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Silicon Fast Charge Cells: Evaluation of Forge Nano’s Small Business Technology Transfer (STTR) 24B Deliverables

by Jeffrey A. Read

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14. ABSTRACT
This technical note covers the performance evaluation of cell deliverables under Small Business Technology Transfer (STTR) 24B, Topic ARL-ARO-24B-007, produced by Forge Nano and Argonne National Laboratory in Phase I of the effort. The goal of this topic is to develop cell technology that can be fast charged using silicon (Si)-dominant anodes. In the Phase I effort, the goal is to demonstrate single-/few-layer Si anode full cells, that when fast charged at 10C (6-min) rates and discharged at 3C, cycle for more than 1000 continuous cycles to 80%. These cells should support the development of multi–ampere hour cells with a specific energy greater than 200 Wh/kg. Deliverables were 10 full cells of more than 100-mAh capacity capable of 10C charge/3C discharge.

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1. Goals and Deliverables

The goals and deliverables for the Small Business Technology Transfer (STTR) 24B topic ARL-ARO-24B-007[1] are outlined in this section. The primary goal was to develop cell technology to achieve fast-charge capability using silicon (Si)-dominant anodes.

1.1 Phase I

Phase I demonstrates single-/few-layer Si-anode full cells that when fast charged at 10C (6-min) rates, cycle for more than 1000 continuous cycles at 3C discharge to greater than 80% capacity. These cells should support the development of multi–ampere hour (Ah) cells with a specific energy of greater than 200 Wh/kg. Deliverables should include 10 full cells of more than 100-mAh capacity capable of 10C charge/3C discharge and greater than 1000 cycles to more than 80% capacity.

1.2 Phase II

Phase II produces cells in sufficient quantities to fully characterize them for rate, temperature performance, and continuous cycling stability. Deliverables include 20 full cells at a rated capacity of more than 2-Ah capable of 10C/3C charge–discharge cycling at an energy density of greater than 200 Wh/kg at the 10C charge rate.

1.3 Forge Nano's Pouch Cell Deliverables

Forge Nano's roll-to-roll prototyping equipment was used to prepare double-sided anodes and cathodes for the cell build. Cathodes and anodes were punched (5.8×6.8 cm = 39.4 cm², and 6.0×7.0 cm = 42 cm², respectively), calendered, and an automated cell stacker was used (z-type separator winding) to form cell stacks with four cathode and five anode electrodes. Tabs were attached by ultrasonic welding; stacks were sealed into pouch cups and vacuum-dried overnight. Electrolyte was filled in an argon-atmosphere glove box and the pouch was sealed, formed, de-gassed, and trimmed. Figure 1 shows a diagram of the completed cell.

1.3.1 Forge Nano's Provided Cell Data

- Nominal capacity: 761 mAh
- Maximum-charge voltage: 4.2 V
- Minimum-discharge voltage: 2.0 V
- Current cutoff at charge: 38 mA
- Direct current internal resistance (DCIR): 53–83 mΩ

1.3.2 U.S. Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) Cell Data Measured

- Dimensions: 74 (W) × 89 (H) × 1.27 mm (T)
- Mass: 14.56 g received, 13.80 g trimmed
- Open circuit voltage (OCV): 3.27 V

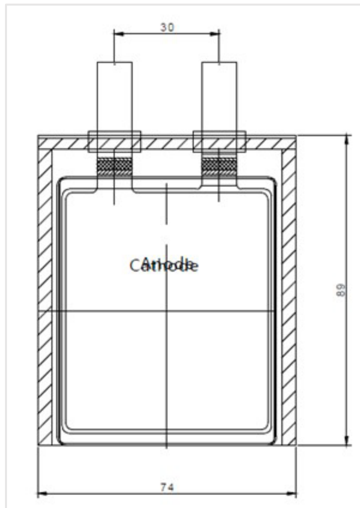


Figure 1. Engineering diagram with expected pouch dimensions produced and nominal cell data.

