國立政治大學商學院國際經營管理英語
碩士學位學程
International MBA Program
College of Commerce
National Chengchi University

碩士論文
Master's Thesis

電池回收產業介紹與台灣市場發展潛力之分析

The Lithium-ion Battery Recycling Business and Its Potential Growth in Taiwan Market

Student: Jason Chen

Advisor: Professor Jack Wu

中華民國一一〇年七月

July 2021

DOI:10.6814/NCCU202101276

電池回收產業介紹與台灣市場發展潛力之分析

The Lithium-ion Battery Recycling Business and Its Potential Growth in Taiwan Market

研究生：陳昱傑　　Student: Jason Chen

指導教授：吳文傑　　Advisor: Jacky Wu

國立政治大學

商學院國際經營管理英語碩士學位學程

碩士論文

A Thesis

Submitted to International MBA Program

National Chengchi University

in partial fulfillment of the Requirements

for the degree of

Master

in

Business Administration

中華民國一一〇年七月

July 2021

DOI:10.6814/NCCU202101276

Acknowledgements

In the process of writing this thesis, I have received great support and assistance.

I would first like to thank my thesis advisor Jack Wu (吳文傑), of the International MBA Program at the National Chengchi University. Professor Jack provided me with his expert knowledge of the industry, offered me the required resource, and encourage me to think as a macro-scope. His patient and instant feedback completed my thesis.

I would also appreciate the IMBA Office and Faculty. They have always been supportive constantly during these two years of my learning. Meanwhile, the selfless devotion distributed by all my classmates gave me great memories and experiences in the program.

In the end, I will like to express my gratitude to my family and colleagues for their encouragement and support throughout the two years of study. Without their support, I could not have had such an opportunity to pursue and complete my graduate studies.

Thank you.

DOI:10.6814/NCCU202101276

Abstract

The Lithium-ion Battery Recycling Business and Its Potential Growth in Taiwan Market

By

Jason Chen

The lithium-ion battery is an energy powering solution that is widely used in electric devices nowadays. Accompany the rapid growth of the electric vehicle market, and the key battery manufactures have increased their capacity to catch the market ramp-up. The battery cell and brand makers are developing the lithium-ion battery recycling business and creating a circular economy.

This thesis will specifically discuss the lithium-ion battery market from the overview, forecast, and the current key manufacturers. It will also introduce the recycling business, the existing players, and solutions to determine opportunities to approach the recycling market in Taiwan.

Keywords: Lithium-ion Battery, Electric Vehicle, Recyclers, Circular Business, Sustainability

DOI:10.6814/NCCU202101276

TABLE OF CONTENTS

DOI:10.6814/NCCU202101276

DOI:10.6814/NCCU202101276

List of Figures and Tables

DOI:10.6814/NCCU202101276

DOI:10.6814/NCCU202101276

1. Introduction

The lithium-ion battery is a type of rechargeable battery widely used in mobile devices, the energy storage system (ESS), and the electric vehicle (EVs) market. Service in the sales department of one of the largest Lithium-ion batteries manufacture company LG Energy Solution, I have experienced the market's rapid growth during the blooming of the EVs market ramp up and the upside demand for the mobile devices during the pandemic time.

Accompany that more and more suppliers enter the lithium-ion battery market; the total manufacturing capacity of the Li-ion battery keeps breaking the peak year by year. With the continuously growing demand generated from the high adoption of electric vehicles for lithium-ion batteries, the leading manufacturing brands have devoted themselves to the recycling business to create a circular economy cycle that reserves a steady material supply and a steady price.

The average life cycle of the lithium-ion battery is 5 to 10 years, and according to Bloomberg research, the retired batteries from the EV market will reach 7 million tons in 2030. Taiwan is located in the center of the APAC region and has a long-term partnership with the key battery suppliers in China, Japan, and South Korea. The recycling business is the next generation for the energy business that Taiwanese firms and startups have the advantages to participate with great business potential growth.

In my following thesis research, I will focus on the global market trend, recycling business overview with its potential growth, and approach opportunity for Taiwanese firms.

DOI:10.6814/NCCU202101276

2. Lithium Battery Market Overview

Akira Yoshino developed the first prototype of lithium-ion batteries in 1985. Sony Corporation successfully launched the first commercial 18650 lithium battery (size with diameter 18mm, high 65mm) in their best seller products, MP3 and camera, in 1991. With characteristics of high capacity and efficiency, no memory effect, low cost, long-life cycle, lightweight, the thin and smaller size of the battery pack, the lithium battery had immediately replaced the existing nickel-cadmium and NiMH battery. Currently, it is widely adopted in portable devices, energy storage systems, electric vehicles, military-used, and aerospace industries.

