GOLDEN DRAGON CAPITAL

TERNARY CATHODE MATERIAL

Market Research Report

Author: Brendan Jephcott

Date: September 2024

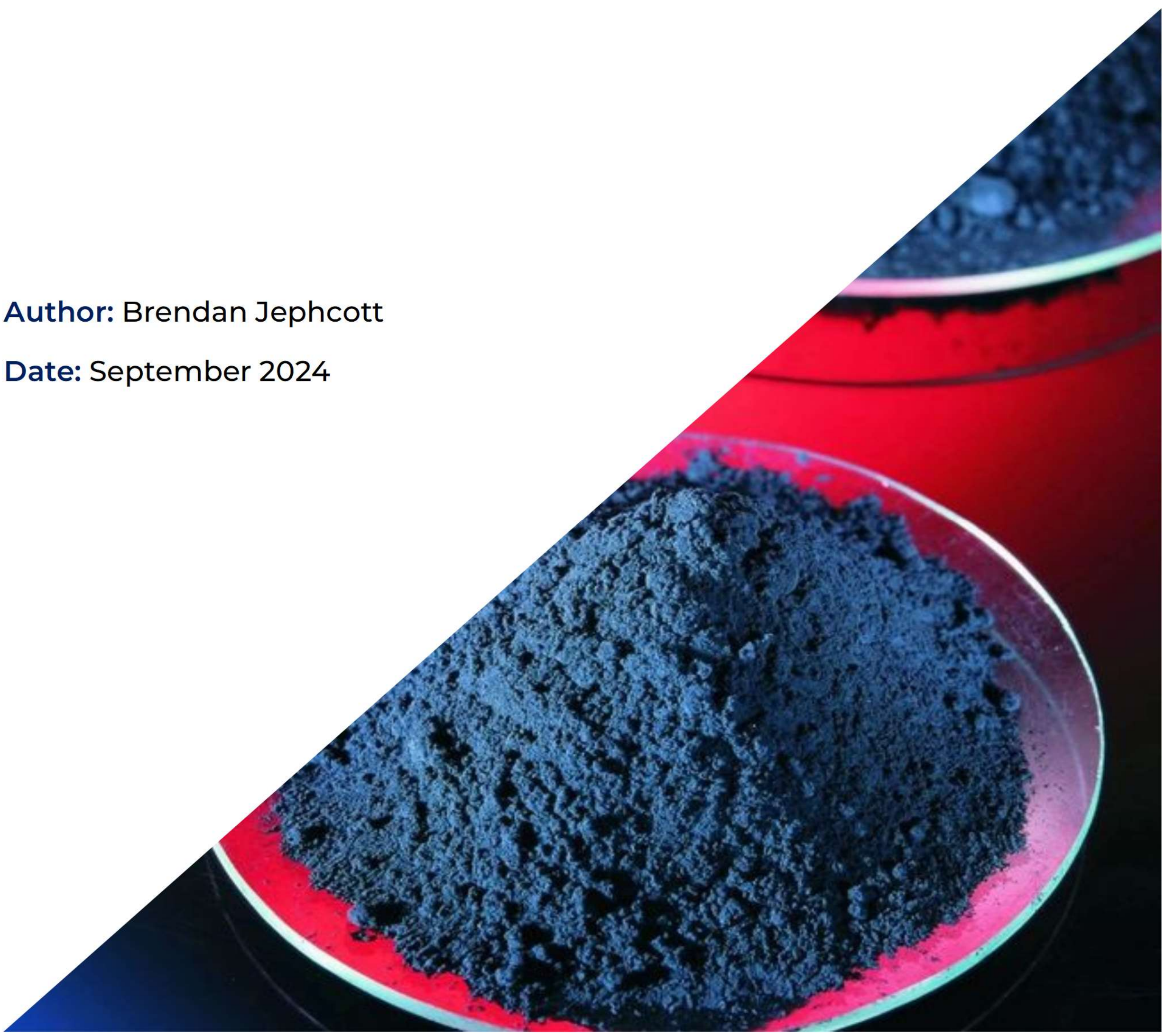

Table of Contents

Executive Summary 2

1.0 Introduction 12

1.1 Ternary Cathode Material Industry Development Trends 12

1.2 Lithium-Ion Battery Technology 15

1.3 Comparison of Mainstream Cathode Materials 21

1.4 Cathode Positioning within the Industry Chain 23

2.0 Ternary Cathode Material 24

2.1 Layered Cathode Oxide Structure 24

2.2 Ternary Material Working Principal 27

2.3 Ternary Material Product Performance 31

2.3.1 Advantages 32

2.3.2 Disadvantages 34

3.0 Ternary Cathode Material Processing Methods 40

3.1 Overview 40

3.1.1 Solid State Method 41

3.1.2 Co-precipitation Method 42

3.1.3 Sol-gel Method 43

3.1.4 Hydrothermal Method 43

3.1.5 Combustion Method 43

3.1.6 Spray Drying Method 44

3.2 Synthesizing Ternary Materials by Hydroxide Co-precipitation-Solid Phase Calcination 44

3.2.1 Production Method 44

3.2.2 Raw Materials 50

3.2.3 Lithiation Mixing 54

3.2.4 Loading 57

3.2.5 Calcination Process 59

3.2.6 Crushing 63

3.2.7 Classification 64

3.2.8 Iron Removal 65

3.2.9 Washing 65

3.2.10 Packing 67

3.3 Synthesizing NCA Ternary Materials 68

3.3.1 Production Method 68

3.4 Ternary Product Modification Methods 69

3.4.1 Element Doping Method 69

