Project Title

Silicon-Nanowire Based Lithium Ion Batteries for Vehicles With Double the Energy Density

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Executive Summary

Amprius researched and developed silicon nanowire anodes. Amprius then built and delivered high-energy lithium-ion cells that met the project's specific energy goal and exceeded the project's energy density goal. But Amprius' cells did not meet the project's cycle life goal, suggesting additional manufacturing process development is required.

With DOE support, Amprius developed a new anode material, silicon, and a new anode structure, nanowire.

- Amprius transitioned from building *small*, *single-layer* anodes to producing *larger*, *double-sided, multilayer* anodes, enabling Amprius to progress from stamp cells with low capacities to larger cells with >2Ah capacities.

- Amprius transitioned from building anodes with *low* silicon mass loading on *thick* substrates to producing anodes with *higher* silicon mass loading on *thin* substrates, enabling Amprius to increase cell energy from 200 Wh/kg and 520 Wh/L to 330 Wh/kg and 791 Wh/L.

During the project, Amprius also began to develop a new multi-step manufacturing process that does not involve traditional anode production processes (e.g. mixing, drying and calendaring).

- Amprius transitioned from a single-step process involving only thermal Chemical Vapor Deposition [CVD] to a multi-step process requiring both thermal CVD and plasma-enhanced CVD, enabling Amprius to extend cell cycle life from 180 cycles to 300-500 cycles.

	Before DOE Project	Budget Period I	Budget Period II	Budget Period III
Anode Size	Exclusively ~529 mm^2	Mostly ~529 mm^2	Overwhelmingly ~2400 mm^2	Overwhelmingly ~2400 mm^2
Anode Side(s)	Exclusively Single-Sided	Mostly Single-Sided	Overwhelmingly Double-Sided	Overwhelmingly Double-Sided
Anode Substrate Thickness	Exclusively 75 µm	Mostly 75 µm Some 15 µm	No 75 µm Some 10 µm Overwhelmingly 15 µm	Exclusively 10 µm
Cathode Areal Loading	Exclusively Lower	Mixed, Mostly Lower	Mostly Higher	Higher
Cell Layers	Exclusively Single-Layer	Overwhelmingly Single-Layer	Split Between Single-Layer and Multilayer	Overwhelmingly Multilayer
Manufacturing Process	Thermal CVD	Thermal CVD	Thermal CVD and PE-CVD	Thermal CVD and PE-CVD

Table 1 – DOE support enabled Amprius to improve both anode structure and manufacturing

Amprius' research added to understanding of the area investigated. Amprius' work advanced understanding of a silicon nanowire anode structure that enables both high energy and long cycle life. Amprius' research also advanced understanding of a new production process for silicon nanowire anodes.

The methods and techniques Amprius investigated are technically effective and economically feasible. Amprius' development effort enabled the company to produce high-energy and long life silicon nanowire-based cells. Amprius' cost model suggests that volume manufacturing will enable production of silicon nanowire anodes at or below the per kilowatt-hour cost of premium graphite anodes.

Amprius' project benefited the public. DOE support accelerated Amprius' progress with silicon nanowire-based cells, facilitating the development and production of high-energy and low-cost batteries that will accelerate vehicle electrification, reducing America's dependence on foreign oil and greenhouse gas emissions.

Accomplishments vs. Goals and Objectives

Amprius delivered 24 end-of-project cells to Idaho National Laboratory [INL]. The cells' average specific energy, 330 Wh/kg, met the project's goal, 330 Wh/kg. The cells' average energy density, 791 Wh/L, far exceeded the project's goal, 680 Wh/L.

Amprius tested end-of-project cells similar to those Amprius had shipped to INL. Amprius' end-of-project cycle life, >300 cycles, did not meet the project's goal, ≥750 cycles. (In Year 2, Amprius achieved >500 cycles. In Year 3, a new electrolyte improved high temperature performance, but at the expense of cycle life). Amprius did demonstrate more than 700 cycles in a single-layer cell, but could not replicate its results in a multi-layer cell – suggesting additional process development is required to achieve the long cycle life required for EV applications.

