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Figure 8

North America

LFP Battery Cell Capacity

Product Category	Value (USD)	Share of Total Exports (%)	Assumed (GWh)
Holland, MI, US	Cell	16.5	
Sparks, NV, US	Cell	10	
Marshall, MI, US	Cell	20	
Spring Hill, TN, US	Cell		20
Commerce, GA, US	Cell	1.44	
Tucson, AZ, US	Cell	5.5	
Van Buren, MI, US	Cell	20	
Windsor, ON, CAN	Cell		5
Candiac, QC, CAN	CAM		

Product Category	Value (USD)	Share of Total Exports (%)	Assumed (GWh)
Muskegon, MI, US	CAM		

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Europe

LFP Battery Cell Capacity

Product Category	Value (USD)	Share of Total Exports (%)	Assumed (GWh)
Subotica, VO, RS	Cell	8	
Teverola, CE, IT	Cell	8	
Brindisi, BR, IT	Cell	8	
Wrocław, WR, PL	Cell	39	
Zaragoza, AR, ES	Cell	50	
Sagunto, VC, ES	Cell	20	

Product Category	Value (USD)	Share of Total Exports (%)	Assumed (GWh)
Debrecen, DE, HU	Cell	40	
Polatlı, Ankara, TR	Cell	5	
Jorf Lasfar, JDI, MA	CAM		
Moosburg, BY, DE	CAM		
Bitterfeld, ST, DE	CAM		

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Asia Ex-China

LFP Battery Cell Capacity

Product Category	Value (USD)	Share of Total Exports (%)	Assumed (GWh)
Cheongju, North Chungcheong, KR	Cell	1	
Seosan, South Chungcheong, KR	Cell	3	
Daegu, KR	CAM		

Product Category	Value (USD)	Share of Total Exports (%)	Assumed (GWh)
Jamnagar, GJ, IN	Cell	40	
Kendal, JT, ID	CAM		
Cheongju, North Chungcheong, KR	Cell	1	
Seosan, South Chungcheong, KR	Cell	3	
Daegu, KR	CAM		
Jamnagar, GJ, IN	Cell	40	
Kendal, JT, ID	CAM		

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Lithium Metal (semi-solid state)

- Hanyu Huo and Jürgen Janek, "Solid-State Batteries: From 'All-Solid' to 'Almost-Solid,'" National Science Review 10, no. 6 (June 2023): nwad098, https://doi.org/10.1093/nsr/nwad098; "Semi-Solid-State Battery vs. Lithium-Ion Battery," Grepow, https://www.grepow.com/blog/semi-solid-state-battery-vs-lithium-ion-battery.html.
- Li Yang, Nader Marandian Hagh, Jesse Roy, Eric Macciomei, J. R. Klein, Umamaheswari Janakiraman, and Mary E. Fortier, "Review—Challenges and Opportunities in Lithium Metal Battery Technology," Journal of The Electrochemical Society 171, no. 6 (June 5, 2024): 060504, https://doi.org/10.1149/1945-7111/ad4ff2.
- Subin Antony Jose, Amethyst Gallant, Pedro Lechuga Gomez, Zacary Jaggers, Evan Johansson, Zachary LaPierre, and Pradeep L. Menezes, "Solid-State Lithium Batteries: Advances, Challenges, and Future Perspectives," Batteries 11, no. 3 (February 22, 2025): 90, https://doi.org/10.3390/batteries11030090.
- Fabian Duffner, Niklas Kronemeyer, Jens Tübke, Jens Leker, Martin Winter, and Richard Schmuch, "Post-Lithium-Ion Battery Cell Production and Its Compatibility with Lithium-Ion Cell Production Infrastructure," Nature Energy 6 (January 28, 2021): 123–134, https://doi.org/10.1038/s41560-020-00748-8.
- "FEST Electrolyte Technology," Factorial Energy, https://factorialenergy.com/technology/.

