Cuberg lithium metal cell technology

External performance validation – July 2022

Cuberg · combining next-generation battery technology, world-class R&D expertise and a global manufacturing capacity to enable entirely new modes of all-electric transportation.

TITLE
Cuberg cell performance validation

DATE
July 2022

northvolt | CUBERG

Lithium metal battery technology

Product overview

Cuberg is developing a novel cell technology based around pure lithium metal anode, NMC cathode and a unique non-flammable liquid electrolyte.

Compatible with existing lithium-ion manufacturing infrastructure, Cuberg's acquisition by Northvolt in 2021 creates a clear path to industrializing the technology and bringing it to market to enable electrification of new applications.

Applications

Cuberg's cell technology is well-positioned to enable the electrification of high-power demanding applications, most notably in the aviation sector.

Lithium metal technology can provide the right combination of high power and high energy required for electric aircraft take-off and landings.

Electric vertical take-off and landing (eVTOL) aircraft are flying today and hold great potential for logistics and commuting.

Validation summary

Test method

A 5.1 Ah (amp hour) cell supplied by Cuberg was tested at 25°C (ambient temperature).

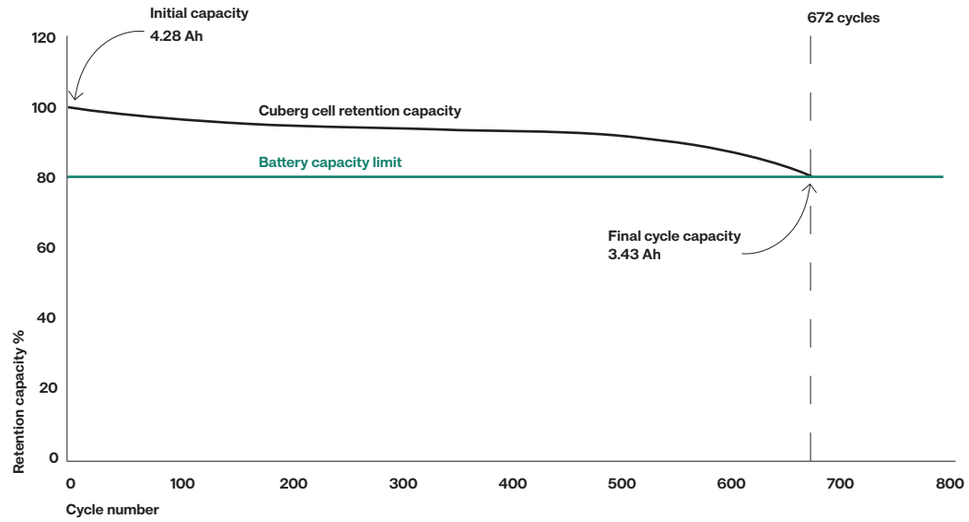
For cycle testing, the sample was cycled at rates of C/2 charge (charged in 2 hours) and 1C discharge (discharged in 1 hour) with an hour of rest in between.

Testing was terminated when the cell reached 80% of its original capacity (the commonly accepted threshold marking the end-of-life (EoL) of a battery cell).

The cell started at an initial capacity of 4.28 Ah and ended at 3.43 Ah. Each cycle starts at 4.28 V and ends at 3.0 V (full depth of discharge).

Test & validation by

MOBILE POWER SOLUTIONS



4.28 V
Max voltage (Vmax)

4.28 Ah
Initial 1C discharge capacity

15.69 Wh
Initial 1C discharge energy

3.0 V
Discharge termination voltage
voltage at which discharge ceases

3.43 Ah
Final 1C discharge capacity

12.14 Wh
Final 1C discharge energy

Results commentary

Cuberg's 5.1 Ah battery cell was charged and discharged 672 times before reaching 80% capacity* – a near-doubling in cycle-life compared to Cuberg's 2020 DOE-validated test results.

* 80% capacity is generally accepted as cell end-of-life capacity

Demonstrating a combination of long cycle life with a competitive charging rate (C/2 charging), the results represent a breakthrough in performance for lithium metal cells with liquid electrolyte in a commercially representative format*

* Multi-Ah pouch cell

The independent validation strengthens Cuberg cell technology's candidacy as the leading next-generation battery technology and one which is critical to enable the electrification of the most demanding mobility applications, including aviation, long-haul trucking and maritime transport.