	Year 2 Project Goal	**Year 2 Amprius Cells***	**Year 3 Project Goal**	**Year 3 Amprius Cells****
Capacity	2 – 2.2 Ah	2.36 Ah	2.2 – 2.4 Ah	2.66 Ah
Wh/kg	250 Wh/kg	271 Wh/kg	330 Wh/kg	330 Wh/kg
Wh/L	580 Wh/L	646 Wh/L	680 Wh/L	791 Wh/L
Cycle Life (to 80% of Initial Capacity)	>300	>500	>750	>300
	at 80% Depth of Discharge	at 80% Depth of Discharge	at 80% Depth of Discharge	at 80% Depth of Discharge

Table 2 – Amprius increased cell energy more than 20% during the project's final year

**Average energy of cells delivered to Idaho National Laboratory (INL), as measured at Amprius before shipment. Maximum cycle life tested at INL, as measured by INL*
***Average energy of cells delivered to INL, as measured at Amprius before shipment. Maximum cycle life tested at Amprius, as measured by Amprius.*

Summary of Project Activities

Amprius divided project work into four key development areas: anode substrate, anode production (i.e. anode template and coating) and cell build. In each area, Amprius made key advances.

Anode Substrate: Amprius successfully transitioned from thick 75 µm foils to thin 10 µm foils. Amprius also established specifications for high yield production and qualified foil vendors capable of meeting Amprius' new specifications.

Anode Production: Amprius developed a multi-step silicon nanowire anode production process that uses thermal CVD to produce nanowire templates and plasma-enhanced CVD to coat the nanowires. Amprius then optimized template growth and coating processes to enable production of short and sparse nanowires with and high silicon mass loading.

Cell Build: Amprius improved cell build processes (e.g. by testing and incorporating new and thinner cell components).

During the project, Amprius encountered and overcame key challenges.

Original hypothesis: Amprius' most important hypothesis turned out to be true. Replacing the traditional anode material, carbon, with a new material, silicon, increases cell energy. More importantly, replacing the traditional anode structure, particles, with a new structure, nanowires, enables silicon to expand and contract successfully, addressing silicon's first-order challenge, swelling. Silicon nanowire anodes thus enable both high energy and long cycle life.

However, several of Amprius' less important hypotheses turned out not to be true. Explicitly, Amprius' project proposal and plan suggested that BASF would successfully develop high-energy NCM and thermal CVD alone would enable production of silicon nanowire anodes with the uniformity required for long cycle life. Implicitly, the project plan assumed that existing substrates would enable production of nanowires with the characteristics necessary for high energy.

Approaches used: Amprius focused on developing silicon nanowire anodes, as proposed and planned. During each project year, Amprius made progress in improving silicon nanowire anode structure, enlarging anode size, and/or increasing anode uniformity. Better silicon nanowire anodes enabled higher-energy cells; Amprius each year achieved higher-energy than prior year.

Problems encountered and departure from planned methodology: Amprius encountered several key challenges during project development. First, BASF didn't advance high-energy NCM as projected. As a result, Amprius was unable to achieve the project's initial energy targets, which Amprius had calculated based on both Amprius' development of silicon nanowire anodes (inside the project) and BASF's projected improvements to NCM cathodes (outside the project). Amprius therefore built the interim and end-of-project cells with LCO cathodes – the material with which Amprius has the most experience and which therefore enabled Amprius to focus on silicon anode development.

Second, thermal CVD alone did not enable the production of silicon nanowire anodes with the attributes required for long cycle life. During Budget Periods I and II, Amprius found that coating nanowires using thermal CVD produced a "base layer," a thick film of silicon at the base of the substrate. This continuous "base layer" provided little to no room for silicon to expand during lithiation, causing anode wrinkling and limiting cycle life. During Budget Period II, Amprius transitioned to PE-CVD for coating nanowires. Amprius then found that PE-CVD did not produce a significant "base layer," and thus enabled long life by eliminating the failure mechanism of anodes coated with only thermal CVD.

