phase HTFs will see traction.

Chemours™ liquidstack°

Image source: Liquidstack

THERMAL INSULATORS

Image source: NASA/Jet Propulsion Lab

UNMET NEEDS

- Target market: Electric vehicles
- High temperature thermal insulation along with high flame retarding capabilities
- Lightweight and multifunctional
- High mechanical strength

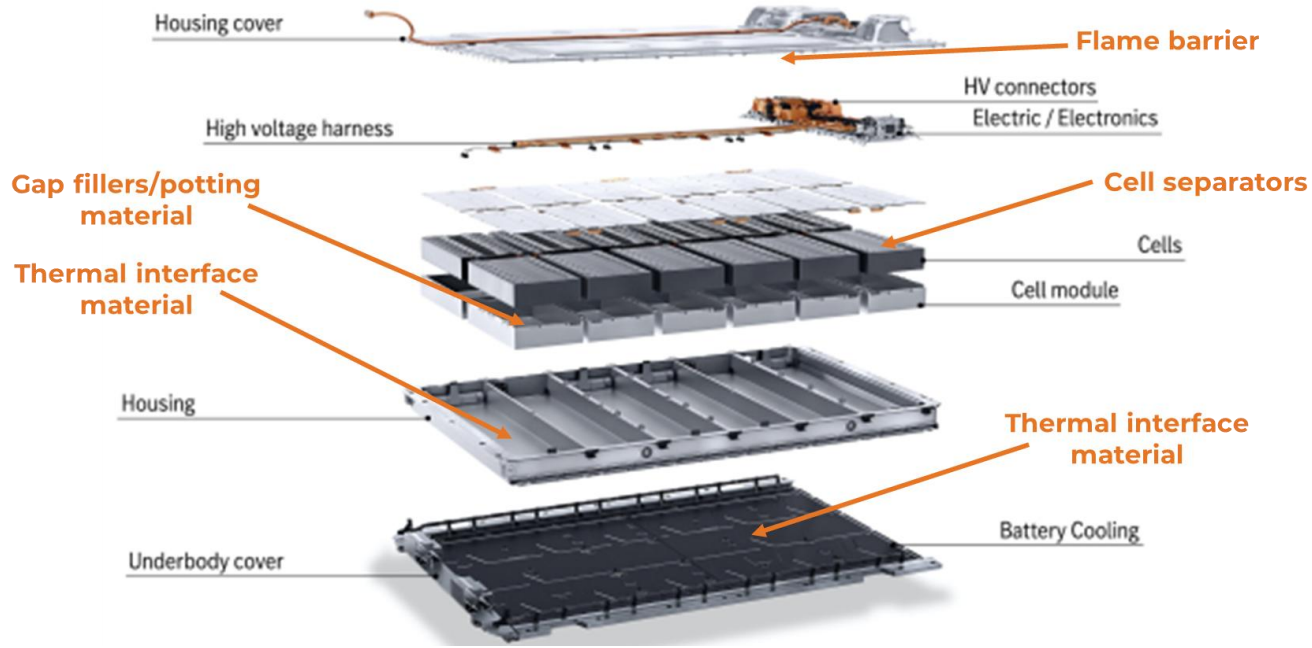


Image source: Daimler AG

STATE OF THE ART: INSULATORS

	Polymer-based insulators	Ceramic coatings	Aerogels
	Primarily foams	Ceramic coatings/sheets/papers	Silica aerogel materials
Stage of development	Scale	Scale	Introduction
Thermal conductivity (W/mK)	0.02–0.04	0.03–0.21	0.01–0.03
Max operating temperature (ºC)	200–300	1,000–1,400	1,000–1,400
Density (kg/m^3)	15–200	100–300	5–350
Cost	USD 60–USD 300/m^3	USD 8–USD 400/m^2	USD 500–USD 2,000/m^3
Ease of use	High	Med	Med
Lux Recommendation	Ignore	Monitor	Engage

AEROGELS FOR EVs

Aspen Aerogels' PyroThin gains traction

- PyroThin can withstand up to 1,400 °C and has low thermal conductivity [14.5 mW/(m·k) to 21 mW/(m·k)]
- Overall pack-weight savings is 5–10 kg
- Although it is suitable for prismatic or pouch cells
- Aspen received USD 670 million loan from U.S. DOE to expand manufacturing in 2024

LUX TAKE

Aerogels provide high-temperature thermal insulation and are well-suited for battery packs; however, they remain costly. Increasing manufacturing capacity and growing competition from APAC will reduce costs.