Cuberg lithium metal cell profiles

METRIC	DESCRIPTION	TESTING	RESULTS – 5.1 Ah CUBERG DEMONSTRATION	RESULTS – 20 Ah CUBERG COMMERCIAL
SPECIFIC ENERGY Wh/kg	Cell level energy per unit mass. State of the art lithium-ion cell is 250-300 Wh/kg*. A higher number indicates longer flight or driving range without increasing weight.	EXTERNAL	380 Wh/kg @ C/20 [1]	-
		CUBERG	380 Wh/kg @ C/20	405 Wh/kg @C/20
CYCLE LIFE C/2 1C	Number of times a cell can be recharged until it fades to 80% of original available capacity. (C/2 1C = charged in 2 hours, discharged in 1 hour.)	EXTERNAL	672 cycles [1]	-
		CUBERG	~670 cycles	Ongoing
SAFETY Onset temperature	Temperature at which thermal runaway begins.	EXTERNAL	180°C [2]	Ongoing
		CUBERG	-	-
POWER Max continuous discharge power	Maximum power that can be delivered with entire depth of discharge per unit mass.	EXTERNAL	-	-
		CUBERG	1,700 W/kg	> 2,000 W/kg
POWER Average pulse discharge power	Average 60s power pulse delivered at mid state of charge (SoC).	EXTERNAL	-	-
		CUBERG	1,850 W/kg, 60s pulse, 50% SoC	> 2,300 W/kg
RELIABILITY Self-discharge	Testing cell chemistry's ability to tolerate various storage conditions and timeframes.	EXTERNAL	-	Ongoing
		CUBERG	< 1% self discharge per month	Ongoing

* Li et al., High-nickel layered oxide cathodes for lithium-based automotive batteries. Nature Energy 5, 26–34 (2020).

[1] Validation by Mobile Power Solutions

[2] Validation ongoing by University of Michigan

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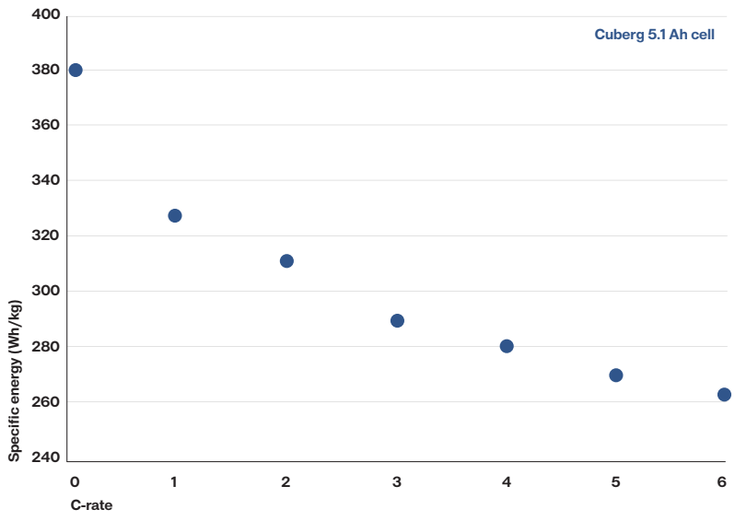
Cuberg's lithium metal power and energy combinations

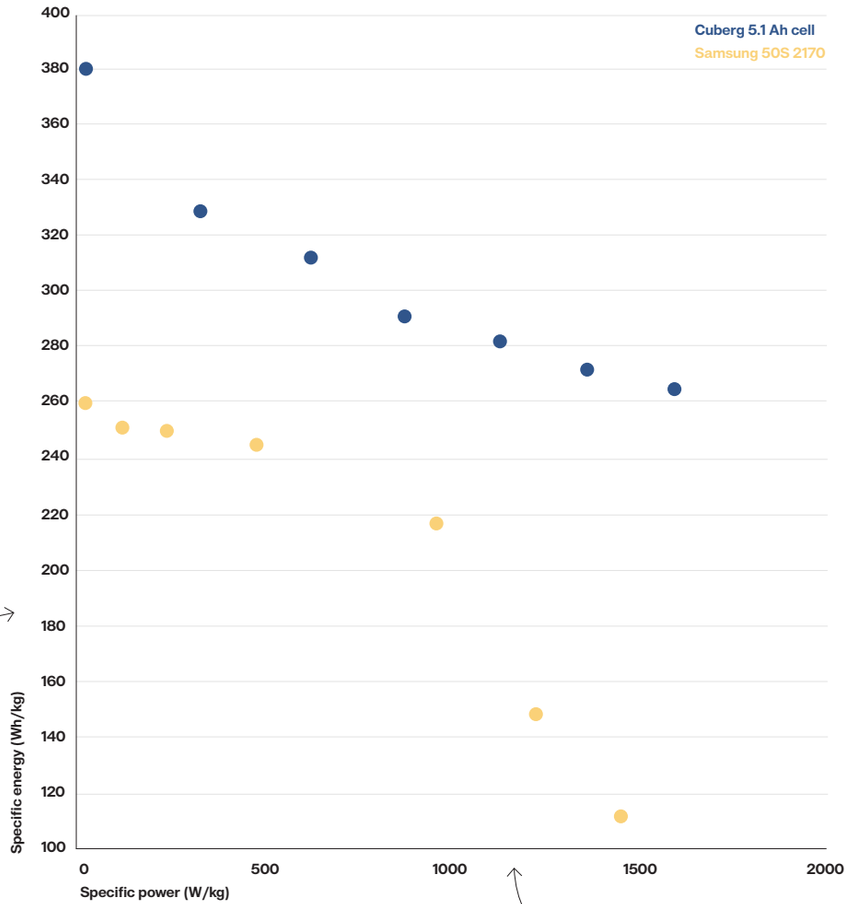
Specific energy vs. discharge rate @25°C



