UNDPATE ON RECHARGEABLE LITHIUM BATTERY DEVELOPMENT FOR SURVIVING THE LUNAR NIGHT. B. J. Elliott[1 *], V. T. Nguyen[1] Rhia Martin[1], and J. Reinicke[1], [1]TDA Research, Inc. 4663 Table Mountain Drive, Golden, CO, 80402. * belliott@tda.com

Introduction: Future science missions to the Lunar surface will require hardware, electronics and energy storage systems that can tolerate the extremely low temperatures of the lunar night. Some missions will require continuous operation throughout the night and others will only need to tolerate it and wake up and operate at the next lunar dawn. Mission near the poles may only receive marginal heating from the sun due to shadows and the low sun angle, so they may experience low temperatures even during the day.

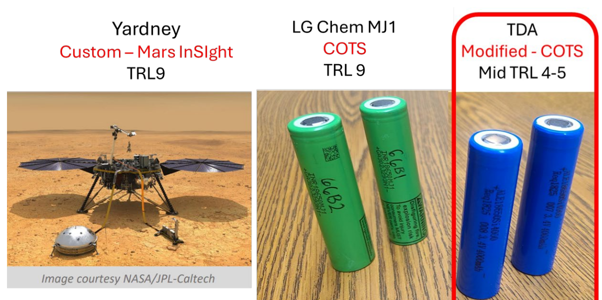
The temperatures expected (about -180 °C at night, lower in craters) dictate that batteries and electronics currently must be housed in temperature regulated chambers kept between 0 °C and +40 °C, because this is where lithium-ion cells have adequate performance. In polar regions, the internal temperature of small rovers and surface-located science instruments may only be maintained at -60 °C (even during the day) to minimize the size and power consumption of thermal management systems. To meet these requirements battery cells are needed that can operate and cycle below 0 °C and preferably down to -60 °C.

Commercial-off-the-shelf (COTS) lithium rechargeable cells are simply not designed for these temperature ranges and require heating to stay above 0 °C to survive the lunar night. This heating consumes energy stored in the batteries themselves and reduces or eliminates any remaining power for other instruments during the night. However, COTS cells have been shown to survive hibernating to these low temperatures (not operating but freezing and shutting down) and then working again once they warm back up, but they do not provide usable discharge energy when the cells are at or below -40 °C, and they also don't charge well below 0 °C.

The low temperature performance of existing COTS lithium batteries is limited by several factors: (1) the conductivity of the electrolyte; (2) the resistance of the solid electrolyte interface or the cathode electrolyte interface; and (3) the charge transfer resistance of these interphases. Advances have been made in liquid electrolytes capable of cycling high energy density anode-cathode combinations down to -80 °C, however improvements in discharge capacity retention at extreme low temperatures (-40 °C to -60 °C) are still needed.

TDA's Development of low temperature battery cells: TDA Research and our partners are developing and testing low temperature 18650 lithium-ion rechargeable battery cells for the unique needs of operating in the lunar night. Our approach combines recent advances in low temperature electrolytes, high energy density anodes and cathodes and a new charge-transfer assisting interfacial layer. We are modifying the chemistry of COTS cells to facilitate rapid development and a more stable supply chain compared to fully custom cells. The interfacial layer in our modified COTS cells reduces internal charge transfer resistances, especially from -40 to -60 °C. We are developing these battery cells in an 18650 format for use in low temperature vacuum (i.e. lunar surface or high-altitude stratosphere). We have produced and tested both 18650 cells and 2P4S CubeSat modules (with eight 18650 cells / 16.4 to 10.0 Volts).