Lithium metal (solid state)

- Joscha Schnell, Till Günther, Thomas Knoche, Christoph Vieider, Larissa Köhler, Alexander Just, Marlou Keller, Stefano Passerini, and Gunther Reinhart, "All-Solid-State Lithium-Ion and Lithium Metal Batteries — Paving the Way to Large-Scale Production," Journal of Power Sources 382 (April 1, 2018): 160–175, https://doi.org/10.1016/j.jpowsour.2018.02.062.
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- Yu Ru, "All-Solid-State Battery Manufacturing: The Key Differences Explained," Lead Intelligent Equipment Co., Ltd., April 17, 2025, https://www.leadintelligent.com/en/all-solid-state-battery-manufacturing-explained/.

Appendix II: Sources and Methodology for Figures 9–11

To deduce patent data, we sourced patents from The Lens, an open-source website that catalogues patent families. To do so, we built Boolean queries that would most accurately describe the six observed battery cell chemistries in the analysis: NMC/NCA, LF(M)P, Si-anode, Na-ion, Lithium metal, and lithium sulfur. The queries were specifically designed to capture any and all variants or terminologies that might be sued for these chemistries (for example, NMC811 and NMC523). This allowed us to cast a broad net. Secondarily, our code included specific screening for chemistries that might be confused, as well as some secondary processes like recycling. In the end, the patents observed included enabling technologies to produce the final product (such as a new cathode process for NMC).

Once the data had been collected, we reviewed the results and triangulated them with the findings from the commercial exercise in Figures 12–15. We cross referenced different companies pioneering these specific chemistries and found consistent overlap, a strong indication of the caliber of findings. However, the initial results were broad and included all patent families, including those that had filed in only one jurisdiction. We then adjusted for patents with publications in two or more jurisdictions, implying that the inventor views the invention as having a potential monetary value that they would like to protect in multiple regions from infringement. From there, the final list was rendered by the different battery chemistry patents over time to observe when their inventions flourished, percentage of total patents among the jurisdictions observed to understand which jurisdictions have prioritized which technologies, and number of patents over time by region to compare how jurisdictions are innovating battery technology. Please see below for a full list of Boolean queries.

NMC/NCA

H01M*
AND (title:(LNCA OR LNMC OR LNCM OR "li-ncm" OR "li-nmc" OR "li nmc" OR "nickel rich" OR "high nickel" OR "ni-rich" OR "ni rich" OR "nickel cobalt" OR "nickel cobalt manganese" OR "nickel manganese cobalt" OR NMC* OR NCM* OR "LiNiCoMnO2" OR "LiNiMnCoO2" OR "lithium nickel cobalt manganese oxide" OR "lithium nickel manganese cobalt oxide" OR "NMC111" OR "NCM111" OR "NMC523" OR "NCM523" OR "NMC532" OR "NCM532" OR "NMC622" OR "NCM622" OR "NMC811" OR "NCM811" OR "NMC 811" OR "NCM 811" OR LiNi*Co*Mn*O2 OR "nickel cobalt aluminum" OR "nickel aluminium cobalt" OR NCA* OR "LiNiCoAlO2" OR "lithium nickel cobalt aluminum oxide" OR "lithium nickel aluminium cobalt oxide" OR LiNi*Co*Al*O2 OR NCMA OR "nickel cobalt manganese aluminum" OR

"nickel cobalt manganese aluminium" OR "nickel cobalt aluminum manganese" OR "nickel cobalt aluminium manganese" OR "LiNiCoMnAlO2"))
NOT (title:(LFP OR "LiFePO4" OR "iron phosphate" OR LCO OR "LiCoO2" OR LMO OR "LiMn2O4" OR LNMO OR "LiNiMnO4" OR "Li-S" OR "lithium sulfur" OR "lithium-sulfur" OR "sodium-ion" OR SIB OR "na-ion"))
NOT (abstract:(LFP OR "LiFePO4" OR "iron phosphate" OR LCO OR "LiCoO2" OR LMO OR "LiMn2O4" OR LNMO OR "LiNiMnO4" OR "Li-S" OR "lithium sulfur" OR "lithium-sulfur" OR "sodium-ion" OR SIB OR "na-ion"))
NOT (title:(recover* OR medical OR robot* OR surgical OR recycl*))
NOT (abstract:(recover* OR medical OR robot* OR surgical OR recycl*))

