BATTERY THERMAL MANAGEMENT SYSTEM CASE STUDY

COMPARISON BETWEEN QOOLERS BTMS-C AND COMPETITIVE PRODUCT

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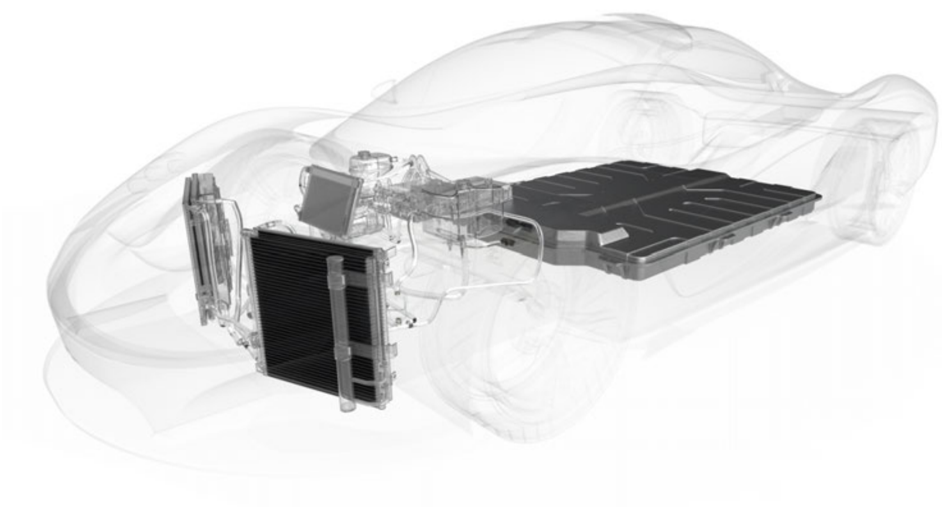
1 Introduction and Motivation

The increasing demand for efficient, lightweight, and space-optimized thermal management solutions in electric mobility and stationary energy storage has intensified the need for advanced cooling concepts for medium-sized battery modules. Conventional aluminum cooling plates, although effective in thermal conduction, significantly increase overall system mass and impose geometric constraints that limit integration flexibility. In medium-scale battery applications, where thermal uniformity, manufacturability, and cost efficiency are critical, these limitations directly influence performance and system optimization.

Against this background, the objective of the present development was to design and validate a thermoplastic-based medium-sized battery cooler capable of serving as a high-performance alternative to traditional aluminum designs. The goal was to achieve comparable or improved heat-distribution characteristics while reducing weight and enabling greater design freedom. The medium-sized battery cooler concept combines low-density polymer materials with optimized internal channel geometries to enhance coolant distribution and convective heat transfer performance.

This case study provides a technical comparison between Qoolers' medium-sized battery cooling solution and a representative aluminum-based competitor. Through controlled testing procedures and detailed CFD simulations, the analysis evaluates thermal efficiency, temperature uniformity, flow distribution, structural thermal behavior, and hydraulic performance. The results demonstrate the feasibility and advantages of replacing conventional aluminum cooling plates with advanced polymer-based solutions that deliver improved thermal performance with significantly reduced mass and enhanced integration flexibility.



2 Description of Compared Systems

2.1 Qoolers BTMS-C

Model: BTMS-C
Application: Thermal control in liquid-cooled battery systems
Design: Modular cooler with internal serpentine channels and dual cross section inlet & outlet
Material: PA12 manifold with PE-MD tubes

Table 1: Technical Specifications of BTMS-C

Parameter	**Value**
Inlet/Outlet Diameter	Ø12 mm (quick-connect)
External Dimensions	550 × 307× 78 mm
Weight (dry)	487 g
Internal Volume	0.434 L
Flexular modulus	700 MPa (ISO 178)
Tensile modulus	650 MPa (ISO 527-1,2)
Yield stress	17 MPA (ISO 527-1,2)
Working Fluid	Water/Glycol (50/50)
Operating Pressure	3 bar
Flammability	Non-flammable (ISO 3795)
Surface resistivity	$10^{14} - 10^{16}$ [Ω/□]per IEC 93
Energy Storage Capacity	46 kW
Recyclability	>90%, PA12 & PE

Figure 1: BTMS-C model preview

2.2 Competing Product (Brand X)

Model: ThermoFlow-L
Application: Battery cooling for light-duty EVs
Design: Aluminum manifolds with multiport aluminum tubes.

