

Background

Electric vehicles depend on battery systems that are efficient, reliable, and safe. In solar car racing, battery packs must deliver high power while meeting strict safety requirements, making fault protection, thermal control, and stable operation essential.

This project developed a high-voltage lithium-ion battery pack designed to satisfy both performance goals and ASC/FSGP safety regulations. The traction pack uses 290 Molicel INR-21700-P50B cells arranged in a 29s10p configuration, producing a nominal voltage of about 104 V.

The battery system integrates major protection and control components, including the main contactors, fuse, and pre-charge circuit, inside a centralized high-voltage enclosure. Power exits through a high-voltage connector that serves as an in-car service disconnect, followed by a manual circuit breaker for maintenance isolation and added protection. A 120 A main fuse provides primary overcurrent protection. Based on the 5 kW traction motor, expected operating current ranges from about 48 A at nominal voltage to 69 A at 72 V, giving adequate protection margin during operation.

To improve performance and pack life, the design uses properly sized conductors to reduce voltage drop under nominal and transient loads. Modular cell grouping and clear isolation points also improve serviceability and fault handling.

Validation includes capacity testing, internal resistance measurement, thermal testing under load, and fault-response verification through the battery management system shutdown logic. These design principles extend beyond competition vehicles and reflect the same balance of energy density, current capability, and safety required in real-world electric vehicle battery systems.