Image source: Aspen Aerogels

OTHER MATERIALS

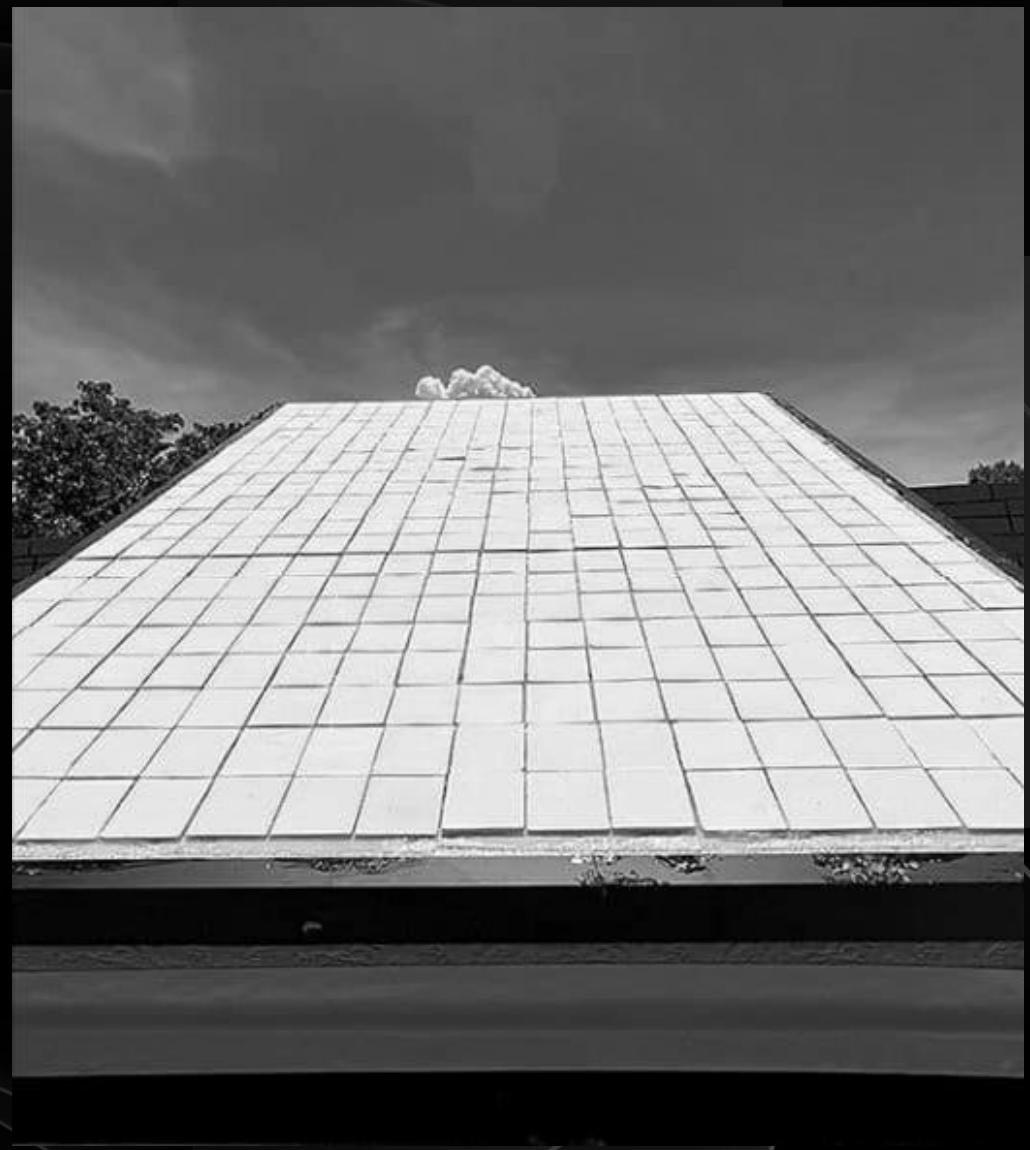


Image source: City University of Hong Kong

UNMET NEEDS

- Target market: Utilities
- Beyond conduction and convection
- Novel materials for improved thermal management and efficiency
- Low cost and ability to withstand rough weather
- Low environmental impact