Table 2: Technical Specifications of Competitive Product

Parameter	**Value**
Inlet/Outlet Diameter	Ø12 mm
External Dimensions	552 × 294 × 92 mm
Weight (dry)	1.09 kg
Internal Volume	0.783 L
Pressure Resistance	4.5 bar
Temperature Range	-30°C to +70°C
Working Fluid	Water
Operating Pressure	3.0 bar
Energy Storage Capacity	44 kWh
Recyclability	65%

Figure 2: Competition model preview

3 Testing Methodology

3.1 Tools and Environment

- Simulation: ANSYS Fluent 2024 R2
- Repeated cycles for consistency and objectivity

3.2 Boundary Conditions

- Fluid: Mixture Water/Glycol (50/50 [mol %])
- Inlet Temperature: 8°C
- Flow Rates: 6 L/min
- Heat generated by charge rate of 3C & 6C

3.3 Objectivity Assurance

Measurements were repeated under identical conditions. The calibration was compliant with ISO 17025 and was verified by a third-party accredited institution.

4 Key Parameter Comparison

The comparison of key thermal and hydraulic parameters between BTMS - C and the competitor reveals distinct differences in cooling behavior under both 3C and 6C operating conditions. Most notably, BTMS - C demonstrates a clear advantage in thermal power. At 3C, the extracted heat increases from 797.5 W to 830.7 W, while at 6C the improvement becomes even more pronounced, rising from 2880.0 W to 3517.5 W. In battery cooling applications, higher thermal power directly reflects e nhanced h eat r emoval c apability, w hich i s e ssential f or maintaining temperature stability under elevated electrical loads. The stronger performance at 6C is particularly significant, a s h igh C -rates r epresent t he m ost t hermally d emanding operating scenarios.

Parameter	**Competition**	**BTMS - C**
P-loss (3C) [kPa]	4.343	9.415
P-loss (6C) [kPa]	4.301	9.241
t-out (3C) [°C]	9.98	11.38
t-out (6C) [°C]	15.55	21.1
W (3C) [W]	797.5	830.7
W (6C) [W]	2880.0	3517.5

Table 3: Comparison of competition and BTMS - C across key thermal and hydraulic parameters.

The outlet temperature results show a slightly different trend. At 3C, BTMS - C ex-hibits a marginally higher outlet temperature (11.38 °C compared to 9.98 °C), and this difference becomes more visible at 6C (21.1 °C compared to 15.55 °C). The higher outlet temperature in-dicates that the coolant absorbs a larger amount of heat while passing through the cooling structure, which is consistent with the increased thermal power values. Rather than indicating reduced performance, this behavior reflects a more intensive thermal exchange between the bat-tery modules and the coolant, particularly under high-load conditions.

As expected from the enhanced thermal performance, BTMS - C exhibits a higher pressure loss compared to the competitor. At 3C, the pressure drop increases from 4.343 kPa to 9.415 kPa, and at 6C from 4.301 kPa to 9.241 kPa. Elevated pressure loss is typically associated with more complex internal channel geometries, increased heat transfer surface area, or higher turbulence levels, all of which contribute positively to convective heat transfer efficiency. In high-performance battery cooling systems, such an increase represents a controlled and acceptable trade-off w hen a ccompanied b y s ubstantial g ains i n h eat r emoval capacity.

Overall, the data confirm that BTMS - C prioritizes thermal effectiveness, particularly under high C-rate operation, where thermal loads are most critical. The combination of increased heat extraction capability and manageable hydraulic penalties demonstrates a design optimized for demanding battery applications requiring robust and stable thermal control.