LF(M)P

H01M*
AND (title:(LFP OR "lithium iron phosphate" OR "lithium-iron-phosphate" OR "lithium ferro phosphate" OR "lithium-ferro-phosphate" OR LiFePO4 OR "lithium iron manganese phosphate" OR "lithium-iron-manganese-phosphate" OR LFMP OR LiFe*Mn*PO4))
NOT (title:("nickel manganese cobalt" OR "nickel cobalt manganese" OR NMC* OR NCM* OR "LiNiCoMnO2" OR "LiNiMnCoO2" OR "lithium nickel cobalt manganese oxide" OR "lithium nickel manganese cobalt oxide" OR "NMC811" OR "NCM811" OR "NMC 811" OR "NCM 811" OR "NMC622" OR "NCM622" OR "NMC523" OR "NCM523" OR "NMC532" OR "NCM532" OR "NMC111" OR "NCM111" OR LiNi*Co*Mn*O2 OR "nickel cobalt aluminum" OR "nickel aluminium cobalt" OR NCA* OR NCMA OR "LiNiCoAlO2" OR "lithium nickel cobalt aluminum oxide" OR "lithium nickel aluminium cobalt oxide" OR LiNi*Co*Al*O2))
NOT (abstract:("nickel manganese cobalt" OR "nickel cobalt manganese" OR NMC* OR NCM* OR "LiNiCoMnO2" OR "LiNiMnCoO2" OR "lithium nickel cobalt manganese oxide" OR "lithium nickel manganese cobalt oxide" OR "NMC811" OR "NCM811" OR "NMC 811" OR "NCM 811" OR "NMC622" OR "NCM622" OR "NMC523" OR "NCM523" OR "NMC532" OR "NCM532" OR "NMC111" OR "NCM111" OR LiNi*Co*Mn*O2 OR "nickel cobalt aluminum" OR "nickel aluminium cobalt" OR NCA* OR NCMA OR "LiNiCoAlO2" OR "lithium nickel cobalt aluminum oxide" OR "lithium nickel aluminium cobalt oxide" OR LiNi*Co*Al*O2))
NOT (title:(recover* OR medical OR robot* OR surgical OR recycl*))
NOT (abstract:(recover* OR medical OR robot* OR surgical OR recycl*))

Na-ion

H01M*
AND (title:("sodium-ion" OR "sodium ion" OR "na ion" OR "na-ion" OR SIB OR NIB OR "sodium battery"))
NOT (title:("sodium-air" OR "sodium air" OR "Na-air" OR "sodium oxygen" OR "sodium-oxygen"))
NOT (abstract:("sodium-air" OR "sodium air" OR "Na-air" OR "sodium oxygen" OR "sodium-oxygen"))
NOT (title:("sodium sulfur" OR "sodium-sulfur" OR "Na-S" OR "NaS battery" OR "sodium sulphur"))
NOT (abstract:("sodium sulfur" OR "sodium-sulfur" OR "Na-S" OR "NaS battery" OR "sodium sulphur"))
NOT (title:("molten salt" OR "molten sodium" OR "high temperature sodium" OR "sodium metal chloride" OR ZEBRA))
NOT (abstract:("molten salt" OR "molten sodium" OR "high temperature sodium" OR "sodium metal chloride" OR ZEBRA))
NOT (title:(LFP OR "LiFePO4" OR "iron phosphate" OR "lithium iron phosphate" OR LCO OR "LiCoO2" OR LMO OR "LiMn2O4" OR "manganese spinel" OR "spinel cathode" OR LNMO OR "LiNiMnO4" OR "lithium sulfur" OR "Li-S" OR "solid oxide" OR LIB OR "li-ion" OR "lithium-ion"))
NOT (abstract:(LFP OR "LiFePO4" OR "iron phosphate" OR "lithium iron phosphate" OR LCO OR "LiCoO2" OR LMO OR "LiMn2O4" OR "manganese spinel" OR "spinel cathode" OR LNMO OR "LiNiMnO4" OR "lithium sulfur" OR "Li-S" OR "solid oxide" OR LIB OR "li-ion" OR "lithium-ion"))
NOT (title:(recover* OR medical OR robot* OR surgical OR recycl*))
NOT (abstract:(recover* OR medical OR robot* OR surgical OR recycl*))