STATE OF THE ART: OTHER MATERIALS

	Thermal metamaterials	Solid refrigerants	
	Metamaterials for passive radiative cooling	Magnetocaloric systems	Elastocaloric systems
Stage of development	Introduction	Introduction	Lab
Temperature span (K)	5–15	5–30	20–30
Environmental impact	Low	GWP 0	GWP 0
Unmet materials needs	Metamaterials	Rare earth magnets	Shape memory alloys
Coefficient of performance	0.4–0.8	3–12	5–15
Cost	Low	High	High
Ease of implementation	High	Low	Low
Lux Recommendation	Monitor	Monitor	Ignore

PASSIVE RADIATIVE COOLING

AssetCool's coating for overhead lines

- Aluminium conductors absorbs 50%–80% of solar radiation which reduces ampacity of power lines
- Photonic coating can increase ampacity by 30% through passive cooling
- AssetCool is testing its coating on 17km long overhead line

LUX TAKE

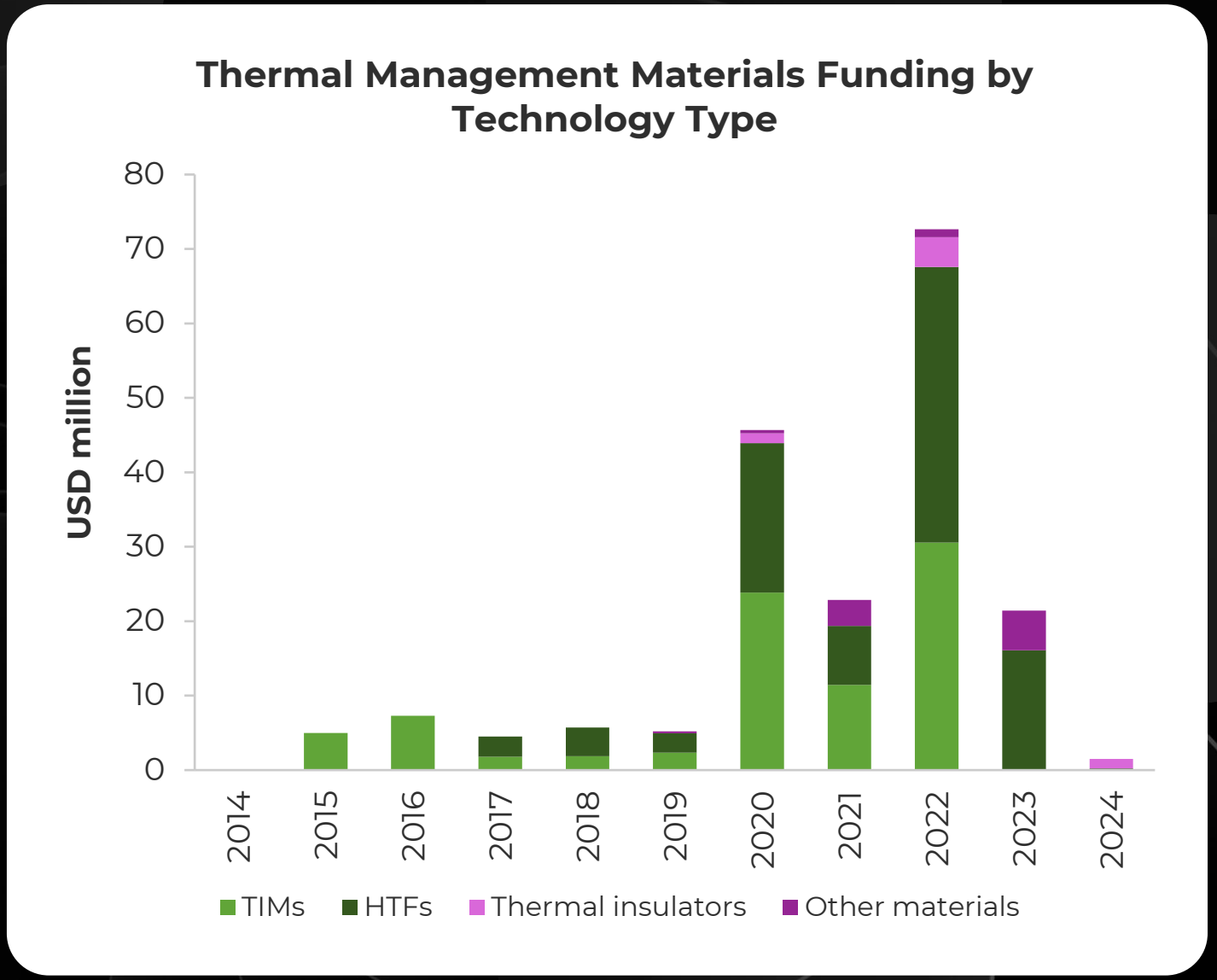
Passive radiative cooling for overhead powerlines is still at an early stage. The commercial viability and its ability sustain rough weather conditions are under evaluation.