3.4.2 Surface Coating Method 70

3.4.3 Core Shell Structure 71

3.4.4 Single Crystal 72

Address: 4th Floor, 9 Queen's Road Central, Central, Hong Kong, China

Phone: +852 4647 0122
Email: brendan@goldendragoncapital.com
Website: www.goldendragoncapital.com

4.0 Chinese Ternary Cathode Material Standards ... 76
4.1 NCM Ternary Cathode Material ... 77
4.1.1 YS/T 798-2012 Lithium Nickel Cobalt Manganese Oxide ... 77
4.1.2 YS/T 1448-2021 Coated Lithium Nickel Cobalt Manganese Oxide ... 79
4.1.3 YS/T 1520-2022 Doped Lithium Nickel Cobalt Manganese Oxide ... 80
4.2 NCA Ternary Cathode Material ... 82
4.2.1 YS/T 1125-2023 Lithium Nickel Cobalt Aluminium Oxide ... 82
4.2.2 YS/T 1614-2023 Doped and Coated Lithium Nickel Cobalt Aluminium Oxide ... 84
5.0 Competitive Landscape ... 87
5.1 China Ternary Cathode Material Production ... 87
5.2 Overseas Ternary Cathode Material Production ... 92
5.2.1 Japan ... 92
5.2.2 South Korea ... 95
5.2.3 United States ... 102
5.2.4 Europe ... 103
6.0 Market Pricing ... 107
6.1 Ternary Cathode Material ... 107
7.0 Market Size Forecast ... 110
References ... 113
Appendix 1: Ningbo Ronbay New Energy Technology Co., Ltd ... 118
1.0 Ningbo Ronbay New Energy Technology Co., Ltd ... 119
1.1 Corporate Overview ... 119
1.2 Ternary Cathode Material Business ... 120
1.3 Financials (1 USD ~ 7 CNY) ... 136
Disclaimer ... 141

