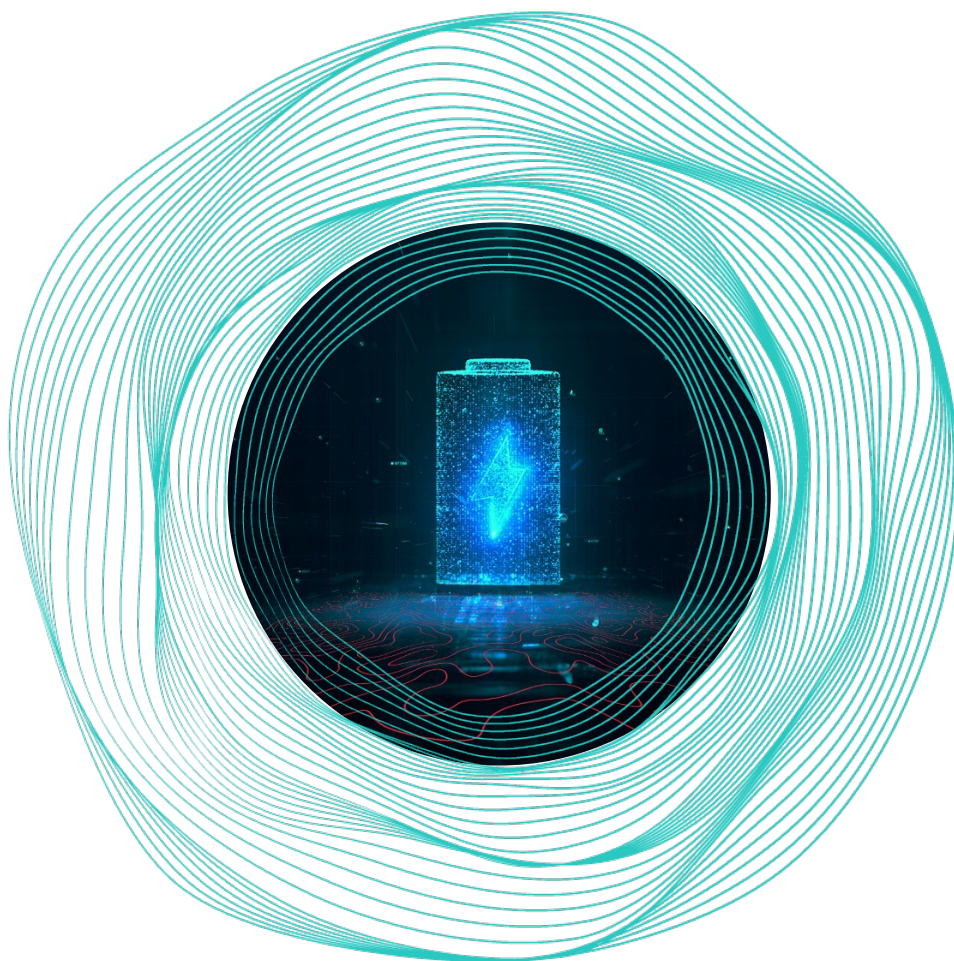


MULTI CLIENT STUDY

Battery Anode Materials

Market Analysis

Published. February 2025



© Copyright 2025 Worley ACN 096 090 158. No part of this document or the information it contains may be reproduced or transmitted in any form or by any means electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without permission in writing from Worley.



Notice

Contents of this study are only for use by the purchaser of Worley Group Inc.'s Global Battery Anode Materials Study and is confidential. Only said purchaser's employees, and employees of companies 51% or more owned by the purchaser may use this study. It is not to be otherwise published or distributed.

Disclaimer

The forecasts, estimates, opinions, analysis, evaluations, or recommendations contained herein are the sole property of Worley Group Inc.

Worley Group Inc., and its affiliates shall have no liability whatsoever to third parties for any defect, deficiency, error, or omission in any statement contained in or in any way related to the presentation. Neither Worley Group Inc. nor any person acting on Worley Group Inc.'s behalf makes any warranty, express or implied, or assumes any liability with respect to use of or reliance on any information, technology, engineering, or methods disclosed or discussed in the report. Any forecasts, estimates, projections, opinions, or conclusions reached in the presentation are dependent upon numerous technical and economic conditions over which Worley Group Inc. has no control, and which may or may not occur. Reliance upon such opinions or conclusions by any person or entity is at the sole risk of the person relying thereon. The data, information and assumptions used to develop the report were obtained or derived from documents or information furnished by others. Worley Group Inc. did not independently verify or confirm such information and does not assume responsibility for its accuracy or completeness. Any forecasts, or cost or pricing estimates in the presentation are considered forward looking statements and represent Worley Group Inc.'s current opinion and expectations of a likely outcome. They do not anticipate possible changes in governmental policies, governmental regulations, military action, embargoes or production cutbacks, regional conflicts or other events or factors that could cause forecasts or estimates to differ materially from what is contained in Worley Group Inc.'s forward-looking statements. The report is dated as of the date Worley Group Inc. completed its work. Worley Group Inc. has no obligation to update or revise the report or to revise any opinions, forecasts or assumptions because of events, circumstances or transactions occurring after the date of the report.