Third, existing substrates did not enable production of nanowires with the characteristics necessary for high energy density. During Budget Periods II and III, Amprius found that currently available substrates were too thick, rough and large-grained to enable production of the short, sparse and uniform nanowires required to facilitate high silicon mass loading and enable high energy density. During Budget Periods II and III, Amprius therefore worked with foil re-rollers to develop a detailed specification for the thin, smooth and small-grained substrate required for high energy density anodes.

Assessment of problems' impact on project results: Amprius was able to overcome the second challenge by incorporating PE-CVD into its production process and address the third challenge by developing a more specific substrate specification. However, the first challenge proved to be more problematic. Without advances in high-energy NCM cathodes, Amprius could not - with silicon anodes alone - achieve the project's initial energy targets. After Amprius concluded – and the DOE concurred – that the project should focus on development of silicon nanowire anodes, Amprius therefore had no choice but to reduce project targets from 396 Wh/kg and 940 Wh/L (to 330 Wh/kg and 680 Wh/L; the maximum values Amprius' model suggested were attainable when the targets were revised).

Amprius completed all projects milestones. *See Table 3.* Amprius reported on prior milestones in the company's quarterly reports – but committed to describing its cost model and commercialization plan in the final report.

Phase	New #	Process Step	Milestone	Planned Completion Month (Since Year 2 Inception)	Status
II	M1	Anode Substrate	Selected Anode Substrate	18	Complete
II	M2	Anode Template	Identified Thermal CVD Process to Build Anode Templates on 10-12 µm Substrates	15	Complete
II	M3	Template	Achieved 250 Anode Templates/Day Processing Capacity	6	Complete
II	M4	Anode Template	Integrated Manufacturing Metrology Into Anode Template Production Process	8	Complete

II	M5	Anode Coating	Demonstrated that a PECVD Tool can Achieve the Target Structure	9	Complete
II	M6	Anode Coating	Identified and Documented Metrology Recipe for Critical Parameters	7	Complete
II	M7	Anode Coating	Identified First Order Process Conditions Necessary to Tune Anode Coating Structure	5	Complete
II	M8	Anode Coating	Set a Working Specification for Process Conditions Necessary to Achieve Target Structure	7	Complete
II	M9	Anode Coating	Revised the Working Specification for Process Conditions Necessary to Achieve Target Structure	9	Complete
II	M10	Anode Coating	Identified a Coating Process and Structure to Enable ≥950mAh/cc and 300+ Cycles when Matched With either LCO in 2-2.2 Ah Multi-Layer Cells	10	Complete
III	M11	Anode Coating	Identified a Coating Process and Structure to Enable ≥1,200 mAh/cc and 750+ Cycles when Matched With LCO in 2-2.2 Ah Multi-Layer Cells	18	Complete
II	M12	Anode Coating	Made a Go/No Go Decision on Additional Electron Beam Evaporation Development	6	Complete
II	M13	Cell Build	Specified Prelithiation Protocol for PECVD Silicon, Brought Tools Online	18	Complete
II	M14	Cell Build	Documented Design of 2-2.2 Ah Multi-Layer Pouch Cell (Interim Cell for Phase 2)	3	Complete
II	M15	Cell Build	Demonstrated Initial Performance Target with an LCO Cathode [Cycle Life ≥200, Wh/kg ≥250 and Wh/L ≥580] in 2-2.2 Ah Multi-Layer Cell (Interim Cell for Phase 2)	6	Complete
II	M16	Cell Build	Demonstrated Interim Performance Target with an LCO Cathode [Cycle Life; ≥300, Wh/kg ≥250 and Wh/L ≥580] in 2-2.2 Ah Multi-Layer Cell (Interim Cell for Phase 2)	10	Complete
II	M17	Cell Delivery	Delivered 18 Interim 2-2.2 Ah Silicon-LCO Multi-Layer Cells and Test Plans	10	Complete
II	M18	Cell Delivery	Delivered Interim Cell Test Report	10	Complete
II	M19	Cell Delivery	Updated Interim Cell Test Report (for Self-Discharge and Shelf Life Test Results)	12	Complete
III	M20	Cell Build	Reported on Latest High-Energy NCM Performance in Quarterly Reports	21	Complete
III	M21	Cell Build	Documented Design of 2.2-2.24 Ah Multi-Layer Cell (Final Cell for Phase 3)	15	Complete