2. Cells Received and Test Protocols

We received eight cells on 01/06/2026 and two cells on 02/05/2026. See Table 1 for formation data. Cell numbers 25P0163 and 25P0168 from the first lot were not shipped due to low formation capacity (see red text in Table 1). These cells were replaced in a subsequent build with 26P0007 and 26P0008, respectively, shipped as replacements.

Table 1. Formation data from Lot 1 with the following conditions: 2.0–4.2 V; C/10 Ch/Dch current with C/20 limit at 4.2 V; 30 °C. After formation, cells were partially charged to the shipping voltage of 3.4 V, returned to a glove box, degassed, and resealed.

Cell	Ch Cap (mAh)	Dch Cap (mAh)	Coulombic efficiency (%)	DCIR at shipping (mΩ)
25P0163	832.3	663.0	79.7	188
25P0164	874.0	756.8	86.6	71
25P0165	880.9	770.3	87.4	53
25P0166	876.6	760.4	86.7	76
25P0167	880.4	766.4	87.1	64
25P0168	653.1	558.5	85.5	73
25P0169	876.7	759.0	86.6	83
25P0170	875.8	763.2	87.1	58
25P0171	868.6	754.8	86.9	62
25P0172	874.3	760.7	87.0	60

Cells were placed in a 9 °C refrigerator upon receipt and kept there until tests could be carried out. Cells were placed in compression fixtures with a stack pressure of 26 psi; three fixtures were available for test. Impedance and OCV values were recorded after cells were placed in fixtures on a Biologic potentiostat and cells were cycled on MACCOR battery test systems. A baseline test procedure was conducted at 25 °C using the Naval Research Laboratory's 6170/MR-2022/8 manual.[2] The reference performance tests (RPTs) in the manual specify the following:

- Three cycles at C/3
- One cycle at C/20
- One cycle using a hybrid pulse power characterization (HPPC) protocol

All tests were designed using the specified capacities and charge parameters provided by the cell manufacturer. After all cells were tested using the RPTs, cells were selected for power curve (PC) testing at 25 °C. These tests are designed to characterize the cells for charge and discharge power metrics, as follows:

- Charge at C/3; discharge at C/10, C/5, C/2, 1C, 2C, 4C, 6C
- Charge at C/3, C/2, 1C, 2C. 3C, 4C, 6C, cut on time; discharge at C/3

Cells were further selected for long-term cycling (LTC) at the charge rates of interest. The goals of this STTR topic were to develop cell technology that is capable of repeated fast charge with high cycle life. The LTC carried out was designed around this goal, as follows:

- 6C charge (10-min time limit)/3C discharge (25 °C)
- 10C charge (6-min time limit)/3C discharge (21–25 °C ambient)

3. Results

Cells were placed in fixtures as shown in Figure 2 with compression provided by two aluminum plates with rubber sheets between the cell and the plates on both sides. The plates were compressed using four bolts with hex nuts torqued to 32 in-oz (2 in-lb). A stack pressure of 26 psi was calculated from Equations 1 and 2. All testing was carried out with fixtured cells.

$$P = F/A \tag{1}$$

where P (pressure), A (stack area ~39.4 cm^2), and F (force).

$$F = 4 * T/(c*D) \tag{2}$$

The four-bolt clamping force where T (torque), c (coefficient of friction ~0.2 for stainless steel), and D is the bolt diameter (0.25 inch).