Table of contents

1. Introduction.....	6
2. Background.....	9
2.1 A summary of the battery value chain.....	9
2.1.1 Overview of the lithium-ion battery value chain	9
2.1.2 Detailed manufacturing process stages	12
2.1.3 Production capacity and scale	13
2.1.4 Geographic considerations for cell manufacturing.....	13
2.1.5 Environmental impact and sustainability	14
2.1.6 Technological advancements and future trends.....	14
2.2 Cost of manufacturing	15
2.2.1 China	15
2.2.2 Other Asia.....	16
2.2.3 United States.....	17
2.2.4 Europe	17
3. Demand sectors.....	18
3.1 Transportation	18
3.1.1 Automotive	18
3.1.2 Aerospace	22
3.1.3 Industrial	23
3.1.4 Marine.....	23
3.2 Stationary storage.....	24
3.2.1 Global overview	24
3.2.2 Front of the meter storage	24
3.2.3 Behind the meter storage	24
3.3 Consumer electronics.....	27
3.3.1 Global overview	27
3.3.2 Regional demand.....	27
3.4 LIB demand by chemistry	29
3.4.1 Lithium iron phosphate.....	30
3.4.2 Nickel based chemistries.....	32
3.4.3 Other chemistries	34
4. Battery manufacturing.....	37
4.1 Battery investment plans	37
4.1.1 China	37
4.1.2 Other Asia.....	37
4.1.3 North America	38
4.1.4 Europe	39
4.1.5 Oceania	39
4.2 Location analysis	41
4.2.1 Proximity to raw materials	41
4.2.2 Availability of skilled labor.....	41
4.2.3 Infrastructure and utilities.....	41

4.2.4	Government incentives and policies	42
4.2.5	Environmental considerations	43
4.2.6	Access to markets	43
4.2.7	Political and economic stability.....	43
4.2.8	Future growth potential	43
4.2.9	Return on investment opportunity by region	43
4.3	Supply demand gap analysis	45
4.3.1	Asia-Pacific.....	46
4.3.2	North America	48
4.3.3	Europe	49
5.	Battery materials.....	52
5.1	Demand.....	52
5.1.1	Overview of anode materials in LIBs	52
5.1.2	Global demand for LIB anode materials	53
5.2	Investment plans	56
5.3	Supply demand gap analysis	58
5.3.1	Global demand for anode materials	58
5.3.2	Regional supply demand analysis	59
5.4	Import/Export dynamics.....	67
5.4.1	Exporting countries.....	67
5.4.2	Importing Countries.....	69
6.	Deep dive into anode materials	72
6.1	Cost of Manufacturing	72
6.1.1	China	72
6.1.2	South Korea and Japan	73
6.1.3	United States.....	74
6.1.4	Europe	74
6.1.5	Other regions (Canada, Australia, and India).....	75
6.2	Estimation of carbon footprint.....	76
6.3	Natural graphite.....	79
6.3.1	Mine production and reserves	80
6.4	Synthetic graphite	82
6.4.1	Coal tar pitch.....	84
6.4.2	Petroleum coke	85
6.5	Emerging anode material compositions	94
6.5.1	Silicon anode material	95
6.5.2	Lithium-Titanate.....	97
6.5.3	Lithium metal-based anode	98
6.5.4	Niobium based anode.....	99
6.5.5	Polymer and recycled based anode	99
6.5.6	Other Emerging Technologies	99
6.6	Margin analysis	104
6.6.1	Synthetic graphite	104
6.6.2	Natural graphite	104
7.	Policy Landscape	105

7.1	China	105
7.2	Other Asia.....	107
7.2.1	Korea	107
7.2.2	India	107
7.3	North America	109
7.4	Europe	110
7.4.1	Russia	111
7.5	Australia	112
8.	Second Life Use and Recycling	114
8.1	Reuse.....	114
8.2	Recycling	115
8.2.1	Pretreatment.....	115
8.2.2	Recovery	116
8.2.3	Sustainability.....	117
8.3	Overview of anode material recycling.....	117
8.3.1	Pretreatment.....	117
8.3.2	Recovery	118
8.4	Historical and forecast of recycling market.....	122
8.5	Policy measures to support recycling	123
8.5.1	Strategic Plans.....	123
8.5.2	Financial Incentives	125
8.5.3	Extended Producer Responsibility	126
8.5.4	Cross-Border Trade.....	127
9.	Challenges and risk mitigation	128
9.1	Scaling up	128
9.2	Project financing	129
9.3	Infrastructure challenges	131
9.4	Value chain challenges	131
9.4.1	Land use conflicts.....	131
9.4.2	Battery mineral supply sustainability.....	132
9.4.3	Geopolitical considerations.....	133
9.4.4	Environmental, social, and governance challenges	134
9.4.5	Risk mitigation techniques	135
9.5	Energy Demands in Battery Manufacturing.....	136
9.6	Global adoption.....	137
10.	Conclusion.....	138