Figures

Figure 1: Transition metal characteristics of NCM cathode material ... 12
Figure 2: Timeline of the development of NCM cathode material from low Ni content to high Ni content (source: Wang, X. et al 2020) ... 13
Figure 3: Parts of a Lithium-ion Battery ... 16
Figure 4: Charging of a Lithium-ion Battery ... 16
Figure 5: Discharging of a Lithium-ion Battery ... 17
Figure 6: Component materials and auxiliary materials used to manufacture cathode material ... 18
Figure 7: Schematics of inner structures of commercial Lithium-ion Batteries. ... 19
Figure 8: Lithium-ion battery cost structure ... 20
Figure 9: Lithium-ion battery component material cost structure ... 20
Figure 10: Cost structure of new energy vehicles ... 21
Figure 11: Power system average cost composition ... 21
Figure 12: Radar chart of cathode material types and their product indicators ... 23
Figure 13: Discharge profiles of cathode material types ... 23
Figure 14: Cathode positioning within the industry chain ... 24
Figure 15: Cathode material industry chain ... 24
Figure 16: Representative O3 structure ... 25
Figure 17: (a) Schematic of NCM111 crystal structure (b) Schematic of ion-ordering in NMC111 TM layers ... 25
Figure 18: NCM crystal structure showing Wyckoff positions ... 26
Figure 19: NCM lithium-ion pathway ... 26
Figure 20: NCM Li-ion diffusion, tetrahedral site pathway (route I), and oxygen dumbbell pathway (route II) ... 27
Figure 21 : Schematic band structure depicting the various transition metal redox energy levels ... 28
Figure 22 : TM–O octahedral complexes in NCM ... 29
Figure 23 : Occupation percentage of Ni^{2+}/Ni^{3+} and Co^{2+}/Co^{3+} cations as the NCM composition varies ... 30
Figure 24 : Typical profile of differential capacity vs. electrode voltage for Ni rich NCM ... 31
Figure 25 : Discharge capacity, thermal stability & capacity retention of NCM material with different Ni contents ... 32
Figure 26 : Voltage vs charge/discharge capacity curves of NCM cathode material ... 33
Figure 27 : Problems and challenges of Ni-rich layered oxides ... 35
Figure 28: Increasing the Ni content effects capacity retention ... 35
Figure 29 : Microcracking generation and electrolyte penetration ... 39
Figure 30 : DSC thermal decomposition temperature of NCM cathode material (x=Ni molar fraction) ... 40
Figure 31 : Comparison of low to medium nickel and high-nickel ternary cathode material processing ... 46
Figure 32: pCAM principal production processing flowsheet ... 50
Figure 33: Relationship between the specific capacity, cycle performance and lithiation ratio of the ternary cathode material NCM523 ... 53
Figure 34: Schematic diagram of lithium mixing process ... 54
Figure 35: Characteristics of ternary cathode material mixing equipment ... 55
Figure 36: Tilt drum mixer ... 55
Figure 37: High-speed mixer ... 56
Figure 38: Sagger used for calcination of ternary cathode materials ... 57
Figure 39: Sample picture of ternary cathode material sagger ... 58
Figure 40 : Comparison of calcination temperatures of several common ternary materials ... 60
Figure 41: Pusher kiln picture ... 61
Figure 42: Roller kiln picture ... 61
Figure 43: Four-row single-layer roller kiln (left), double-row three-layer roller kiln (right) ... 62
Figure 44: Particle size distribution of materials before classification ... 64
Figure 45: Particle size distribution of materials after classification ... 64
Figure 46: The effect of the number of washing times on the pH of high nickel ternary cathode ... 66
Figure 47: The morphology of high nickel ternary cathode before washing ... 66
Figure 48: The morphology of high nickel ternary material after washing ... 66
Figure 49: Finished ternary material packaging diagram ... 67

Figure 50: Ternary cathode material (illustrative) ... 67
Figure 51: NCA cathode material production route with NCA precursor ... 68
Figure 52: NCA cathode material production route with NiCo precursor and Al ... 68
Figure 53: NCA cathode material production route with NiCo precursor and Al_2O_3 ... 68
Figure 54: Schematic ternary product modification by element doping and surface coating ... 69
Figure 55: Inorganic coating process for NCM cathode materials ... 71
Figure 56: Difference between the core–shell and concentration-gradient Ni-rich ternary material ... 72
Figure 57: Morphological and interfacial changes of polycrystalline and single crystalline cathode during electrode pressing and electrochemical cycling ... 73
Figure 58: SEM image comparison of single crystal (left) and polycrystalline (right) cathode materials ... 73
Figure 59: Preparation processes of single crystal high-nickel cathode materials ... 74
Figure 60: Changes in China's ternary and LFP battery market share (2017 to 2023) ... 87
Figure 61: China cathode material shipments (2014 to 2023) ... 88
Figure 62: China cathode material shipments by type x10,000t (2014 to 2023) ... 88
Figure 63: China cathode material product market share (2023) ... 88
Figure 64: Global ternary cathode material production (2022 and 2023) ... 89
Figure 65: China ternary cathode material production (2018 to 2023) ... 89
Figure 66: China ternary cathode material market structure (2020 to 2023) ... 90
Figure 67: China ternary cathode material market share (2023) ... 90
Figure 68: Shipment market share of each ternary cathode material product (2020 to 2023) ... 91
Figure 69: Sumitomo Metal Mining three major businesses ... 92
Figure 70: Sumitomo Metal Mining cathode material production forecast (2025 to 2030) ... 93
Figure 71: Sumitomo Metal Mining cathode material customer structure ... 93
Figure 72: Nichia Corporation cathode materials ... 94
Figure 73: EcoPro BM's CAM 7 cathode manufacturing facility in Pohang, South Korea ... 95
Figure 74: EcoPro BM NCA energy density ... 96
Figure 75: EcoPro BM NCM core shell gradient technology ... 96
Figure 76: POSCO Future M planned production capacity (2023E to 2026E) ... 97
Figure 77: POSCO Future M domestic sites ... 98
Figure 78: POSCO Future M Gwangyang cathode material plant ... 98
Figure 79: POSCO Future M Pohang cathode material plant ... 99
Figure 80: LG Chem Cheongju cathode material plant ... 100
Figure 81: LG Chem manufacturing process of cathode materials ... 100
Figure 82: L&F NCM cathode materials ... 101
Figure 83: L&F business sites ... 102
Figure 84: BASF's global layout of battery materials sites ... 103
Figure 85: Umicore's 20-year innovation process in the field of cathode materials ... 105
Figure 86: Umicore global layout of battery materials sites ... 105
Figure 87: Jiangmen Umicore Changxin New Materials Co., Ltd ... 106
Figure 88: Umicore Cheonan South Korea ... 106
Figure 89: Umicore Nysa gigafactory Poland ... 107
Figure 90: Simplified overview of the CAM production process in Nysa ... 107
Figure 91: Ternary cathode material prices Dec 2019 to Jun 2024 (CNY per tonne) ... 109
Figure 92: Ternary pCAM prices Dec 2019 to Jun 2024 (CNY per tonne) ... 109
Figure 93: Lithium salt prices Jan 2019 to Jul 2024 (CNY per tonne) ... 110