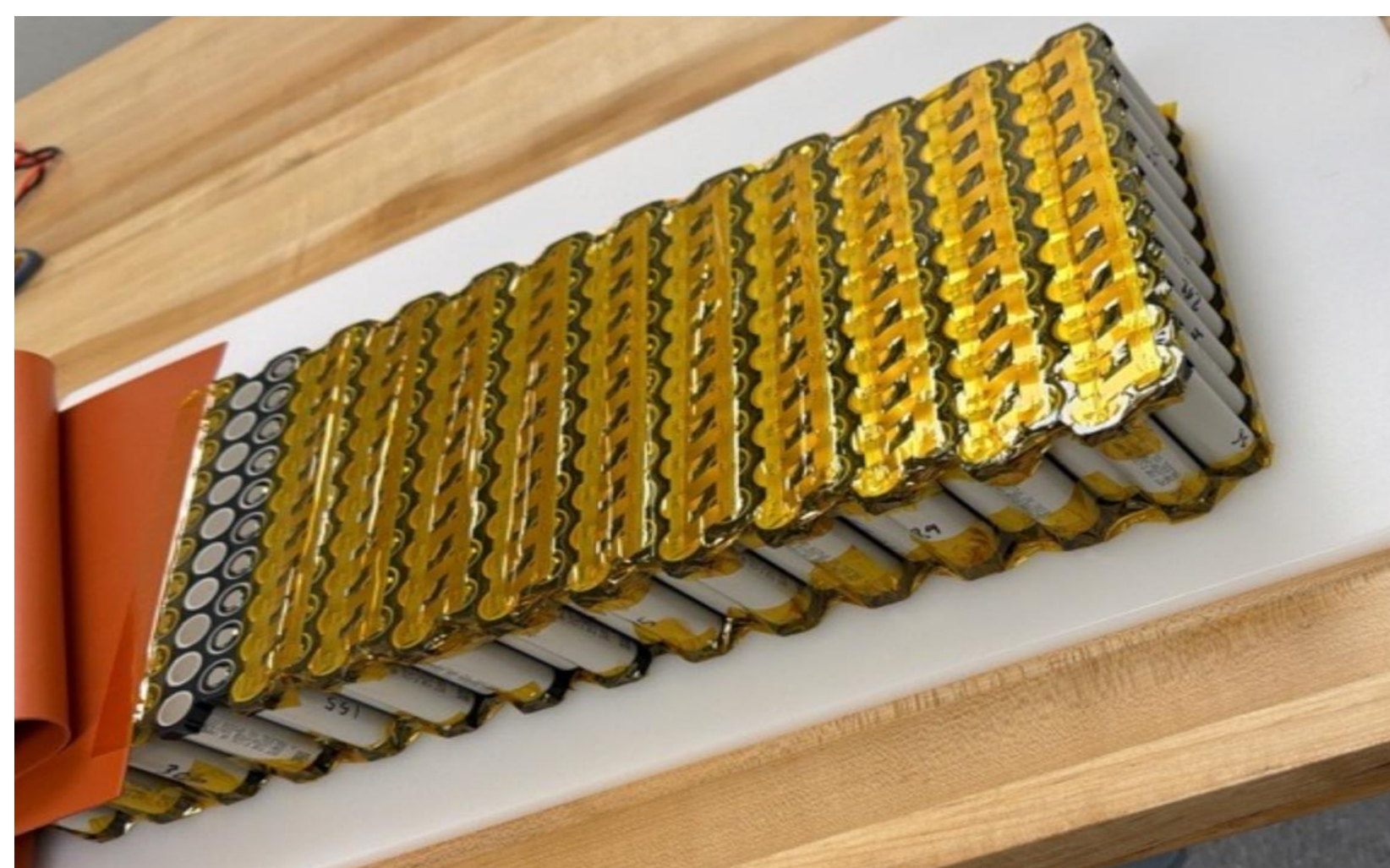


Figure 1. Cell assembly of the 29s10p lithium-ion traction battery pack during construction.

Methods (Battery Cell Optimization)

All candidate Molicel P50B cells were evaluated to determine the most suitable arrangement for the final build. Measured capacity and internal resistance data for each cell were compiled in Excel and processed with a Python-based optimization program. This step was used to improve uniformity across the pack by reducing imbalance between series strings. The program was configured specifically for the 29s10p architecture, using 10 strings and 29 positions per string, and relied on the required test data fields for cell number, capacity, and BITE internal resistance. The code calculated a weighted performance score for each cell by combining normalized capacity and internal resistance values, with capacity weighted more heavily at 0.9 and internal resistance weighted at 0.1. After ranking the cells from highest to lowest score, the program distributed them sequentially across all 10 strings position by position. This method helped spread higher- and lower-performing cells more evenly throughout the pack.

The final results were exported to a new Excel workbook with separate sheets showing the cell identification layout, capacity layout, and internal resistance layout, which were then used as the reference for placing each cell in its assigned location during battery assembly.

	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6
String 1	300	320	304	260	363	364
String 2	61	263	317	315	277	274
String 3	148	269	114	29	334	353
String 4	4	9	203	229	365	361
String 5	265	309	47	149	275	359
String 6	306	34	235	206	339	356
String 7	147	15	196	151	342	343
String 8	170	39	157	175	355	280
String 9	78	111	186	38	6.11	344
String 10	119	312	40	162	329	360

Table 1: Assigned Cell numbering Table

	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6
String 1	5268	5265	5264	5262	5247	5246
String 2	5206	5200	5206	5207	5208	5210
String 3	5191	5180	5192	5187	5191	5186
String 4	5186	5185	5178	5176	5176	5179
String 5	5164	5168	5176	5171	5171	5169
String 6	5159	5163	5159	5161	5168	5160
String 7	5153	5157	5153	5158	5155	5155
String 8	5150	5149	5140	5142	5154	5134
String 9	5138	5135	5133	5135	5132	5126
String 10	5125	5122	5123	5128	5115	5106

Table 2. Capacity based 10-String Layout Table 3. Internal Resistance based 10-String Layout

Methods (Battery Pack Assembly)

The pack was assembled in a 29s10p configuration using structural holders for alignment and stability. Cells were spot welded into parallel groups and then connected in series using nickel strips. Insulating Kapton tape was applied over nickel interconnects to prevent short circuits.