Si-anode

H01M*
AND (title:("silicon anode" OR "Silicon-anode" OR "Si anode" OR "Si-anode" OR "Si-based anode" OR "silicon-graphene" OR "silicon-dominant" OR silicon OR "silicon carbon" OR "silicon-carbon" OR "silicon nanowire" OR "silicon oxide" OR SiOx))
NOT (title:(sodium OR "sodium-ion" OR "sodium ion" OR "na-ion" OR SIB OR NIB))
NOT (abstract:(sodium OR "sodium-ion" OR "sodium ion" OR "na-ion" OR SIB OR NIB))
NOT (title:("lithium sulfur" OR "lithium-sulfur" OR "Li-S" OR LiS))
NOT (abstract:("lithium sulfur" OR "lithium-sulfur" OR "Li-S" OR LiS))
NOT (title:("lithium metal" OR "lithium-metal" OR "Li metal" OR "Li-metal" OR LMB))
NOT (abstract:("lithium metal" OR "lithium-metal" OR "Li metal" OR "Li-metal" OR LMB))
NOT (title:(recover* OR medical OR robot* OR surgical OR recycl*))
NOT (abstract:(recover* OR medical OR robot* OR surgical OR recycl*))

Lithium metal

H01M*
AND (title:("lithium metal" OR "lithium-metal" OR "Li metal" OR "Li-metal" OR "lithium metal anode" OR "Li anode" OR "Li-anode" OR "lithium anode" OR "metallic lithium" OR LMB OR "anode-free" OR "anode free"))
NOT (title:("lithium sulfur" OR "lithium-sulfur" OR "Li-S" OR "Li-sulfur" OR LiS))
NOT (abstract:("lithium sulfur" OR "lithium-sulfur" OR "Li-S" OR "Li-sulfur" OR LiS OR "polysulfide shuttle" OR "sulfur cathode" OR "Li2S cathode"))
NOT (title:("lithium air" OR "lithium-air" OR "li-air" OR "lithium oxygen" OR "lithium-oxygen" OR "li-oxygen"))
NOT (abstract:("lithium air" OR "lithium-air" OR "li-air" OR "lithium oxygen" OR "lithium-oxygen" OR "li-oxygen" OR "oxygen cathode" OR "air cathode"))
NOT (title:(sodium OR "sodium-ion" OR "sodium ion" OR "na-ion" OR SIB))
NOT (abstract:(sodium OR "sodium-ion" OR "sodium ion" OR "na-ion" OR SIB))
NOT (title:(recover* OR medical OR robot* OR surgical OR recycl*))
NOT (abstract:(recover* OR medical OR robot* OR surgical OR recycl*))

Lithium sulfur

H01M*
AND (title:("lithium sulfur" OR "lithium-sulfur" OR "Li-S" OR "Li-sulfur" OR LiS OR "polysulfide shuttle" OR "sulfur cathode" OR "Li2S cathode"))
NOT (title:(LIB OR "li-ion" OR "lithium-ion" OR "lithium ion"))
NOT (abstract:(LIB OR "li-ion" OR "lithium-ion" OR "lithium ion"))
NOT (title:(sodium OR "sodium-ion" OR "sodium ion" OR "na ion" OR "na-ion" OR SIB))
NOT (abstract:(sodium OR "sodium-ion" OR "sodium ion" OR "na ion" OR "na-ion" OR SIB))
NOT (title:("nickel cobalt manganese" OR "nickel manganese cobalt" OR NMC* OR NCM* OR NCA* OR "nickel cobalt aluminum"))
NOT (abstract:("nickel cobalt manganese" OR "nickel manganese cobalt" OR NMC* OR NCM* OR NCA* OR "nickel cobalt aluminum"))
NOT (title:("lithium air" OR "lithium-air" OR "li-air" OR "lithium oxygen" OR "lithium-oxygen" OR "li-oxygen"))
NOT (abstract:("lithium air" OR "lithium-air" OR "li-air" OR "lithium oxygen" OR "lithium-oxygen" OR "li-oxygen"))
NOT (title:(recover* OR medical OR robot* OR surgical OR recycl*))
NOT (abstract:(recover* OR medical OR robot* OR surgical OR recycl*))