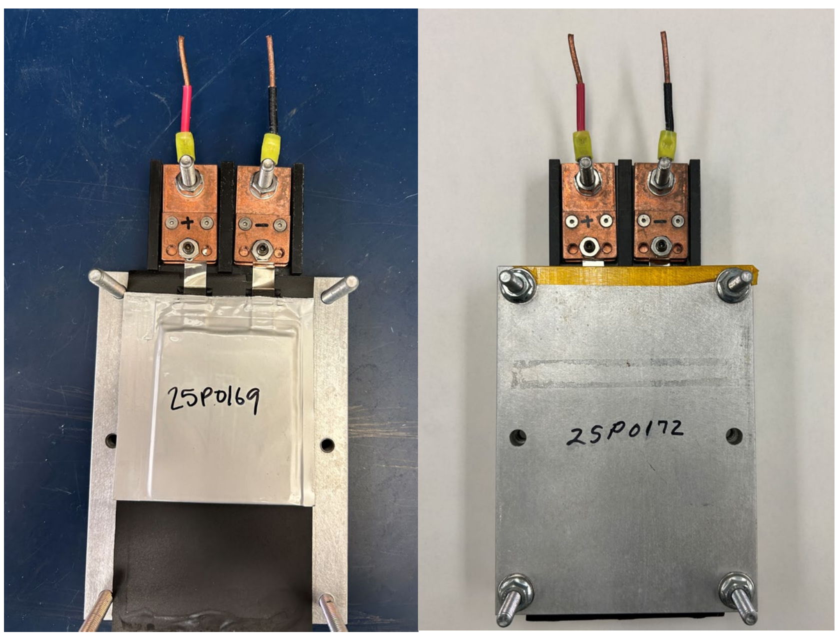


Figure 2. Cells in fixtures with tabs clamped in copper blocks for proper contact.

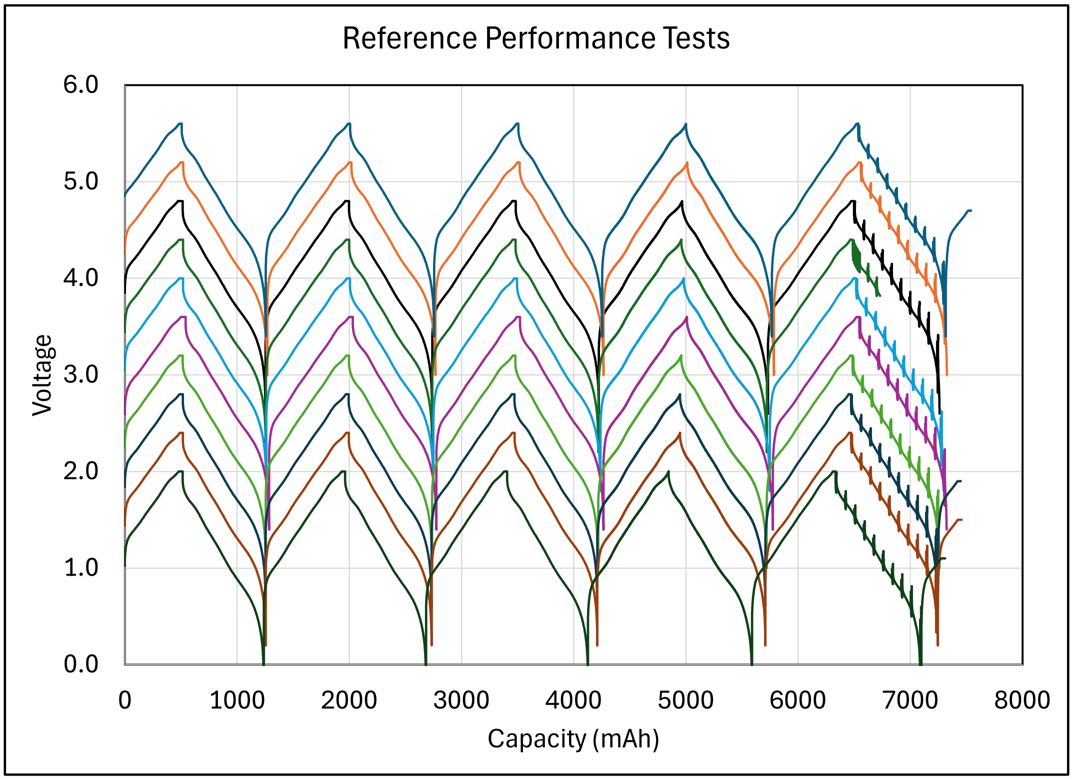
Table 2 shows the as-received cell impedances at 1 Hz ranged from 136 to 185 mΩ before the RPTs, significantly higher than the DCIR values of 58–76 mΩ reported in Table 1. Cells were left discharged posttest or were charged to 3.3 V depending on the routine used. Impedance growth or decline was not consistent from cell to cell but remained low except for cell 25P0170, which immediately failed on the LTC 10C charge, 3C discharge test. The reason for the failure appeared to be dendrite shorting on high-rate charge.