III	M22	Cell Build	Selected Candidate Cell Designs for State of the Art Builds	15	Complete
III	M23	Cell Build	Demonstrated Final Performance Target with a LCO Cathode [Cycle Life; ≥750, Wh/kg ≥330 and Wh/L ≥680] in 2.2-2.4 Ah Multi-Layer Cell (Final Cell for Phase 3)	18	Complete; *Cycle Life >300-500, not ≥750*
III	M24	Cell Delivery	Delivered 24 Final 2.2-2.4 Ah Silicon-LCO Multi-Layer Cells and Test Plans	21	Complete
III	M25	Cell Delivery	Delivered Final Cell Test Report	21	Complete
III	M26	Technology Commercialization	Identified Large Scale Manufacturing Process, Tools and Costs	20	Complete
III	M27	Technology Commercialization	Manufacturing Cost Model (in Final Report)	21	Complete
III	M28	Technology Commercialization	Commercialization Plan (in Final Report)	21	Complete
III	M29	Reporting	Delivered Quarterly Reports	Quarterly	Complete

Table 3 – Amprius completed all project milestones

Manufacturing Cost Model. Amprius' cost model suggests that volume manufacturing will enable Amprius to produce (1) silicon nanowire anodes at or below the per kilowatt-hour cost of premium graphite anodes and (2) silicon nanowire-based cells at or below the per kilowatt-hour cost of State of the Art cells.

During (and outside) the project, Amprius demonstrated proof-of-concept for continuous, roll-to-roll manufacturing. Amprius then initiated design of a pilot tool – a design that better enables Amprius to project costs for volume manufacturing. Amprius' latest model assumes that to enable high energy and reduce production costs, Amprius will commercialize silicon anodes with specific capacities of at least 1,500 mAh/g. *See Figure 1*.

Amprius' cost model details three scenarios: (1) conservative (2) improved manufacturing and (3) improved manufacturing and lower-cost materials. The (1) conservative scenario assumes that Amprius will continue to produce silicon nanowire anodes using its existing process and substrate material. The (2) improved manufacturing scenario assumes that Amprius will eliminate or increase the efficiency of its third and final anode manufacturing step, the [post-PE-CVD] use of thermal CVD to create a "cap" that reinforces the nanowire. The (3) improved manufacturing and lower-cost materials scenario assume that Amprius eliminates or increases the efficiency of its thermal CVD "cap" AND transitions to a lower cost anode substrate. *See Figure 2.*