2.1. The Composition of Lithium-ion Battery

The lithium-ion battery is a rechargeable energy powering component with advanced technology, and lithium-ion is a key metal in the charge and discharge electrochemistry process. A lithium-ion battery is basically composed of three functional structures, a positive electrode (cathode), a negative electrode (anode), and a separator.

The connection between cathode and anode terminals in the battery cell can store and release electrochemical energy to drive an external electrical load. During the discharge, the Li-ion moves from the anode to the cathode and move from cathode to anode as the battery is charged; the process of Lithium-ion battery incorporates into the structure of the electrode material is known as intercalation. Figure 1, demonstrates the flowing map of the lithium-ion during the charging and discharging process.

DOI:10.6814/NCCU202101276

(Charging) (Discharging)

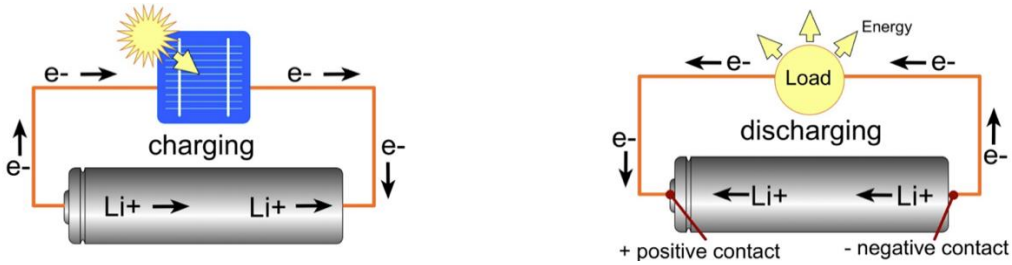

Figure 1 – The Process Flow of Battery Charging & Discharging

The separator is a polymeric membrane saturated with a liquid electrolyte that enables lithium-ion transport but prevents direct contact between the electrodes.

Lithium-ion batteries are classified according to the composition of the positive electrode (cathode) material, and Table 1 lists the five major types of cathodes that are commercially used in the market nowadays.

Table 1 - The Composition of Cathode Materials used in the Current Market

Item	Material	Abbr.	Description
1	Lithium Cobalt Oxide (LiCoO2)	LCO	Original commercial type. Expensive raw material.
2	Nickel Cobalt Aluminum (LiNi0.8Co0.15Al0.05O2)	NCA	Highest energy density
3	Nickel Manganese Cobalt (LiNi1-x-yMnxCoyO2)	NMC / NCM	Promising technology. Safter, better life-cycle.
4	Lithium Manganese Oxide (LiMn2O4)	LMO	Safer but poor life-cycle.
5	Lithium Iron Phosphate (LiFePO4)	LFP	Safest, high power and high temperature stability but low energy density.

DOI:10.6814/NCCU202101276

Limited by the current technology development, only two materials are used in electrode (anode). Carbon base and lithium Titanate are summarized in Table 2.

Table 2 – The Composition of Anode Materials used in the Current Market

Item	Material	Description
1	Carbon Base	Graphite formulations are used in the majority of Li-ion battery.
2	Lithium Titanate	Only used with LMO and NMC. Long life-cycle, excellent thermal stability and safety but lower energy density.

2.2. The Category of Lithium Battery

Categorized by the construction of the battery cell, three types of lithium-ion batteries have been designed in the market: Cylindrical, Prismatic, and Polymer.

Cylindrical cells are made by rolling long strips of cathode foil, separator, and anode foil together and inserting into a rigid stainless steel or aluminum cell housing or "can." The can is filled with liquid electrolyte, safety disks are inserted into the top, and the electrodes are welded to the outer battery terminals. The cell is hermetically sealed by crimping the top disk assembly closed. The Composition and the Structure of the cylindrical cell are demonstrated in Figure 2.

DOI:10.6814/NCCU202101276

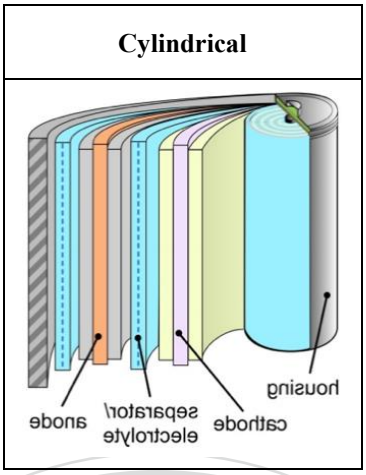

Figure 2 – The Composition and Structure of Cylindrical Cell

Prismatic cells are similar in construction to cylindrical cells but use a flat rectangular housing to lower the overall thickness of the cell. The electrode/separator assembly can be rolled, as with cylindrical cells or a rectangular stack of individual electrodes. The battery terminals can be placed as contact pads on the top or side of the housing. The prismatic cell thin form factor is well suited to consumer electronics, particularly when ease of battery replacement is desirable. The Composition and the Structure of the cylindrical cell are demonstrated in Figure 3.