Table 2. Impedance data pre- and posttest.

Cell	Fresh		Post RPT		Posttest		
	OCV	Z' (mΩ)	OCV	Z' (mΩ)	OCV	Z' (mΩ)	Test
25P0164	3.268	NR	2.876	246	NT	NT	NT
25P0165	3.271	NR	2.881	213	NT	NT	NT
25P0166	3.265	NR	3.681	100	3.255	320	LTC10/3
25P0167	3.263	152	3.209	160	3.253	132	LTC10/3
25P0169	3.215	185	2.814	183	3.219	209	LTC10/3
25P0170	3.263	137	2.819	166	3.142	3730	LTC10/3
25P0171	3.258	141	3.235	112	3.020	71	PC and LTC6/3
25P0172	3.258	136	3.235	106	3.013	70	PC and LTC6/3
26P0007	3.251	161	3.227	126	NT	NT	NT
26P0008	3.159	166	3.220	195	NT	NT	NT

NR = not recorded, NT = not tested.

Figure 3 shows the voltage curves for the RPTs on the 10 cells tested. Cell 25P0166 failed to complete the HPPC cycle due to a test error. Only P260007 appeared as an outlier in the RPT. Specific energy calculated from cell weight was 175–180 Wh/kg at C/3 and 184–186 Wh/kg at C/20. HPPC testing showed comparable performance to C/3 rates with more spread in performance.



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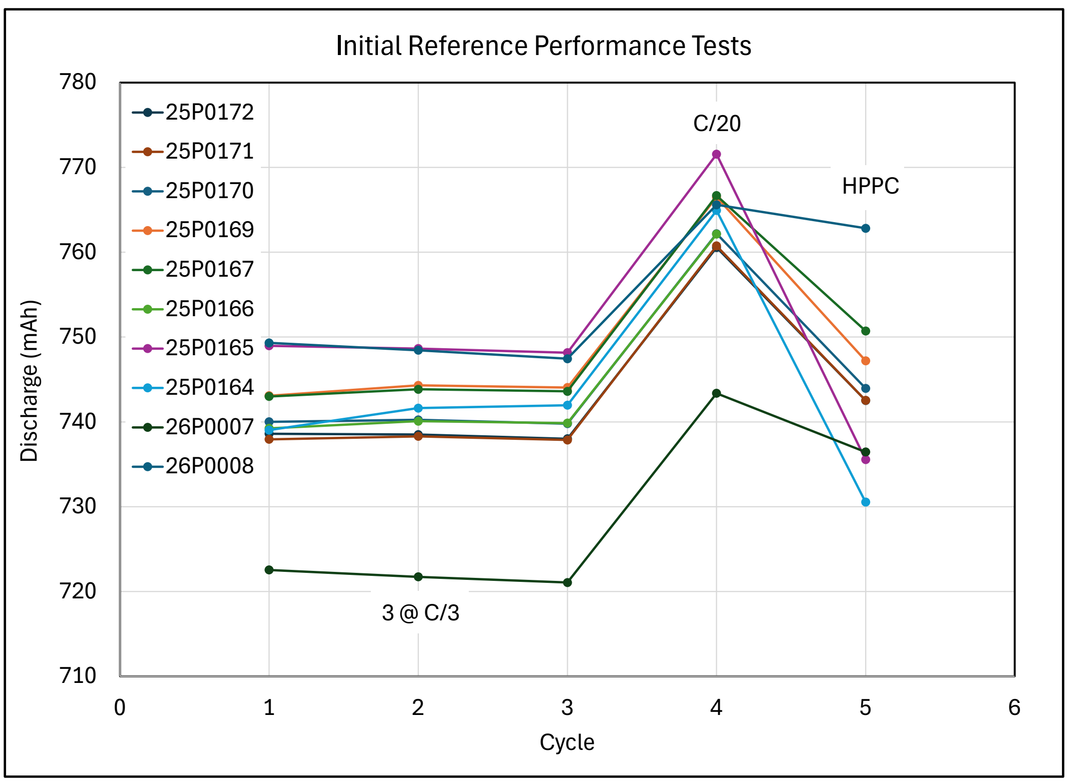
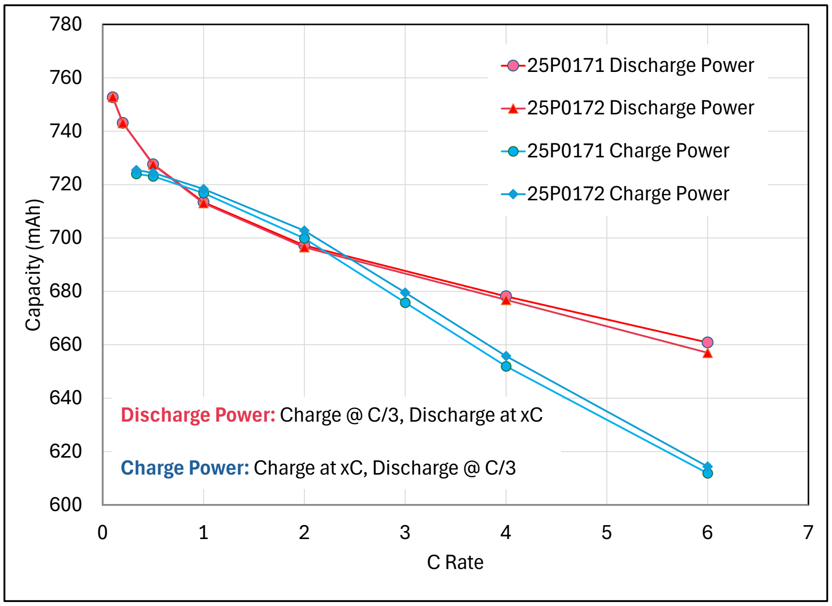