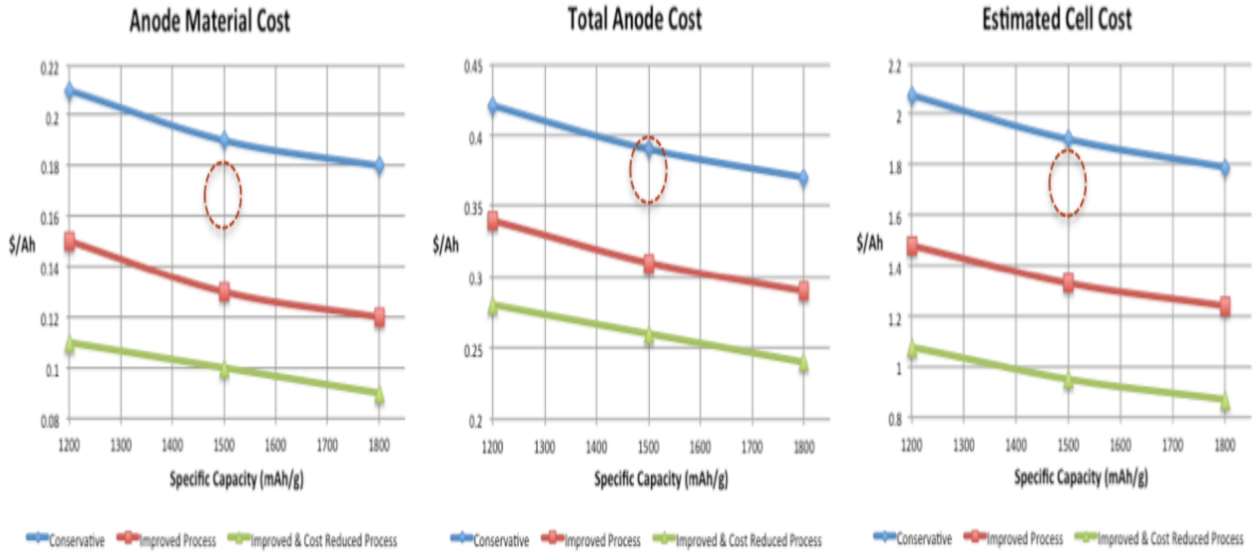

Figure 1 – Higher specific capacity lowers anode and cell costs

Anode cost is dominated by thermal CVD and substrate costs

Assumptions	Thermal Cap (Y/N)	Argon (slm)	Substrate ($/kg)	Silane ($/kg)	Anode Cost ($/Ah)	Material Only ($/Ah)	Cell Cost* ($/Ah)
Conservative	Y	4	60	33	0.39	0.19	1.90
Improved Process	N	2	60	33	0.31	0.13	1.33
Improved Process & Lower Cost	N	2	35	28	0.26	0.10	0.95

Likely cost in between these values

* cell cost assumes 10% anode material cost

Specific Capacity: 1,500 mAh/g
Reversible Capacity: 3.85 mAh/cm^2

Figure 2 – Eliminating (or increasing the efficiency of) Amprius' thermal CVD "cap" and transitioning to a lower cost substrate would significantly reduce anode and cell costs

Commercialization Plan. Amprius and its investors believe strongly in the electric vehicle opportunity. During Amprius' DOE-supported development, Amprius in 2014 briefed nearly all the major car companies on the company's progress. In January 2015, Amprius began a USABC-supported 3-year project to develop vehicle-size cells that will meet PEV requirements. At project's end, Amprius will start producing and selling cells for EV applications. In the interim, Amprius will continue to increase cell performance and support pilot tool development for anode production. In 2016, Amprius will begin to sample and sell cells for small form-factor products. Starting to sell silicon nanowire-based cells for such applications will help Amprius improve its anode and cell production processes and prepare the company to enter the EV cells market.

Products Developed

Amprius regularly reported to the DOE about its progress, summarized project progress during DOE visits to Amprius' laboratory and presented at DOE Annual Merit Reviews. In addition, Amprius has made and elected title to more than 20 invention disclosures as a result of DOE-funded research.

However, Other than DOE required reporting, Amprius has not publicly released information about its progress in the DOE project. Amprius has not reported on its progress in publications, conference papers or presentations, detailed its results on any websites or shared details on its proprietary technologies and techniques.

Amprius developed and delivered high-energy cells matching silicon nanowire anodes with LCO cathodes. During Budget Period II, Amprius delivered 18 cells to Idaho National Laboratory. *See Figure 3*. As measured at Amprius, the cells' average energies, 271 Wh/kg and 646 Wh/L, far exceeded the project's interim targets, 250 Wh/kg and 580 Wh/L. *See Table 4* for individual cell specifications. As tested at INL, maximum cycle life, >500 at C/3 and 80% depth of discharge, far exceeded the project's interim target, ≥300 cycles at C/3 and 80% depth of discharge.