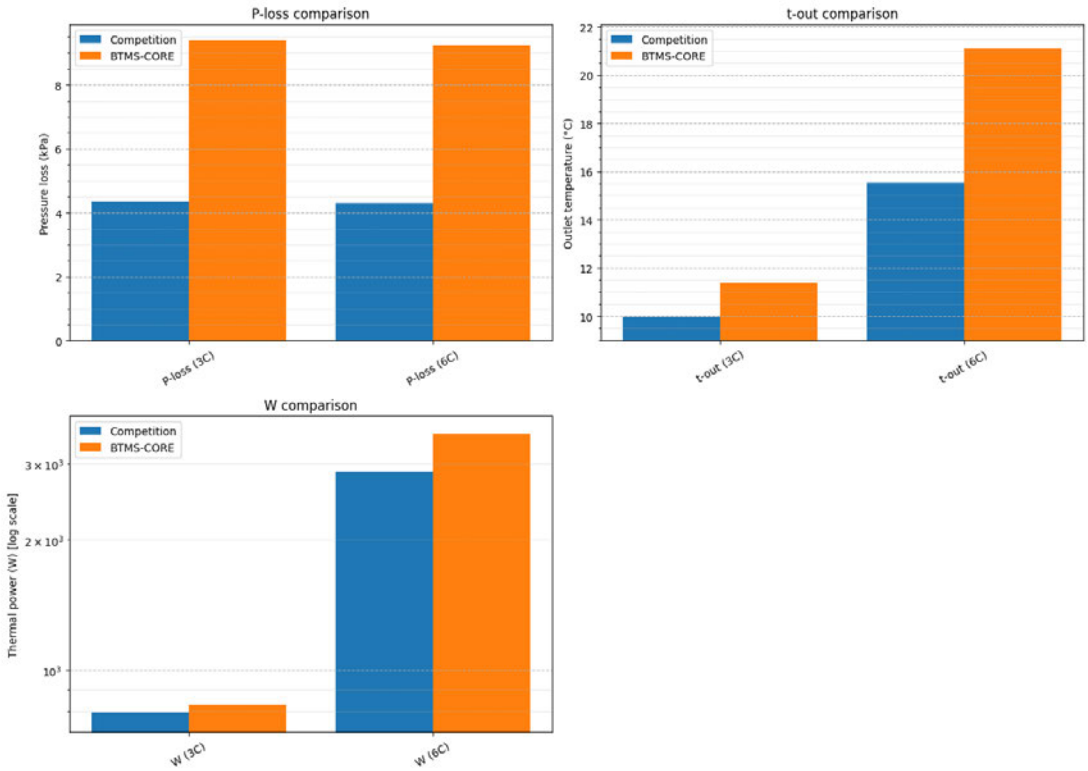


Figure 3: Temperature distribution contours at battery conduction faces

In general, the collective results show that BTSM - Cprovides superior thermal control in the areas that matter the most for battery cooling. Provides improved heat extraction and better suppression of thermal hotspots. The additional pressure loss is minor in context and does not detract from the overall thermal performance benefits. Therefore, BTSM - C represents a more effective solution for maintaining safe and stable thermal conditions in high-power battery applications.

5 Results Interpretation

5.1 BTMS - C

The wall-temperature contours of **BTMS - C** indicate a smooth and progressively developing thermal field across the cooling channels, with temperatures spanning approximately **281 K to 296 K**. The gradient from the cooler inlet regions (blue–green) toward the warmer downstream sections (yellow–red) reflects the expected cumulative heat absorption of the coolant along the flow path.

Despite the broader temperature range compared to lower-load cases, the distribution remains spatially coherent and well-structured, without evidence of abrupt thermal discontinuities or isolated hot spots. The color transitions are continuous and consistent across adjacent channels, suggesting balanced coolant allocation and effective c onvective h eat t ransfer throughout the geometry.

Slightly elevated temperatures appear toward the terminal sections of the channels, corresponding to the downstream region where the coolant has absorbed the majority of the thermal load. However, these warmer zones are uniformly distributed rather than localized, indicating controlled thermal buildup rather than stagnation.

Overall, the contour field confirms that **BTMS - C maintains stable and predictable wall-temperature behavior under the evaluated operating conditions**, supporting efficient heat removal and reliable thermal management performance even at elevated thermal loads.