(b)

Figure 3. (a) Voltage vs. capacity profiles and (b) capacity vs. cycle for RPTs.

Figure 4 shows the power curve data for two cells during charge and discharge. The data shows good cell-to-cell consistency with discharge power being better at higher rates than charge power. Part of this could be the fact that charge was cut on time so that a full charge cannot be achieved at higher rates. Specific energy is less than the 200 Wh/kg desired at all rates but is expected to reach higher values for 2- to 3-Ah cells. The drop-off in specific energy from C/2 to 6C indicates that the cell design is not optimized for high-rate applications. This would have to be addressed in scaled-up designs.



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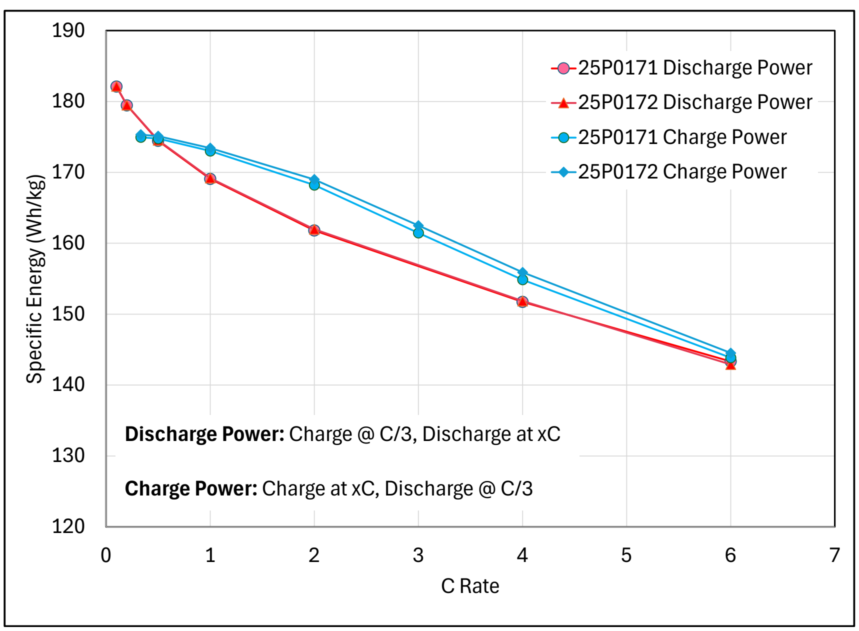