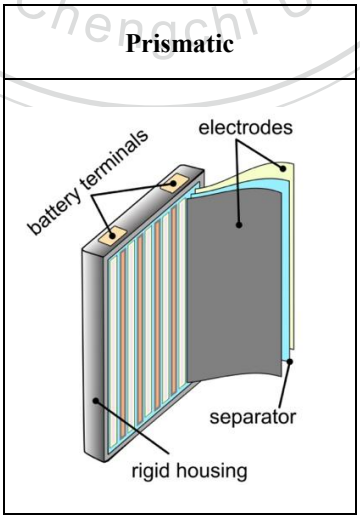

Figure 3 – The Composition and Structure of Prismatic Cell

DOI:10.6814/NCCU202101276

Polymer cells have a thin rectangular form factor. They are composed of rectangular stacks of individual electrode/separator layers, but instead of a rigid metal case, they use a laminated flexible polymer/aluminum "bag." The electrodes have tabs along one side; these are welded together with battery terminal tabs that stick out of the top of the bag. The assembly is saturated with a liquid electrolyte, and the bag is heat-sealed. By eliminating the rigid housing, pouch cells save on cost, weight, and thickness. However, the flexible pouch is prone to swelling, which can pose problems with lifetime, capacity loss, and safety. The Composition and the Structure of the cylindrical cell are demonstrated in Figure 4.

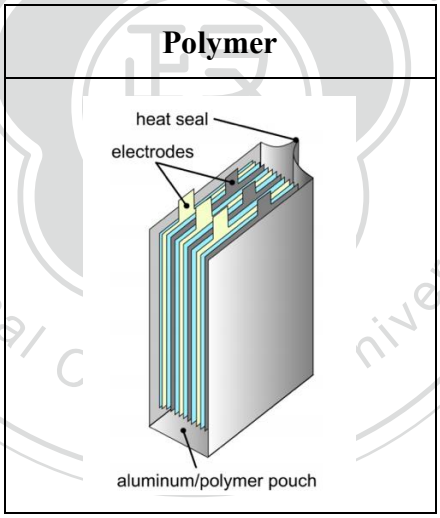

Figure 4 – The Composition and Structure of Polymer Cell

2.3. The Forecast of Lithium-Ion Battery

The global lithium-ion battery market had reached USD 44.2 billion in 2020 and is expected to reach USD 94.4 billion in 2025, with growth at a CAGR of 16.4 percent. Accompany with strong market demand driven by China, North America, and Europe due to the carbon emission policy, the electric vehicle market will dominate the lithium-ion battery market and generates

DOI:10.6814/NCCU202101276

strong market growth. The global capacity is expected to increase from 455 GWh in 2020 1,447 GWh in 2025 and 9,300 GWh in 2030. (MarketsandMarkets, 2020)

2.4. The Key Lithium Battery Cell Manufacturers

The key lithium battery cell manufacturers are majority located in the Asia region because of the early development by Panasonic and the regional advantages of the material and labor supply. In this chapter, I will have a brief introduction of the top lithium-ion battery cell suppliers globally.

Contemporary Amperex Technology Co. Limited (CATL):

CATL is the largest Chinese lithium battery manufacturer globally, established in 2011, located in Ningde, Fujian Province. It is specialized in manufacturing electric vehicles (EVs), energy storage systems (ESS), and battery management systems (BMS). Its manufacturing facilities are widely established in China and overseas, and the total capacity that CATL can generate is 50GWh in 2020.

CATL collaborates with many international EV manufacturers, including PSA, Hyundai, Honda, BMW, Daimler AG, Tesla, Toyota, Volkswagen, and Volvo.

LG Energy Solution (LGES):

LG Energy Solution, the new company spined off from LG Chemical battery division in December 2020, it is the second-largest lithium battery manufacturer globally, located in Seoul, Korea. It started the lithium battery business back in 1999.