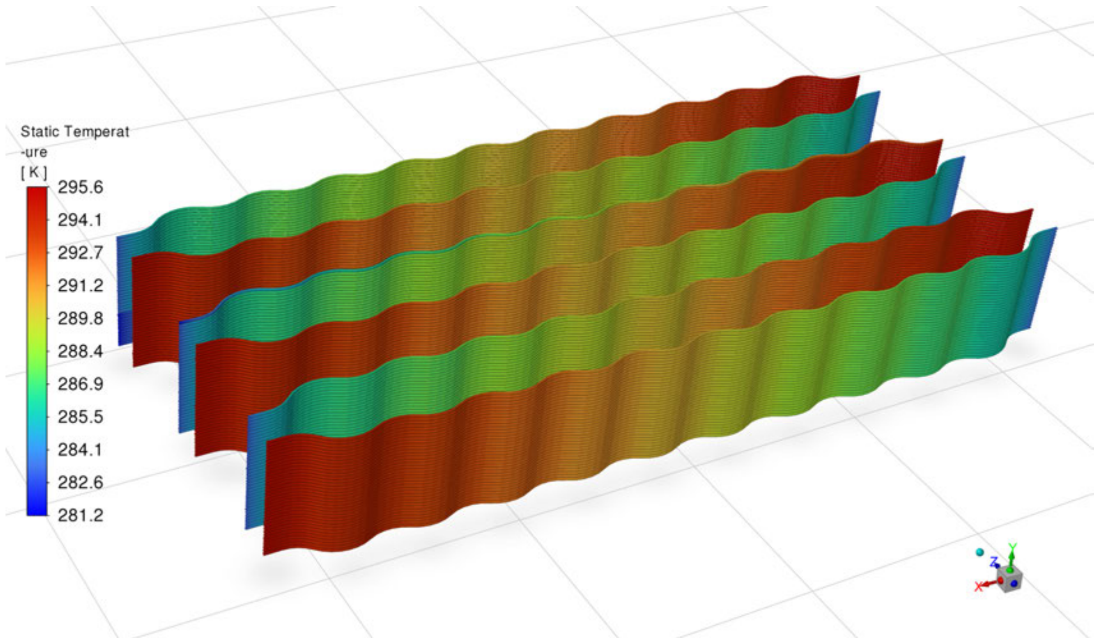


Figure 4: BTSM - C temperature distribution contours at battery conduction faces

The velocity pathlines of BTMS - C reveal a smooth, well-organized coolant flow through the cooling channels, characterized by high velocities near the inlet regions and a gradual, controlled reduction in velocity along the flow direction. The transition from red and yellow near the inlets to predominantly green and blue downstream indicates steady momentum dissipation as the coolant absorbs heat, without abrupt deceleration.

Importantly, the flow remains largely attached to the channel walls throughout the serpentine passages, with no evidence of large-scale recirculation zones or stagnant pockets within the active cooling region. Minor localized vortical structures are confined to the inlet and outlet manifolds and do not propagate into the core channels, demonstrating effective flow guidance by the channel geometry.

Overall, the velocity field confirms that BTMS - C ensures uniform coolant distribution, stable velocity profiles, and efficient mass-flow utilization, all of which contribute to reliable convective heat transfer and robust thermal management performance under the evaluated operating conditions.

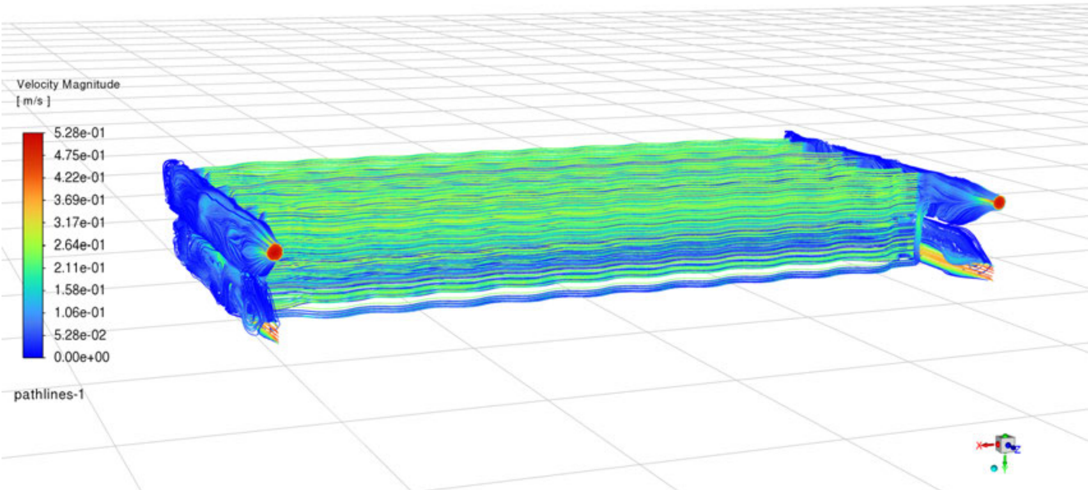


Figure 5: BTSM - C velocity pathlines from simulation

5.2 Competitor's BTMS

The temperature contours of the competitor's cooling system reveal a more pronounced longitudinal thermal gradient across the channel length, with temperatures increasing steadily from the inlet region toward the outlet. The distribution spans approximately 281 K to 284 K, but unlike the more uniform profiles observed in BTMS - C, the warmer regions occupy a larger portion of the downstream geometry.