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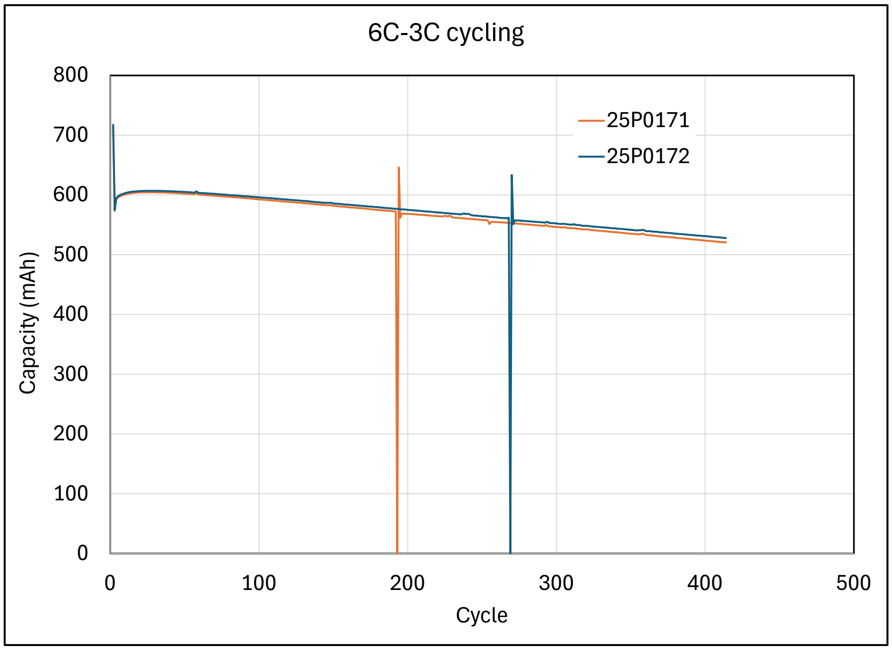
Figure 4. (a) Power curves capacity vs. C-rate and (b) specific energy vs. C-rate.

Figures 5 and 6 demonstrate that long-term, high-rate cycling is possible at both 6C and 10C charge rates with Si-dominant anode cells. The goal of 1000 cycles to 80% capacity was not achieved at either 6C or 10C charge rates, with only 500 cycles being within reach. The fade rates appeared to be constant after 300 cycles, leading to a graceful failure condition. The 10C/3C cells showed fluctuations due to the variations in room temperature (21–25 °C) as these were cycled in ambient conditions.