DOI:10.6814/NCCU202101276

LGES has eight factories in South Korea. It has a network of 29 business locations in 15 countries, including a holding company in Nanjing, China, and 14 overseas manufacturing subsidiaries that can produce 48 GWh capacities in 2020. LGES is devoting to all the applications includes information Technology (Apple, Dell, Lenovo, and HP), e-Tools (Bosch), and EVs (GM, Chevrolet, Tesla, and Volkswagen). It announced to invest a USD 5 trillion to build at least two plants in the U.S and with a joint venture with G.M for a separate investment on Ultum cell.

Panasonic Corporation:

Panasonic is a Japanese multinational electronics company found in 1918 and headquartered in Kadoma, Osaka. It starts developing lithium-ion batteries in 1994 and widely uses in its consumer electronics products.

Panasonic has a famous USD 5 billion investment in Tesla Motors Gigafactory project in Storey County, Nevada, in 2014 that helps Tesla reduce the 30 percent cost. This facility can generate 24.0 GWh in 2020 compares to the total capacity of 33.0 GWh.

Samsung SDI:

Samsung SDI is a Korean-based company established in 1970. It operates two business segments: the digital display devices and the energy segment; SDI has a strong supply network generated by 26 facilities globally that support the energy business devotes to the energy storage system (ESS) and EVs markets and provides 12.8 GWh capacity in 2020.

DOI:10.6814/NCCU202101276

SDI was ranked as number 5 in global EVs power share in 2020, and it has a close relationship with European automakers, especially with BMW and Volkswagen; SDI announced in Feb 2014 that SDI would invest USD 901 million to ramp up the capacity of its plant in Hungary and hopes to expand its presence in Europe where demand for an electric vehicle is rapidly growing.

SK Innovation

SK Innovation is a South Korean enterprise spun off from SK Energy and found in 2007. SK Innovation has 30 facilities globally, and its major manufacturing plants are located in China and the USA, generating 11.5 GWh in 2020.

SK Innovation also aims at the rapid growth EV market in Europe. It invested USD 1.5 million in its Hungarian subsidiary to expand the capacity with an expected 30 GWh per year. Besides, SK Innovation signed a memorandum of understanding (MoU) with Ford for a joint-venture company called "BlueOvalSK" to manufacture battery cells in the U.S. It is expected to produce 60 GWh annually. (*SK Innovation to Invest W1.3tr in 3rd EV Battery Plant in Hungary*, 2021)

The Figure 5 and Table 3 illustrate the capacity generated by individual cell manufacturers and their allocation with market share.

DOI:10.6814/NCCU202101276

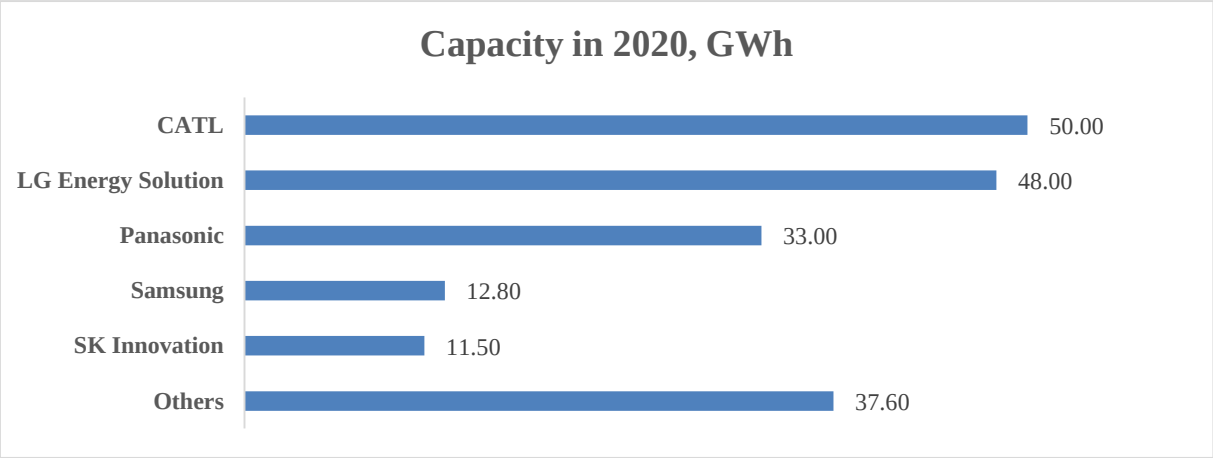

Figure 5 - The Capacity Generated by the Top of the Battery Cell Manufacturers in 2020

Table 3 – The Allocation of the Top Lithium-ion Battery Manufacturers

Rank	Company	Region	Market Share
1	CATL	China	25.9%
2	LG Energy Solution	Korea	24.9%
3	Panasonic	Japan	17.1%
4	Samsung SDI	Korea	6.6%
5	SK Innovation	Korea	6.0%
6	Others	N/A	19.5%
Total			100.0%

DOI:10.6814/NCCU202101276

3. Recycled Lithium-ion Battery Market Overview

According to the London-based research and consulting group Circular Energy Storage (CES) analysis, only 97,000 tons of end-of-life lithium-ion batteries were recycled than the total 500 thousand wasted batteries released in 2020; the collection rate was only 19.4 percent.