At INL, Amprius' cells also passed Hybrid Pulse Power Characterization [HPPC] testing and demonstrated impressive capacity across a wide temperature range. Amprius' cells retained ~85% of their capacity at 0^{o}C and C/3 and achieved ~105% of their capacity at 45^{o}C and C/3.

Figure 3 – 12 of the 18 cells Amprius shipped to INL during Budget Period II

Device-ID	Nominal Device Capacity (mAh)	Nominal Device Energy (Wh)	Nominal Discharge Voltage at C/2 (V)	GED (Wh/kg)	VED (Wh/L)	Shipping OCV (V)	Shipping Z(1kHz) / mΩ	Shipping Thickness / mm	Weight/ g
D-15326	2471.51	8.74	3.54	286	680	3.53	14.6	4.48	30.59
D-15444	2368.64	8.31	3.51	272	638	3.56	18.7	4.54	30.55
D-15453	2374.74	8.32	3.50	274	641	3.56	20.2	4.52	30.36
D-15479	2402.49	8.45	3.52	274	650	3.55	16.2	4.53	30.90
D-15489	2345.52	8.24	3.51	267	629	3.56	16.4	4.56	30.84
D-15532	2337.12	8.20	3.51	265	621	3.57	15.5	4.63	30.95
D-15809	2348.51	8.30	3.53	270	659	3.55	15.0	4.37	30.70
D-15810	2398.39	8.53	3.56	279	673	3.54	17.3	4.35	30.57
D-15811	2291.63	8.07	3.52	261	618	3.57	19.6	4.42	30.90
D-15812	2335.52	8.22	3.52	267	633	3.57	17.1	4.49	30.81
D-15856	2340.72	8.23	3.52	266	634	3.56	15.7	4.49	30.98
D-15857	2394.41	8.48	3.54	272	653	3.54	15.8	4.45	31.13
D-15858	2381.25	8.41	3.53	278	650	3.54	16.5	4.48	30.25
D-15859	2393.10	8.46	3.54	276	646	3.54	15.7	4.52	30.71
D-15860	2394.57	8.47	3.54	271	652	3.54	16.2	4.47	31.21
D-15861	2258.15	8.00	3.54	264	646	3.54	15.0	4.28	30.35
D-15864	2359.38	8.33	3.53	270	659	3.56	14.4	4.38	30.85
D-15865	2335.14	8.25	3.53	267	653	3.55	15.4	4.37	30.83
Average	**2362.82**	**8.33**	**3.53**	**271.06**	**646.39**	**3.55**	**16.41**	**4.46**	**30.75**
St. Dev	**46.84**	**0.17**	**0.01**	**6.15**	**16.24**	**0.01**	**1.64**	**0.09**	**0.26**
St. Dev, %	1.98%	2.10%	0.42%	2.27%	2.51%	0.35%	9.99%	1.94%	0.86%

Table 4 –Specifications for the 18 Budget Period II cells Amprius shipped to INL

During Budget Period III, Amprius delivered 24 cells to Idaho National Laboratory. *See Figure 4*. As measured at Amprius, the cells' average energies, 330 Wh/kg and 791 Wh/L, met the project's final specific energy goal, 330 Wh/kg, and far exceeded the project's final energy density goal, 680 Wh/L. *See Table 5* for individual cell specifications. As tested at Amprius, maximum cycle life, >300 at C/3 and 80% depth of discharge did not approach the project's final cycle life goal, ≥750 cycles at C/3 and 80% depth of discharge.