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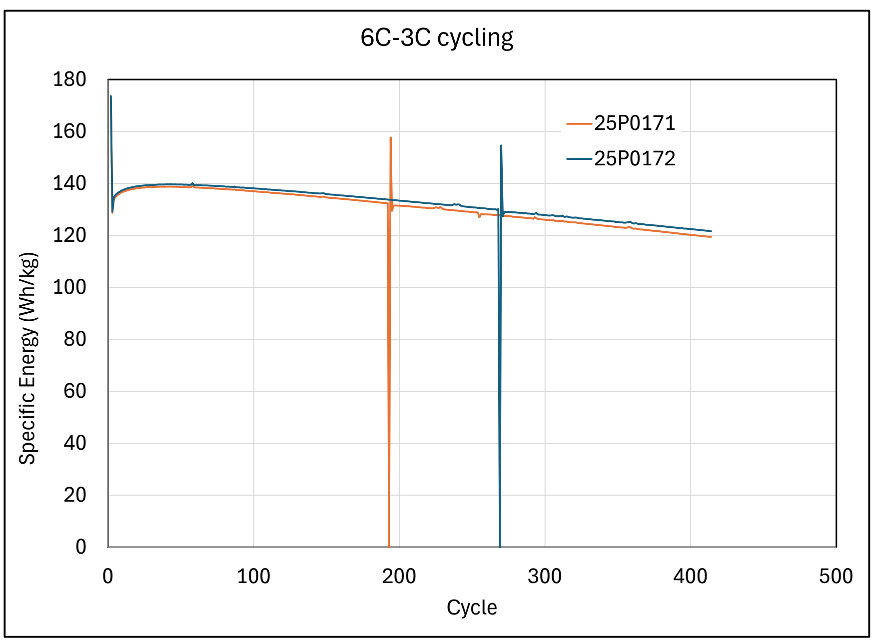

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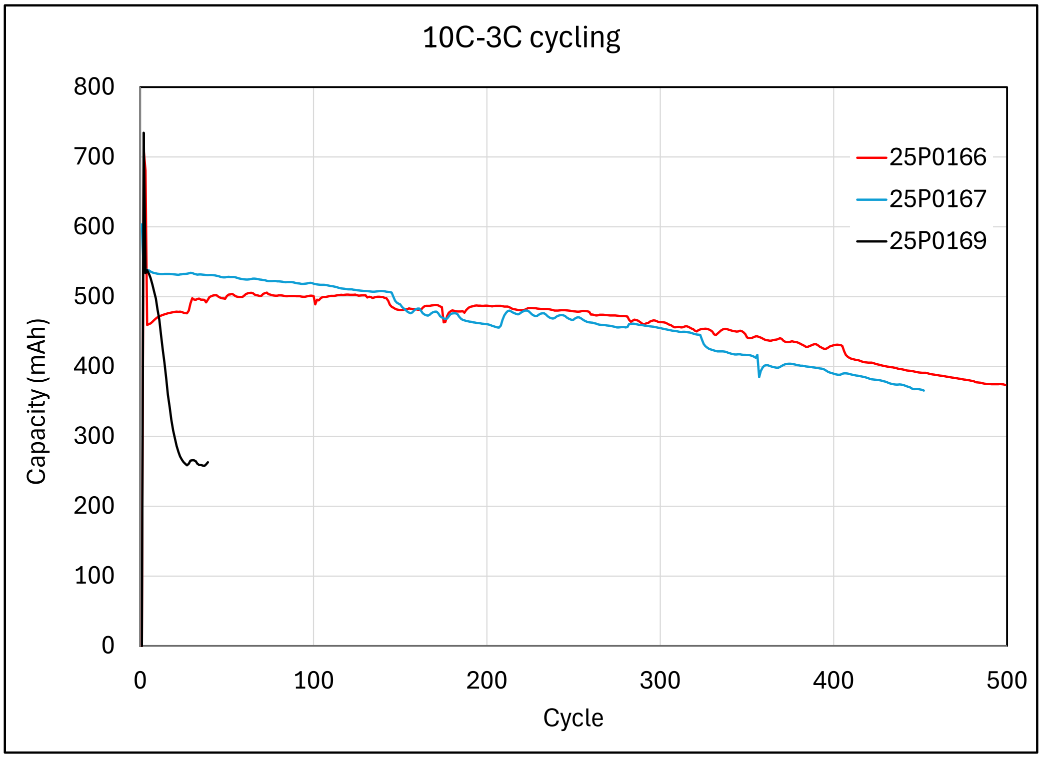
Figure 5. (a) Capacity and (b) specific energy vs. cycle at 6C charge/3C discharge.