Address: 4th Floor, 9 Queen's Road Central, Central, Hong Kong, China

Phone: +852 4647 0122
Email: brendan@goldendragoncapital.com
Website: www.goldendragoncapital.com

Tables

Table 1: Classification and composition of NCM and NCA cathode materials....14
Table 2: Comparison of mainstream ternary cathode material products....14
Table 3: Comparison of mainstream cathode materials used in high-performance lithium-ion batteries....22
Table 4: Comparison of the characteristics of Mn, Co, and Ni in NMC cathodes....28
Table 5: Comparison of various ternary cathode material synthesis methods....41
Table 6: Main raw and auxiliary materials of ternary material production line....46
Table 7: Summary of the core process and equipment used in the preparation of ternary materials....47
Table 8: Comparison of common ternary and high nickel ternary processes and equipment....47
Table 9: Main factors affecting the capacity of ternary materials....48
Table 10: Main factors affecting the rate of ternary materials....49
Table 11: Main factors affecting the specific surface area of ternary materials....50
Table 12: Lithium source selection for high-nickel ternary cathode materials....52
Table 13: Effects of different lithium ratios of NCM622 materials on material cycle performance....53
Table 14: Effects of different types of additives....54
Table 15: Differences between low-medium and high nickel ternary cathode lithium mixing processes....54
Table 16: Comparison of the main advantages and disadvantages of ternary material mixing equipment. 56
Table 17: Comparison of performance of saggers of different materials....58
Table 18: Differences between the calcination processes of high-nickel ternary cathodes and low-medium ternary cathodes....60
Table 19: Comparison of push plate kiln and roller kiln....61
Table 20: Requirements for kiln equipment for high-nickel and low-medium nickel ternary cathode materials....62
Table 21: Performance comparison of common crushing equipment....63
Table 22: Sources of metal impurities in the preparation of ternary cathode materials....65
Table 23: Comparison of the advantages and disadvantages of two types of iron removal equipment....65
Table 24: Research and mass production progress of high-nickel single crystal products of leading China cathode companies....75
Table 25: Relevant standards for lithium nickel cobalt manganese oxide....76
Table 26: Relevant standards for lithium nickel cobalt aluminium oxide....77
Table 27: Major China ternary cathode material companies' production capacity (2021 to 2025E)....91
Table 28: China ternary cathode material market share concentration....91
Table 29: Major China ternary cathode material companies' products....91
Table 30: Sumitomo Metal Mining NCA capacity expansion 2015 to 2019....93
Table 31: POSCO Future M Co., Ltd — Cathode material products....97
Table 32: 3M main NCM patents....103
Table 33: BASF SE battery material locations....104
Table 34: Global demand for ternary lithium-ion batteries....111
Table 35: Calculation of global demand for ternary cathode materials (1 USD ~ 7 CNY)....111

Address: 4th Floor, 9 Queen's Road Central, Central, Hong Kong, China

Phone: +852 4647 0122
Email: brendan@goldendragoncapital.com
Website: www.goldendragoncapital.com