The contour field shows clearer banding and steeper local gradients between successive channel segments, suggesting less homogeneous heat extraction along the flow path. Elevated temperatures accumulate toward the terminal section of the module, indicating progressive thermal buildup as the coolant absorbs heat without sufficient redistribution.

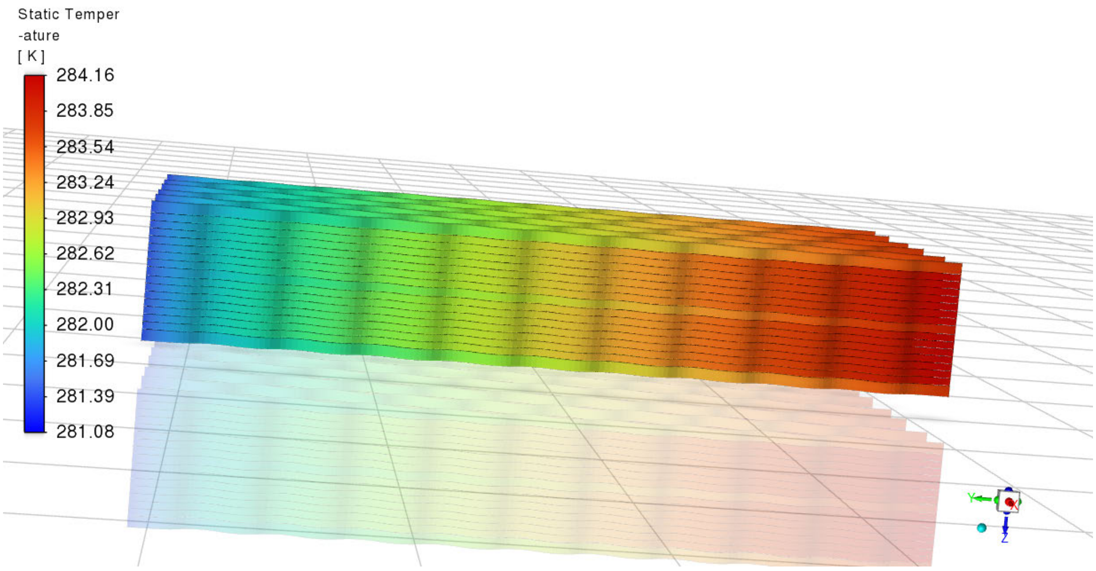


Figure 6: Competitor's BTMS temperature distribution contours at battery conduction faces

The velocity field of the competitor's design exhibits a highly non-uniform coolant distribution across the channel network. Elevated velocities are concentrated near the inlet regions, where the flow enters with significant momentum, while the majority of the downstream channels are dominated by low-velocity flow, as indicated by the extensive blue regions.

The pathlines reveal pronounced flow distortion near both the inlet and outlet manifolds, including clear signs of recirculation, flow separation, and swirling structures. These features disrupt coherent flow development and lead to poor penetration of mass-flow into the core of the cooling channels. As a result, large portions of the geometry experience weak convective transport, increasing the likelihood of thermal stagnation in regions where heat removal is most critical.