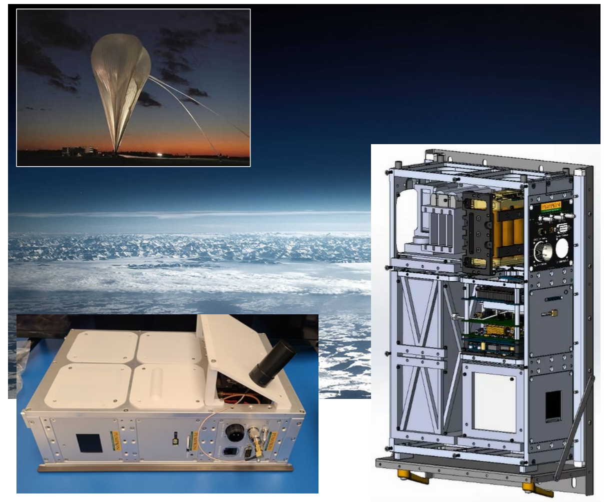
These new 18650 cells, with our new chemistry, have a specific energy of 290 Wh/kg at +20 °C, 182 Wh/kg at -40 °C, 137 Wh/kg at -60 °C (all when first charged at RT and the discharged at C/10 discharge rate). However, with a C/48 charge we were able to cycle these cells at -60 °C and obtain 98 Wh/kg (i.e. slow cycling at -60 °C consistent with lunar polar usage). Below is a comparison on our new modified COTS 18650 cells to a full COTS cell (LG Chem MJ1) and a heritage custom-made cell used for the Mars InSight mission.



	Yardney Mars InSight ϕ	LG Chem MJ1	TDA
+60 °C		273 Wh/kg	289 Wh/kg
+40 °C		272 Wh/kg	290 Wh/kg
+22 °C	ϕ 273 Wh/kg	265 Wh/kg	289 Wh/kg
-40 °C	ϕ 100 Wh/kg	2 Wh/kg	182 Wh/kg
-60 °C *discharge to 2 V	ϕ 78 Wh/kg	0 Wh/kg	137 Wh/kg

The best performing low temperature batteries used on a planetary mission to date is the Yardney battery, which was custom developed for the Mars InSight lander. These cells were designed to cycle and operate down to -30 °C, and also were demonstrated to have 78 Wh/kg at -60 °C (when first charged at RT). More recently, NASA has pivoted away from custom battery cells to using COTS cells for a more sustainable / predictable supply chain and lower costs. NASA JSC maintains a battery strategic reserve of pre-screen COTS 18650 cells; however, the low cost and high availability of COTS cells comes with the limitation that COTS cells require careful thermal control in spacecraft, lunar landers, and rovers. Our approach is a compromise between COTS and fully custom produced battery cells. We are modifying existing COTS cells and tailoring their chemistry to meet the low temperature needs of small rovers and experiments that have limited thermal management while on the lunar surface and operating at night. This approach combines the benefits of having stable, scalable COTS cell production with the benefit of custom modification for specific temperature ranges. Using recent advances in commercial anode and cathode production we also exceeded the prior specific energy of the last custom-made planetary science cells with our modified-COTS cells producing 137 Wh/kg vs. 78 Wh/kg at -60 °C.

Stratosphere testing: We are designing, building and will fly a 6U CubeSat payload to test these 18650 cells on a zero-pressure balloon reaching the stratosphere. We are targeting 60,000 feet to maximize cooling passing through the tropopause on ascent and then reaching a cruising altitude with about 50 mbar pressure or lower to simulate operating in vacuum. The test will emulate extreme low temperature testing and near-vacuum as a low-cost surrogate for the lunar surface. The payload will contain our 18650 cells adapted to a commercial flight-qualitied satellite battery module housing (a 2P4S battery). The payload will also demonstrate this 2P4S battery operating with a flight-qualified CubeSat power module and on-board-computer (used on prior CubeSat missions by NASA and others). The system will contain altitude tracking, have air-to-ground telemetry and ground-to-air change command ability via an iridium satellite link. The basic structure of the 6U CubeSat is shown in the next image. The top is open to the air on ascent to cool the battery cells, while the bottom 4 U's are closed to maintain heat around the on-board computer and avionics.



Further collaborations: We are working with lunar asset providers to test these low temperature cells in both the laboratory and in space environments. We invite further collaborations for technology demonstrations of our 18650 cells or 2P4S battery modules in the laboratory, stratosphere, low earth orbit or on the lunar surface.

Status: SBIR Phase II project in progress. 3.7 Volt (4.2 to 2.7 Volt) 18650 cells are in production. Prototype 2S4P CubeSat battery modules are in production. Seeking input from lunar surface instrument and hardware providers on future low temperature battery performance needs and targets.

Acknowledgments:

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References:

[1] US Pat. No. 7,931,824
[2] Additional patents pending
[3] Spacecraft Lithium-Ion Battery Power Systems, Thomas P. Barrera, 2023