At Amprius, end-of-project cells also passed HPPC testing and demonstrated impressive capacity across a wide temperature range. During Budget Period III, Amprius' cells retained ~90% of their capacity at 0^{o}C and C/3 – a 5% improvement over Budget Period II – and achieved ~105% of their capacity at 45^{o}C and C/3. *During Budget Period III, Amprius' new electrolyte thus improved high temperature performance – but at the expense of cycle life.*

Figure 4 – 40 of the 48 end-of-project cells Amprius built during Budget Period III. Amprius kept 24 cells for internal testing and delivered 24 to INL for independent testing

During the project's final year, Amprius significantly improved anode and cell uniformity. The standard deviation of the specific energies of Amprius' Budget Period III cells – less than 1% – was far lower than that of Amprius' Budget Period III cells – more than 6%.

During Budget Period III, Amprius also increased cell energy by more than 20%. *See Figure 5.* Amprius' end-of-project silicon anode-based cells have ~35-40% higher energy than similarly sized graphite anode-based cells.

	Nominal Values at C/20 Rate					Nominal Values at C/3 Rate					Specifications at Shipping					
Device- ID	Capacity (Ah)	Energy (Wh)	Voltage (V)	GED (Wh/kg)	VED (Wh/L)	Capacity (mAh)	Energy (Wh)	Voltage (V)	GED (Wh/kg)	VED (Wh/L)	OCV (V)	Z@1kHz (mΩ)	Thicknes s (mm)	Width (mm)	Height (mm)	Weight (g)
20452	2.635	9.540	3.621	341	799	2.537	9.060	3.572	324	758	3.65	17.7	4.34	49.77	57.16	27.95
20453	2.650	9.570	3.611	342	823	2.577	9.200	3.571	329	791	3.65	15.3	4.23	50.23	57.27	27.99
20463	2.647	9.590	3.622	341	798	2.569	9.200	3.581	327	765	3.65	14.9	4.37	50.02	56.68	28.15
20500	2.696	9.494	3.521	347	825	2.651	9.160	3.455	334	796	3.61	12.5	4.19	50.02	56.63	27.39
20524	2.625	9.500	3.619	341	816	2.562	9.170	3.579	329	788	3.64	16.5	4.23	50.45	57.55	27.86
20594	2.679	9.624	3.593	340	807	2.616	9.269	3.543	328	777	3.63	14.1	4.34	50.12	56.66	28.27
20601	2.660	9.624	3.619	338	803	2.612	9.377	3.590	330	783	3.64	12.3	4.36	49.56	56.01	28.45
20603	2.654	9.627	3.627	339	808	2.607	9.372	3.595	330	786	3.65	13.0	4.34	49.76	56.72	28.40
20605	2.661	9.600	3.608	341	829	2.583	9.224	3.572	328	797	3.64	14.5	4.21	50.17	57.02	28.13
20606	2.658	9.618	3.619	345	845	2.583	9.245	3.579	332	813	3.64	14.3	4.14	50.08	56.61	27.86
20607	2.653	9.595	3.616	341	836	2.589	9.207	3.556	327	802	3.65	13.3	4.17	50.04	56.94	28.15
20609	2.675	9.665	3.614	341	803	2.612	9.373	3.588	330	779	3.64	14.5	4.38	50.35	57.20	28.39
20629	2.673	9.668	3.617	340	797	2.626	9.413	3.584	331	776	3.64	13.0	4.41	49.93	56.91	28.46
20630	2.660	9.639	3.624	342	787	2.607	9.357	3.590	332	764	3.65	12.4	4.46	50.01	56.63	28.15
20631	2.675	9.656	3.610	343	806	2.626	9.388	3.575	333	783	3.63	13.4	4.36	49.80	56.61	28.16
20632	2.669	9.648	3.614	344	811	2.615	9.354	3.578	333	786	3.64	13.4	4.33	49.57	56.83	28.05
20684	2.661	9.660	3.630	344	809	2.623	9.432	3.596	336	790	3.65	13.4	4.34	50.07	56.71	28.09
20687	2.627	9.454	3.599	336	782	2.566	9.150	3.565	325	757	3.64	13.6	4.40	49.90	56.85	28.12
20708	2.669	9.653	3.616	343	836	2.625	9.387	3.576	333	813	3.38	16.8	4.20	49.95	56.47	28.17
20710	2.668	9.661	3.621	338	854	2.626	9.411	3.584	330	832	3.38	14.9	4.11	50.01	56.89	28.55
20757	2.618	9.457	3.612	336	824	2.593	9.245	3.566	328	806	3.40	20.3	4.17	49.59	57.09	28.16
20759	2.659	9.587	3.605	343	854	2.595	9.242	3.561	331	824	3.33	18.6	4.08	49.91	56.67	27.93
20760	2.687	9.691	3.607	340	841	2.646	9.443	3.569	332	819	3.36	17.3	4.19	49.76	57.23	28.47
20761	2.670	9.641	3.612	341	845	2.630	9.395	3.572	333	823	3.37	15.5	4.15	49.66	56.57	28.25
Average	**2.66**	**9.60**	**3.61**	**341.16**	**818.23**	**2.60**	**9.29**	**3.57**	**330.21**	**791.98**	**3.57**	**14.81**	**4.27**	**49.95**	**56.83**	**28.15**
St. Dev	**0.02**	**0.07**	**0.02**	**2.57**	**20.86**	**0.03**	**0.11**	**0.03**	**2.92**	**21.21**	**0.12**	**2.09**	**0.11**	**0.23**	**0.32**	**0.25**
St. Dev, %	**0.72%**	**0.71%**	**0.58%**	**0.75%**	**2.55%**	**1.08%**	**1.17%**	**0.77%**	**0.88%**	**2.68%**	**3.37%**	**14.12%**	**2.53%**	**0.47%**	**0.57%**	**0.90%**