List of tables

Table 1: Sustainability initiatives.....	14
Table 2: ROI opportunity by region	45
Table 3: Cancelled and postponed gigafactories in Europe since 2022	51
Table 4: Natural and synthetic graphite manufacturers outside of China	57

Table 5: Contributing factors to cost of manufacturing (by %)	76
Table 6: Carbon footprint by cathode chemistry.....	78
Table 7: Graphite production and reserves	81
Table 8: 2024 Needle coke production capacity by region.....	91
Table 9: Emerging anode materials	95
Table 10: Silicon anode manufacturers.....	97
Table 11: Challenges of reuse by category	115
Table 12: Graphite recovery methods	120
Table 13: Potential applications for recycled graphite	121
Table 14: Recycling capacity by region.....	122
Table 15: Contracts and associated ownership of risk	130
Table 16: Supply chain challenges and risk mitigation	136
Table 17: List of abbreviations.....	142

List of figures

Figure 1: Key stages of battery value chain	9
Figure 2: Manufacturing process stages	12
Figure 3: Cost of manufacturing in selected region/country	15
Figure 4: Global demand for LIBs in EVs.....	18
Figure 5: EV growth drivers	19
Figure 6: Regional demand for LIBs in EVs.....	21
Figure 7: Aerospace growth drivers	23
Figure 8: LIB demand for ESS	25
Figure 9: ESS growth drivers.....	26
Figure 10: LIB demand for consumer electronics.....	27
Figure 11: Consumer electronics growth drivers	28
Figure 12: Material requirement by chemistry	29
Figure 13: LIB demand by chemistry	30
Figure 14: LFP demand for EVs.....	31
Figure 15: LFP demand for ESS	32
Figure 16: Nickel based chemistry demand for EVs	33
Figure 17: Nickel based chemistry demand for ESS.....	34
Figure 18: LMFP manufacturers	34
Figure 19: Other chemistry LIB demand for EVs	35
Figure 20: Other chemistry LIB demand for ESS	36
Figure 21: Lithium-ion cell manufacturing capacity by region	40
Figure 22: Cost of electricity by region (March 2024).....	42
Figure 23: Global LIB manufacturing capacity vs demand.....	46
Figure 24: China's LIB manufacturing capacity vs demand.....	47
Figure 25: Rest of Asia's LIB manufacturing capacity vs demand	48
Figure 26: North America's LIB manufacturing capacity vs demand.....	49
Figure 27: Europe's LIB manufacturing capacity vs demand.....	50
Figure 28: Demand by anode material	53

Figure 29: Demand by other anode material	54
Figure 30: Regional anode demand by kmt	55
Figure 31: Supply demand gap analysis for anode material	59
Figure 32: China supply demand gap.....	60
Figure 33: Other Asia supply demand gap	61
Figure 34: North America supply demand gap	63
Figure 35: Europe supply demand gap	64
Figure 36: Rest of world supply demand gap.....	66
Figure 37: Supply demand gap by region	67
Figure 38: Top 5 synthetic graphite exporting countries.....	68
Figure 39: Top 5 natural graphite exporting countries.....	69
Figure 40: Top 5 importing country for synthetic graphite	70
Figure 41: Top 5 importing country for natural graphite.....	71
Figure 42: Factors influencing manufacturing costs	72
Figure 43: Key factors of battery anode production costs in China	73
Figure 44: Key factors of battery anode production costs in South Korea and Japan.....	73
Figure 45: Key factors of battery anode production costs in the United States.....	74
Figure 46: Europe - key factors impacting battery anode production costs	75
Figure 47: Lifecycle analysis.....	77
Figure 48: Regional demand for natural graphite	80
Figure 49: Regional demand for synthetic graphite.....	83
Figure 50: Synthetic graphite manufacturing from coal tar pitch.....	84
Figure 51: Coal tar pitch demand for synthetic graphite.	85
Figure 52: Synthetic graphite manufacturing from petroleum coke	86
Figure 53: Petroleum coke demand for synthetic graphite	87
Figure 54: Regional petroleum based needle coke demand	88
Figure 55: Regional calcined petroleum coke demand	89
Figure 56: Regional green petroleum coke demand	91
Figure 57: 2023 vs 2024 needle coke operating rates by region	92
Figure 58: Needle coke capacity	93
Figure 59: Needle coke supply demand gap	94
Figure 60: Lithium metal manufacturers.....	98
Figure 61: FOAK roadmap.....	128