ASSETCOOL
THERMAL METAPHOTONICS

Why there are no unicorns in TMMs?

CHALLENGES

- Cost of new materials
- Long qualification cycles
- Competition
- Reliability as adoption barrier



Source: Investment Trends: Thermal management materials

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KEY TAKEAWAYS

1

Focus on new applications.

The existing TMM market is crowded and difficult to penetrate for new entrants. Startups can't compete as materials suppliers; they should focus on a specific applications and develop products.

2

Startups are not competitors but enablers.

Startups are developing novel materials but struggle with long development cycles. Incumbents should view them as collaborators for targeting emerging markets.

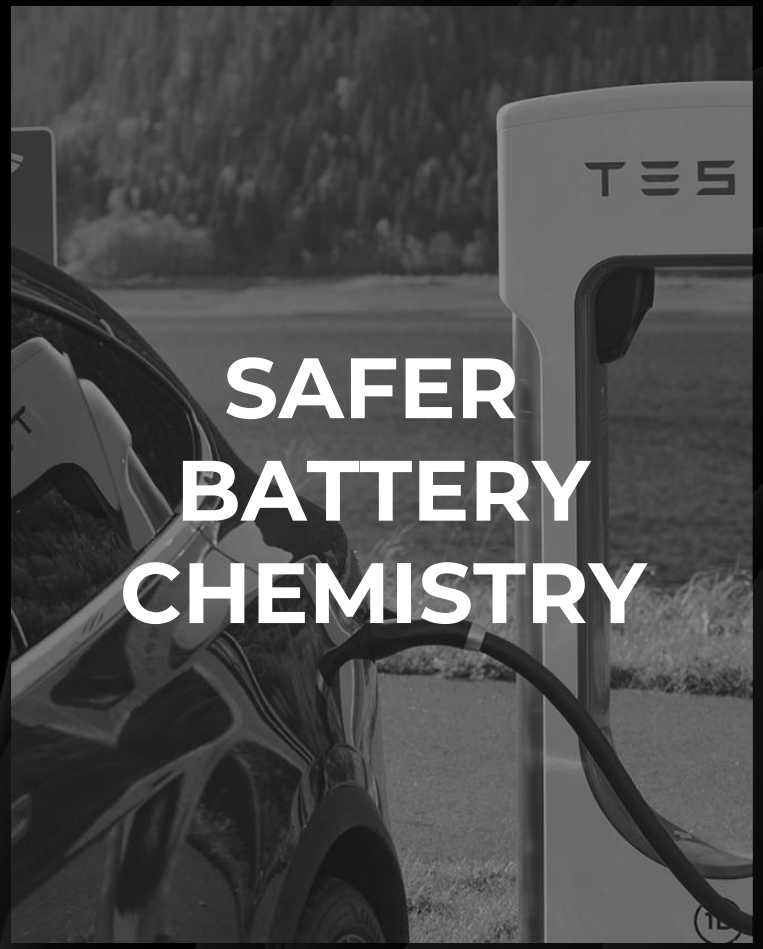
3

Monitor adjacent applications and adopt quickly.

Potential disruptors...