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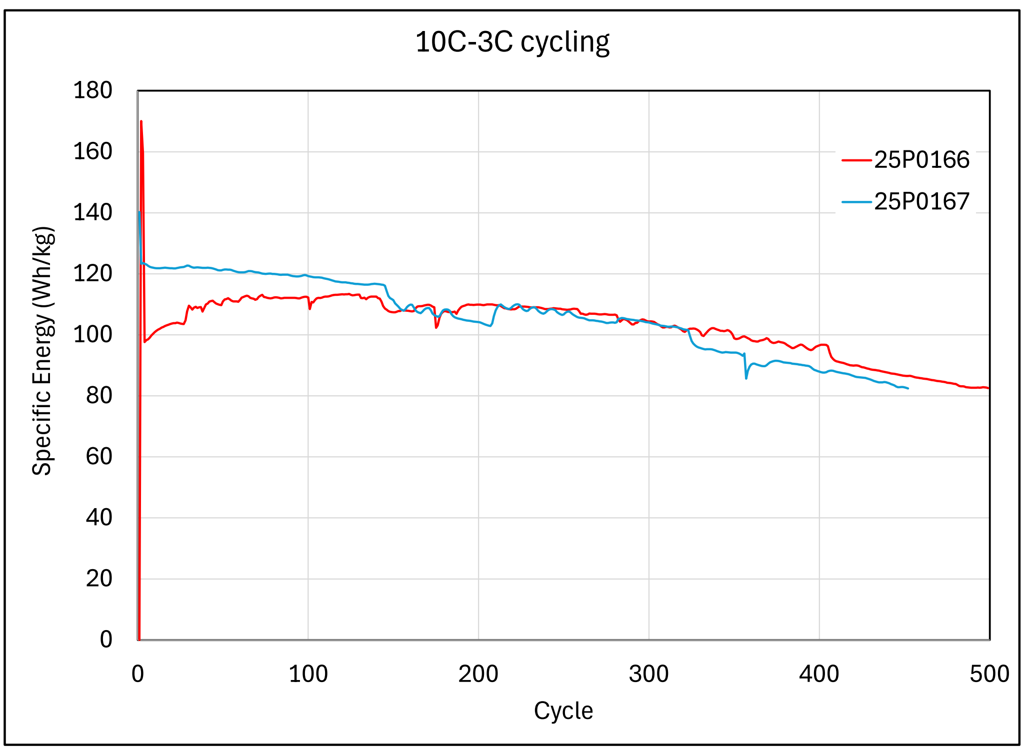

(b)

Figure 6. (a) Capacity and (b) specific energy vs. cycle at 10C charge/3C discharge.

4. Conclusions

Forge Nano's Si-dominant cells demonstrated the capability to fast charge at both 6C and 10C with moderate cycle life, achieving approximately 400–500 cycles to 80% capacity. The cell design resulted in a 15% drop in charge capacity and a 20% drop in specific energy at 6C charge rates as compared with C/2. This drop in energy would need to be addressed in any future cell design. The specific energy during 10C/3C cycling was at best 110–120 Wh/kg, not near the desired 200 Wh/kg; therefore, it is unclear whether a Si-dominant anode cell with these components could achieve the Phase I topic's metrics even in a larger Ah cell.

5. References

1. Fast charge silicon anode lithium-ion cells for small UAS systems. US Army SBIR/STIR; 2026 July 28. https://armysbir.army.mil/topics/fast-charge-silicon-anode-lithium-ion-cells-small-uas-systems/

2. Love CT, Haymen D. Battery test manual for baselining and benchmarking pre-commercial cells. Naval Research Laboratory (US); 2022 Oct. Navy Regulation No.: 6170/MR-2022/8.

List of Symbols, Abbreviations, and Acronyms

Ah	Ampere Hour
ARL	Army Research Laboratory
DCIR	Direct Current Internal Resistance
DEVCOM	U.S. Army Combat Capabilities Development Command
HPPC	Hybrid Pulse Power Characterization
LTC	Long-Term Cycling
NR	Not Recorded
NT	Not Tested
OCV	Open Circuit Voltage
PC	Power Curve
RPT	Reference Performance Test
Si	Silicon
STTR	Small Business Technology Transfer

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