specific energy in Wh/kg x C-rate

= **specific power in W/kg**

Specific energy vs. specific power @25°C



Samsung 2170 cells demonstrate high-rate discharge energy limited by maximum specified operating temperature of 80°C (data via www.batemo.de).

Results commentary

At a rate of C/20 (20-hour discharge) Cuberg 5.1 Ah cells exhibit a specific energy of 380 Wh/kg. At a rate of 6C (10-minute discharge), specific energy remains above 260 Wh/kg.

The results indicate that even at ultra-high discharge rates of 10 minutes, Cuberg cells maintain relatively high energy output.

A long-standing challenge with conventional lithium-ion battery chemistry is the inherent tradeoff between energy and power.

Testing of Cuberg 5.1 Ah cells demonstrates that even with increased levels of specific power, cells are able to maintain a high specific energy – a characteristic which is critical to enable high power takeoffs and landings for electric aviation.

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Cuberg validation 2020

Initial validation

Independent third-party validation of Cuberg cells in May 2020 demonstrated the step-change cell improvements of Cuberg's novel lithium metal anode and non-flammable liquid electrolyte.

Test method

Cuberg 5.1 Ah lithium metal cells were tested at 25°C (ambient temperature).

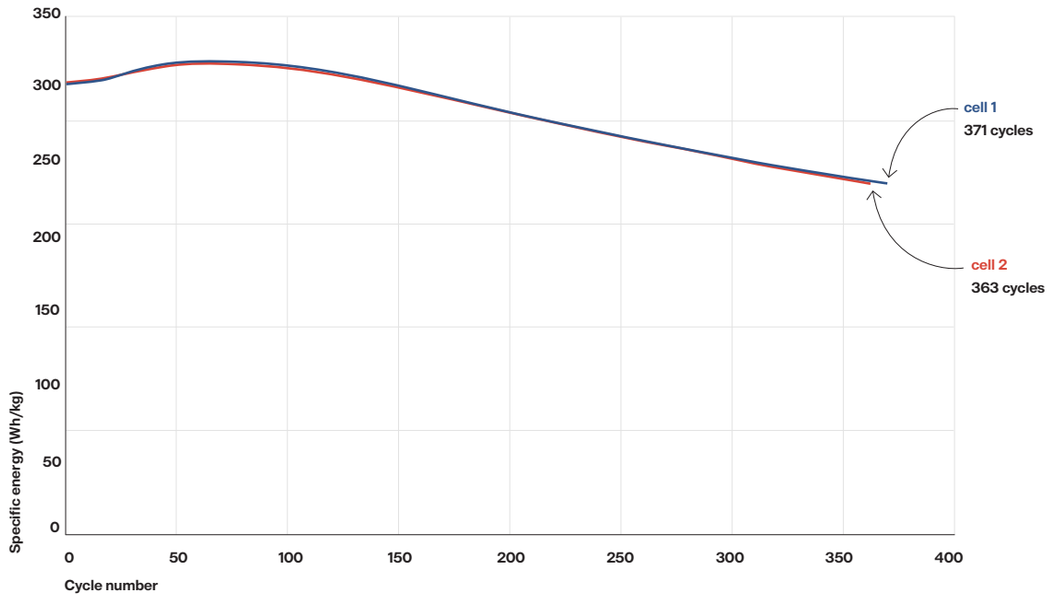
For cycle testing, sample cells were cycled at rates of C/2 charge (charged in 2 hours) and 1C discarge (discharged in 1 hour) with a 15 minute rest between each charge and discharge.