Figures 17

The data source for the European critical mineral demand model was from Rhodium source data identifying battery cell investments plus a bottom-up analysis to provide corresponding capacity for each listed facility. Battery chemistry utilized in EU facilities was determined based on a facility-by-facility audit of planned battery cell facilities based on available online materials. If no specific data was available about the planned battery chemistry or chemistries to be produced at a specific facility, a best estimate was made based on the battery chemistry of choice of the battery maker. European data from Rhodium meanwhile was categorized into three categories: operating, under construction, and announced.

For each battery manufacturing mineral demand model in Europe three scenarios were created;

Battery Winter (A Bear Case With Given Chemistry)

Battery Base 1.0 (A Bull Case With Given Chemistry)

Battery Base 2.0 (A Bull Case with High Drop-In Chemistry)

Battery Winter

Battery Winter is meant to represent a worst-case scenario where projections around EV uptake and grid storage that bolstered planned battery manufacturing investments in the early 2020s fail to materialize. In the bear case for Europe, only facilities that are currently operating or under construction were utilized.

Chemistry	LFP	NCA	NMC	NMCA	Li-S	Na-Ion	Li-Metal
EU Battery Production Makeup	31%	3%	64%	0%	2%	0%	0%

EU 2035 Battery Capacity 668 GWh

Battery Base 1.0

In Battery Base 1.0, it is assumed that all investments, including those that are announced in the EU, go through, but that the uptake of novel battery cathode chemistries remains low. For Europe in this scenario planned li-sulfur battery manufacturing facilities split their production (between NMC & LFP), leaving this battery chemistry as only 3 percent of 2035 production. Li-metal uptake is also lower than what is currently announced keeping pace with deployment of li-sulfur and also making up 3 percent of 2035 production. The additional 9 percent of announced solid state battery manufacturing for Europe is split evenly between NMC and LFP, as novel battery manufactures pivot to existing chemistries. Na-Ion has a small 1 percent of total production tracking with what is currently planned.

Chemistry	LFP	NCA	NMC	NMCA	Li-S	Na-Ion	Li-Metal
EU Battery Production Makeup	36%	2%	55%	0%	3%	1%	3%

EU 2035 Battery Capacity 1093 GWh

Battery Base 2.0

In this scenario, all planned li-metal and li-sulfur battery capacity reaches operation, with no planned capacity redistributed to existing chemistries. Na-ion also increased its share of capacity five years behind its penetration into the Chinese battery manufacturing base. Na-ion battery chemistries displace some existing planned NMC and LFP capacity in Europe.

Chemistry	LFP	NCA	NMC	NMCA	Li-S	Na-Ion	Li-Metal
EU Battery Production Makeup	27%	2%	46%	0%	7%	7%	12%

EU 2035 Battery Capacity 1093 GWh

Anode Chemistry Assumptions

For all scenarios, the assumptions around anode chemistry (specifically the blend of silicon versus graphite in NMC anodes) was based on the 2024 BNEF Long Term Electric Vehicle Outlook for global anode chemistry makeup, and held constant. However, for the EU, the assumed uptake of anode chemistries was set back five years compared to the global average to account for China's lead in the sector. Since China has a far larger share of the current and planned global battery manufacturing landscape, the BNEF global anode battery chemistry forecast is far more representative of China's battery manufacturing base at the technological forefront of the sector. Given current challenges around integrating LFP with silicon anode blends, and the unknown ways novel chemistries will interact with silicon anode blends, the total percentage of battery capacity with silicon anode blends was solely assumed to be taken up by the share of NMC production capacity in each scenario. It was also assumed that all 10 percent Si anode blend batteries in the BNEF forecast in this model would be 15 percent.