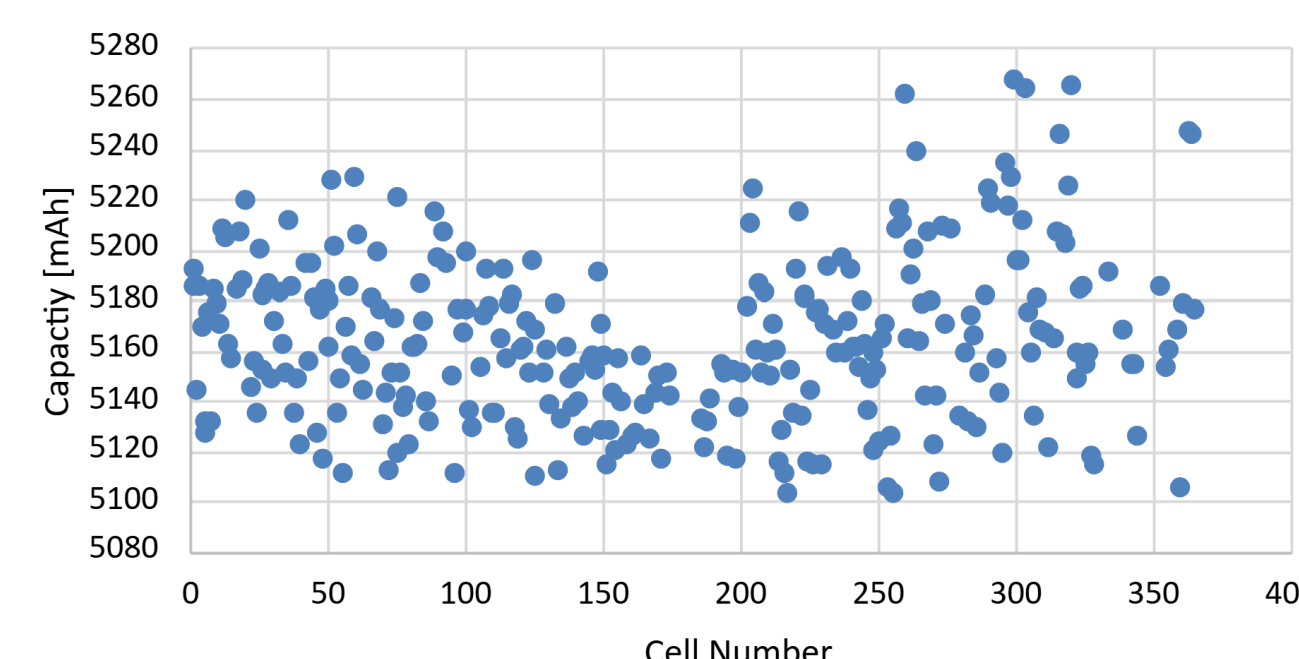


Figure 2. Capacity vs. Cell Number Graph

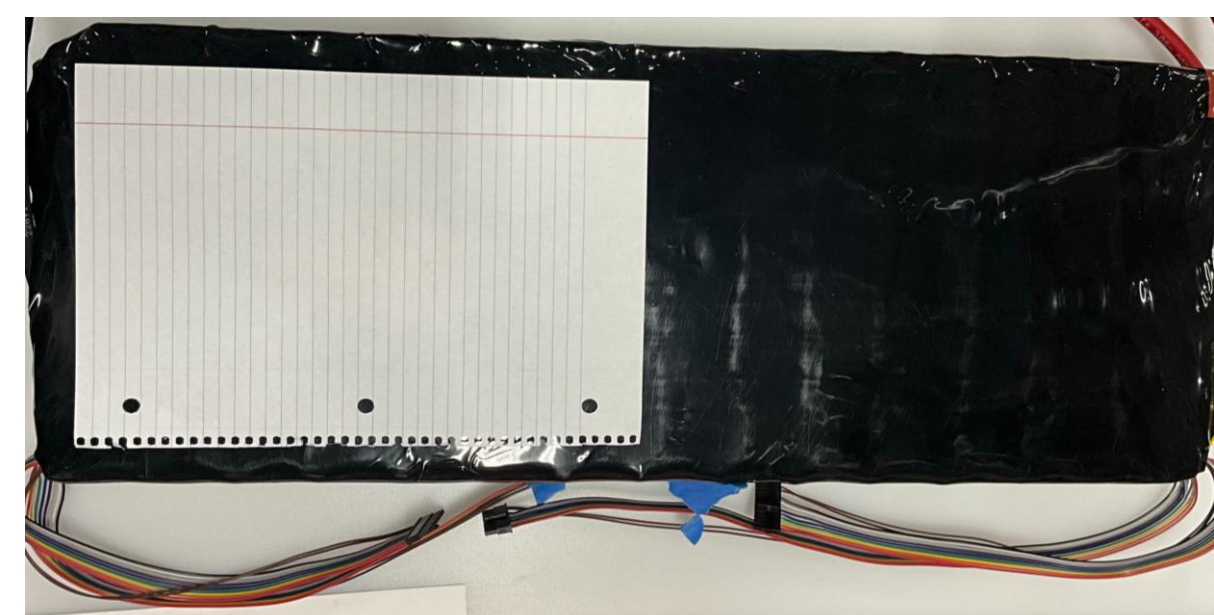


Figure 3. 29s10p Lithium-Ion Traction Battery Pack

Afterwards, nickel tabs from each parallel group were connected to an aluminum busbar, providing a low-resistance path for the main output current. Wires for the CMUs were then connected to the positive and negative busbars to enable voltage and temperature sensing. A heat shrink layer was applied to insulate the overall assembly. Finally, wires to the main contactors were bolted to the bus bar to connect the battery to the HV circuit.

Experimental Results

Because the completed battery pack was not available for full physical testing at the time of this report, performance validation was carried out through simulation. A Simulink model of the 29s10p Molicel P50B battery pack was used to generate realistic theoretical charge and discharge results for the designed 104 V nominal system. Under a constant 5 kW discharge load, the simulated pack voltage began near 121 V and decreased gradually through most of the discharge interval before dropping more sharply near the end, eventually reaching approximately 73 V. The corresponding discharge current increased from about 41 A to approximately 68–69 A as the voltage decreased, which is expected under constant-power operation since lower voltage requires higher current to maintain the same power output.

Additional simulation was performed for pack charging using a 25 A constant-current/constant-voltage (CCCV) profile. During charging, the pack voltage increased steadily during the constant-current stage and then approached a near-constant maximum value as the charge cycle transitioned into the constant-voltage region. The charging current remained at 25 A during the initial bulk-charging stage, then tapered downward toward zero as the pack approached full charge. These simulated charging and discharging responses were consistent with expected lithium-ion battery behavior and provided realistic theoretical results for the battery pack in the absence of completed physical testing.