Table 5 –Specifications for the 24 Budget Period III cells Amprius shipped to INL

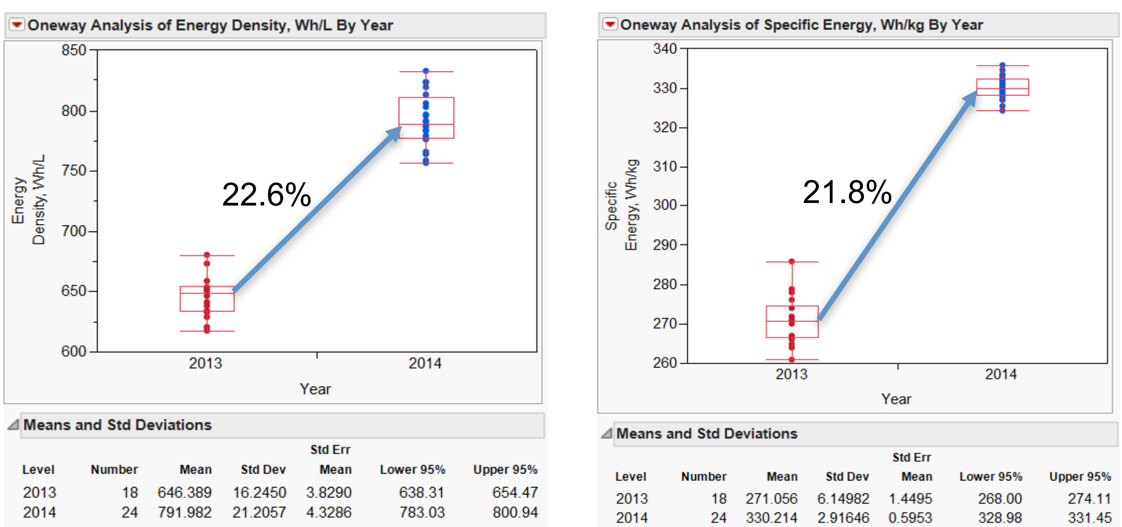

Figure 5 – During Budget Period III, Amprius increased both energy density (left) and specific energy (right) by more than 20%