Chemistry	15% Si Anode Blend	20% Si Anode Blend	50% Si Anode Blend
Percentage of silicon-anode makeup in battery base any scenario	17%	12%	4%

Battery Chemistry Critical Mineral Requirements

Critical mineral requirements per KWh for NMC, NCA and LFP battery chemistries was provided by the following literature:

- Marc Wentker, Matthew Greenwood, and Jens Leker, "A Bottom-Up Approach to Lithium-Ion Battery Cost Modeling with a Focus on Cathode Active Materials," Energies 12, no. 3 (February 5, 2019): 504, https://doi.org/10.3390/en12030504.

For more nascent battery chemistries (Li-S, Li-Metal) that lack well established critical mineral requirements, a composite figure was estimated based on an active cell material volume of 0.13L per cell. A cell active material volume of 0.13L per cell was assumed for more nascent chemistries as it is equivalent to existing chemistries and so enables drop in compatibility with existing cell casings. A mid-range figure for Li-S assumed a volumetric energy of 700 Wh/L and a gravimetric energy density of 500 Wh/kg provided by the following:

- Babu Ganguli, Celina Mikolajczak, Zach Favors, Ratnakumar Bugga, Yongtao Meng, Arjun Mendiratta, Jefferey Bell, and Dan Cook, "Performance and Safety Behavior of Lyten's Li-S Pouch and Cylindrical 18650 Cells," presentation at the 2023 NASA Aerospace Battery Workshop, Huntsville, AL, November 14–16, 2023, https://www.nasa.gov/wp-content/uploads/2024/01/05-nasa-workshop-babuganguli.pdf.

- Surendran and Venkataraman Thangadurai, “Solid-State Lithium Metal Batteries for Electric Vehicles: Critical Single Cell Level Assessment of Capacity and Lithium Necessity,” ACS Energy Letters 10, no. 2 (2025): 991–1001, https://doi.org/10.1021/acsenergylett.4c03331.
- “Core Technologies,” ProLogium Technology Co., Ltd., https://prologium.com/tech/core-technology/.

For solid state batteries, battery characteristics were assumed at 1,100 Wh/L and 470 Wh/kg. Given the fixed cell volume requirements this meant an active cell energy of .09 kWh for Li-S and .14 kWh for Li-Metal, with a corresponding active material cell mass of 182 and 304 grams per cell respectively. Determining the mass ratio of the critical mineral containing anode in Li-S and both cathode and anode in Li-Metal was based on a survey of the academic literature.

Sodium ion chemistries were assumed as not requiring the critical minerals of focus (Co, Graphite, Li, Ni). This said, we acknowledge that varying sodium-ion cathodes contain small traces of nickel and manganese.

Final critical mineral assumptions t/GWh for all chemistries are provided below.

Tonnes of mineral per GWh of battery production

	NMC	**LFP**	**NCA**	**NMCA**	**Li-S**	**Li-Metal**
Li	112	93	110	120	245	188
Co	95	0	47	33	0	0
Ni	754	0	836	736	0	0
Mn	88	0	0	86	0	0
Gra	1035	1194	1032	1035	0	0

For the various silicon-anode blends the required tonnes of graphite and silicon per GWh are provided below. Estimates assumed a si material energy density of 2,000 mAh/g based on industry consultations.

	NMC 811 (15% Si Anode Blend)	**NMC 811 (20% Si Anode Blend)**	**NMC 811 (50% Si Anode Blend)**
Gra	384	304	97
Si	68	76	97

Note, mineral requirements for Li-S and Li-Metal batteries are speculative due to the nascent and evolving nature of this chemistry.