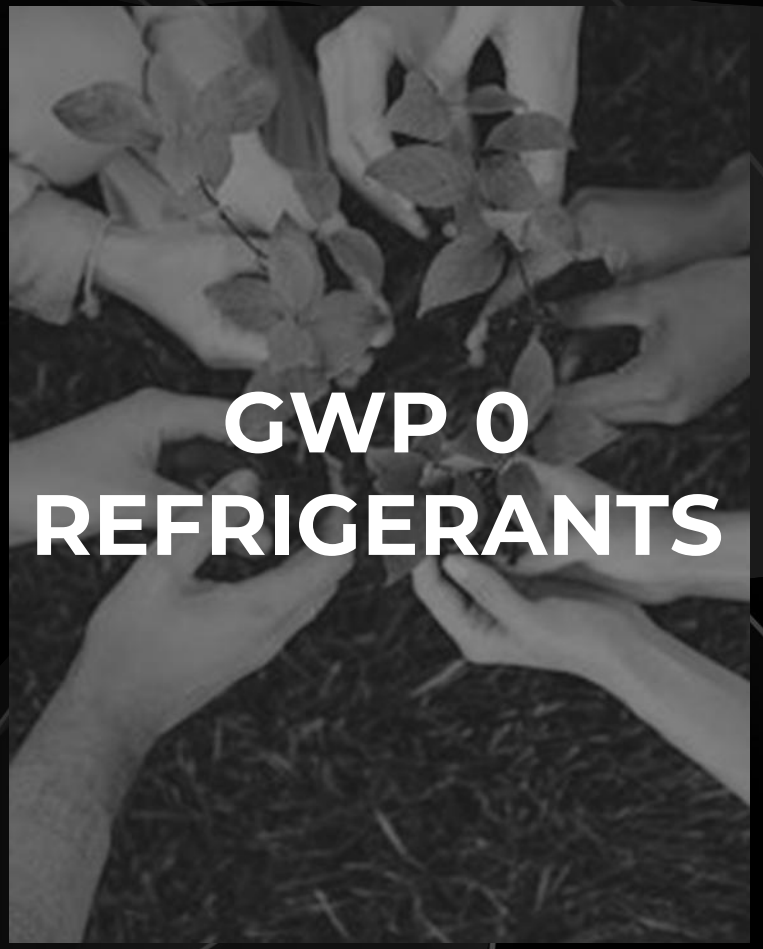
Potential Disruptors

ELECTRIFICATION



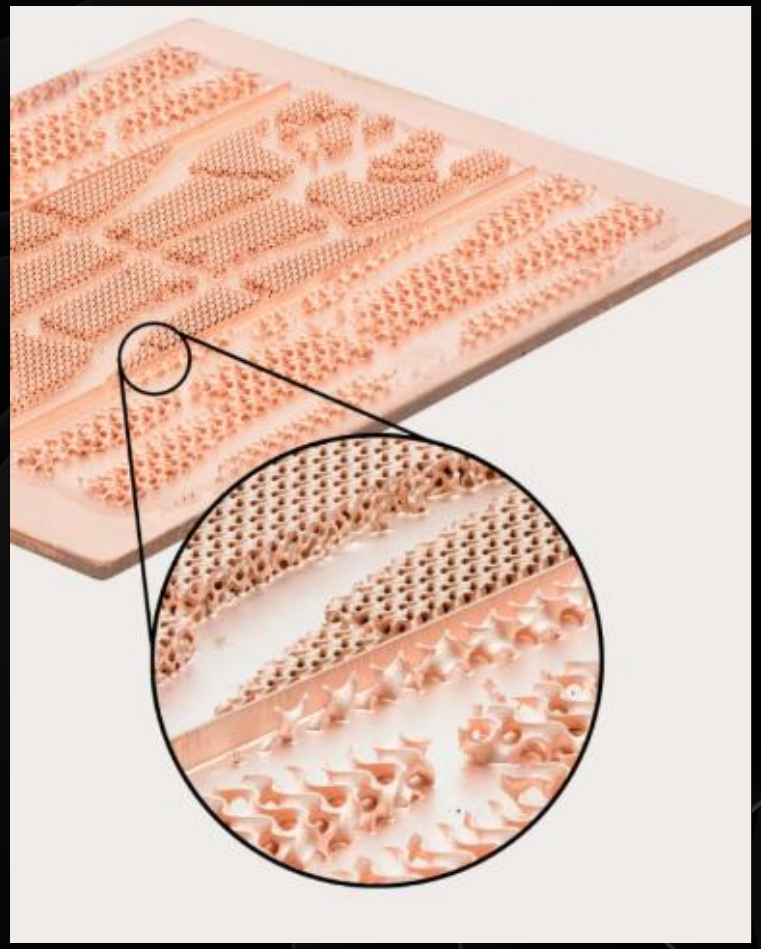
DIGITALIZATION

SUSTAINABILITY



SAFE BATTERIES

TIMS FREE CHIPS



SOLID REFRIGERANT

Image sources: Innovation Origin, Fabric8Labs, and Universität des Saarlandes

Potential ~~Disruptors~~ Opportunities

THANK YOU

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