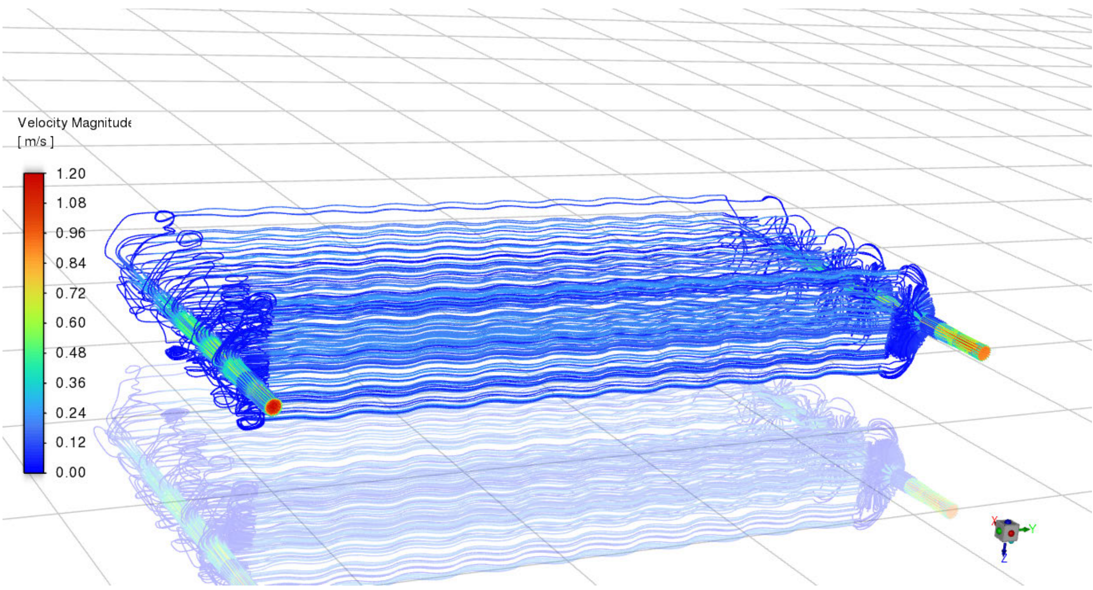


Figure 7: Competitor's BTSM velocity pathlines from simulation

5.3 BTMS - C Advantages

- Demonstrates higher thermal extraction capacity at both 3C and 6C discharge rates, reflected by increased thermal power values (830.7 W vs. 797.5 W at 3C and 3517.5 W vs. 2880.0 W at 6C).
- Superior high-load performance at 6C, where the significantly higher thermal power indicates enhanced convective heat-transfer effectiveness under elevated thermal stress.
- More uniform and controlled coolant flow distribution, as confirmed by CFD pathline analysis showing stable velocity fields and minimal large-scale recirculation within the cooling channels.
- Higher thermal throughput per unit mass and volume, achieved despite substantially lower dry weight (487 g vs. 1.09 kg) and smaller internal coolant volume (0.434 L vs. 0.783 L), resulting in improved thermal power density.
- Integrated electrical insulation due to polymer-based construction, ensuring compliance with electrical safety requirements typically expected in modern battery systems.

5.4 Competition Advantages

- Lower pressure loss at both operating points (4.343 kPa vs. 9.415 kPa at 3C and 4.301 kPa vs. 9.241 kPa at 6C), reducing pumping power requirements.
- Lower coolant outlet temperatures (9.98 °C vs. 11.38 °C at 3C and 15.55 °C vs. 21.1 °C at 6C), indicating lower temperature rise across the cooling module under the evaluated flow conditions.

6 Conclusion

Summary:

The combined simulation and performance results demonstrate that BTMS - C provides significantly higher thermal extraction capability than the competing solution, particularly under high-load conditions. This is evidenced by higher thermal power at both discharge rates, with a pronounced advantage at 6C (3517.5 W vs. 2880.0 W), confirming enhanced convective heat-transfer effectiveness.

Although BTMS - C exhibits higher pressure loss and higher outlet temperatures, these characteristics are consistent with increased thermal throughput and intensified heat-transfer interaction within the cooling channels. The higher pressure drop represents a predictable trade-off associated with improved heat-transfer performance.

Importantly, BTMS - C achieves this performance within a substantially lighter and more compact design (487 g vs. 1.09 kg and 0.434 L vs. 0.783 L), resulting in superior thermal power density. Additionally, the polymer-based architecture provides intrinsic electrical insulation, enhancing system-level safety compared to the aluminum-based competitor design.

Overall, BTMS - C demonstrates stronger high-load thermal capability and improved performance efficiency per unit mass, making it particularly suitable for demanding battery applications where compactness and thermal throughput are critical.

Outlook:

- Geometric optimization of internal channel topology to reduce pressure loss while preserving high thermal power capability.
- Fine-tuning of manifold flow distribution to moderate outlet temperature rise under extreme 6C operation.
- Further enhancement of thermal power density through structural weight optimization and material refinement.
- Integration of embedded sensing (temperature, pressure, and flow) to enable predictive thermal control strategies.
- Development of advanced CFD-driven digital twin models to assess long-term durability, ageing, and real-world duty-cycle performance.