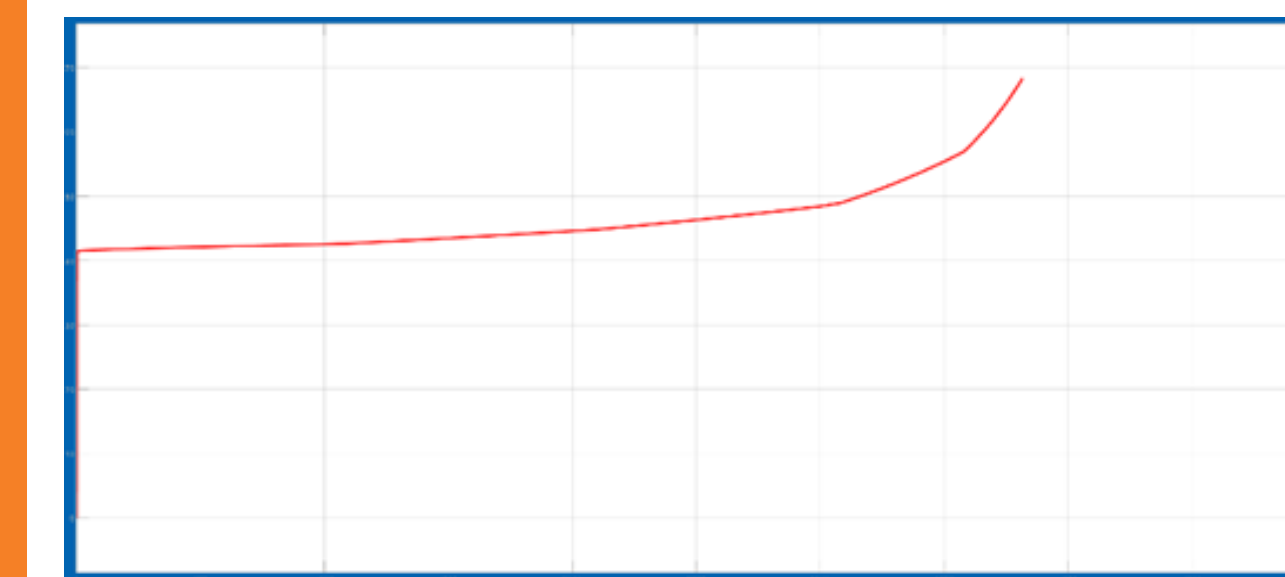


Figure 4. Discharge Current at 5kW constant

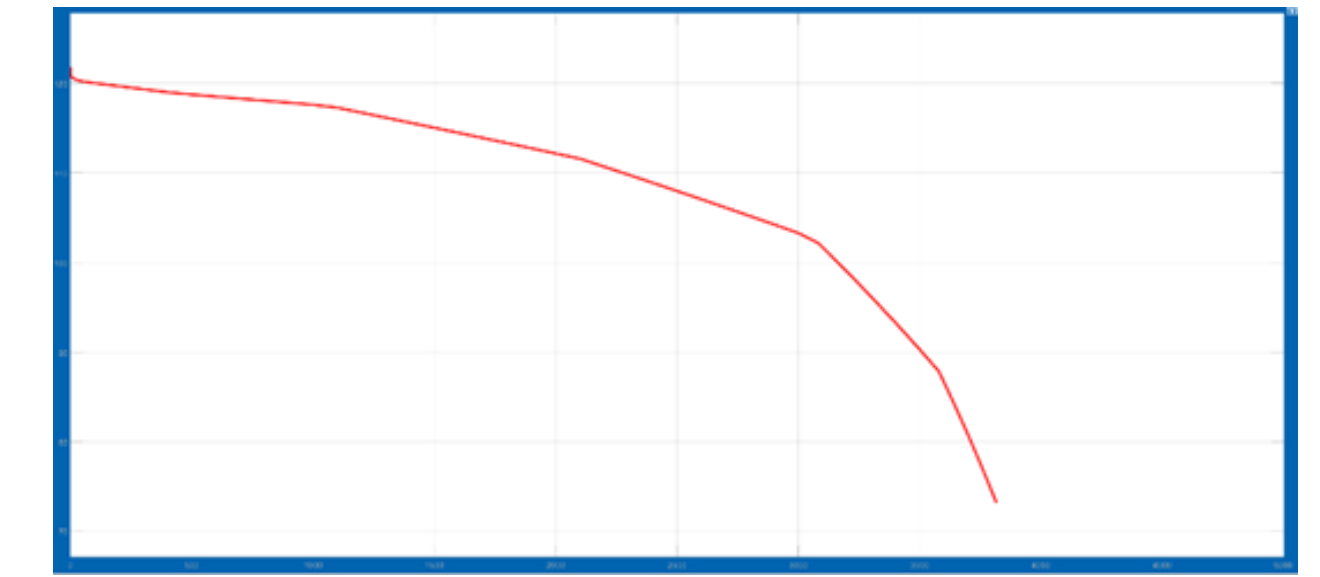


Figure 5. Discharge Voltage at 5kW constant

Summary

This project developed a lightweight 29s10p lithium-ion battery pack for the UTA Blaze Raycers solar vehicle using 290 Molicel INR-21700-P50B cells and a data-driven cell optimization process to improve pack balance before assembly. The final design produced a nominal voltage of approximately 104 V and incorporated major high-voltage safety features required for solar vehicle operation. Because full physical testing was not available during this phase, Simulink charge and discharge simulations were used to generate realistic theoretical results, which supported the feasibility of the pack design and established a baseline for future validation.

Future Direction

- Future designs aim to adopt a modular battery architecture which divides the battery pack into removable submodules with dedicated CMUs for easier fault isolation and maintenance.
- Thermal performance can also be improved by optimizing cell holder layout to enhance airflow through central areas of the modules.

References

- 1) Prohelion Pty Ltd, "Prohelion BMS D1000 Gen1," *Prohelion Documentation*, 2025. [Online]. Available: https://docs.prohelion.com/Battery_Management_Systems/Prohelion_BMS_D1000_Gen1/index.html. [Accessed: Sept. 6, 2025].
- 2) C. Boyer (2025). *Battery fabrication instructions*. [PowerPoint slides]. Available: [Battery Fabrication Instructions_Nov2025ccb.pptx](#)