Test & validation by

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

INL Idaho National Laboratory

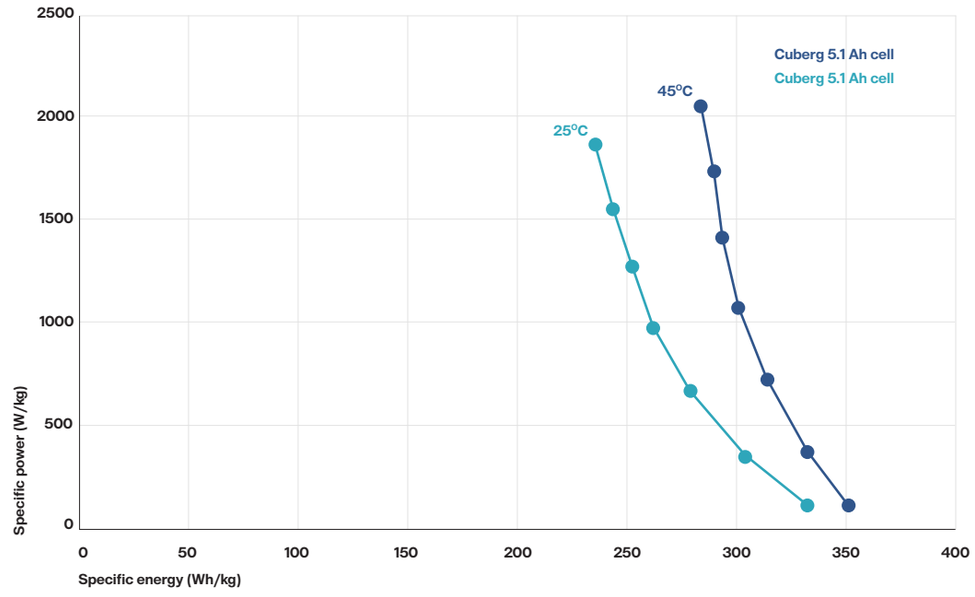
Cell cycle life test



Ragone plot

A commonly used chart in battery research illustrating the inherent tradeoff between energy and power capabilities.

Cell rate test



Results commentary

Cuberg's initial lithium metal cell was tested in 2020 and was demonstrated to exhibit greater power capabilities while retaining higher energy than conventional lithium-ion cells.

Through continued innovation, Cuberg has improved greatly upon its 2020 cell design.

Independent third-party validation of Cuberg cells published in July 2022 reports an increase from 371 to 672 cycles in a 5.1 Ah cell.

This level of cycle life is considered to be sufficient for first-generation electric aircraft.

Cuberg has also demonstrated improvements in the tradeoff between power and energy capability.

Previously, to achieve up to 1,600 W/kg continuous power, the specific energy of the cell would be around 240 Wh/kg.

The latest generation of Cuberg cells demonstrate 265 Wh/kg at higher discharge rates.

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Cuberg's competitive advantage

Customer engagements & deliveries

Cell orders

2021	2022	Total to date
2,591	1,030	3,621

Customer deliveries

2021	2022 to date	Upcoming
1,151	790	1,680

Robust safety

Safety features
Non-flammable electrolyte systems passivate lithium metal surface and shorten thermal runaway profile.

Prevents dendrites with proprietary liquid electrolyte.

Using robust safety testing to validate
Accelerated Rate Calorimetry (ARC)

UN 38.3 testing (short circuit, nail penetration, overcharge, etc.)

DO-311A testing (cell to cell thermal propagation for aviation module safety)

IEC-62133 (safety standards for lithium batteries entering global markets)

Manufacturability

Manufacturability
Drop-in replacement with Li-ion manufacturing using standard liquid electrolyte systems.

Benefits
Pilot lines and equipment fully integrated with mature lithium-ion industry processes.

Electrolyte mixing, sealing, filling, cell assembly, and cell finishing (soaking, formation) processes use similar factory design to lithium-ion battery cells.

Leveraging expertise from Cuberg's parent company Northvolt enables rapid scale-up without major redesign of equipment and tooling, which is typically required for other next-generation battery technologies

Contact Cuberg

Please reach out to us via press@cuberg.net

Or learn more about us at www.cuberg.net