The most critical obstruct to promoting the recycling of lithium-ion batteries is that the cost of processing a new battery is 1.13 USD per kilogram. The value of recovered raw material is one-third of the total cost. Therefore, how to reach the economic scale of recycling scrapped lithium-ion batteries is become the bottleneck that the recyclers have to overcome before the first batch of batteries retired from the electric vehicle market in 2030.

3.1. The Forecast of the Scraped Lithium-ion Battery

To meet the global target of reducing greenhouse gas emission, the electric vehicle market has had a rapid growth to replace the gasoline-motored vehicles. However, this growth represents a critical waste-management challenge for lithium-ion battery.

The retired lithium-ion battery had reached 500 thousand tons in 2020, the majority contributed by consumer electronics. Accompany with the rapid growth of hybrid and EVs launched in the 2010s, the forecast of the retired lithium-ion battery will reach 5 million tons in 2030 that can generate USD 18 billion revenue in the recycling market compares to USD 1.5 billion in 2019. (*It's Time to Get Serious about Recycling Lithium-Ion Batteries*, 2019)

DOI:10.6814/NCCU202101276

According to Yole Development's research, the end-of-life (malfunction) lithium-ion battery has reached 253,531 tons in 2020, consumer product generates161,534 tons (64.3%), e-mobility generates 77,862 tons (30.9%), stationary storage generates 2,274 tons, and the other application generates 11,816 tons (4.8%). However, the end-of-life lithium-ion battery retired from the electric vehicle market is estimated to exceed consumer products. It generates the majority of 167,146 tons (47.2%) out of 335,567 tons in 2022 and 481,196 (68.2%) out of 704,745 tons in 2030. Figure 6 and Table 4 summarize the end-of-life batteries generated by applications.

(Unit: Tons)

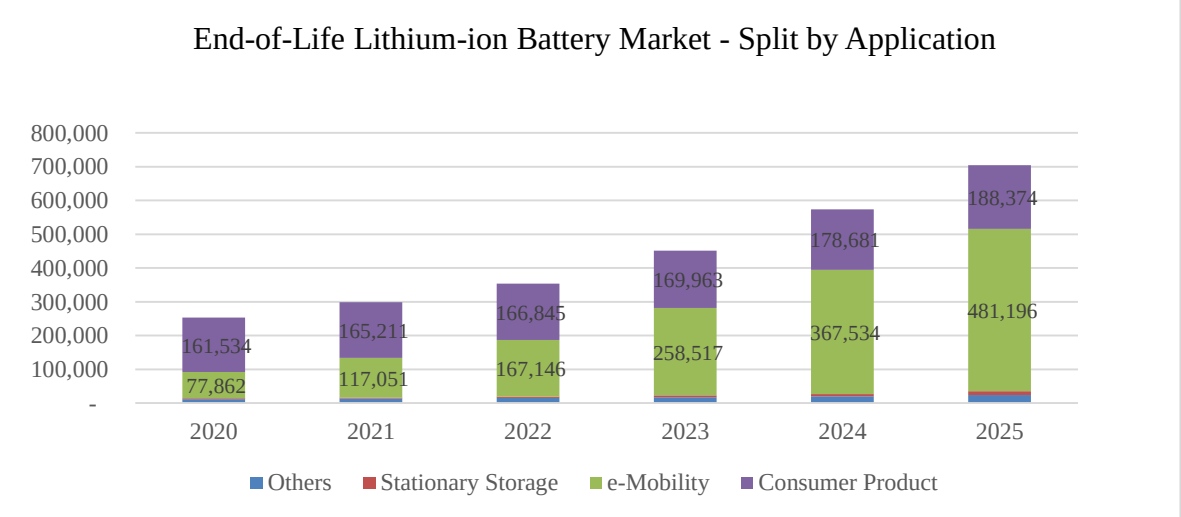

Figure 6 – The End-of-Life Batteries Generated by Applications

DOI:10.6814/NCCU202101276

Table 4 - The End-of-Life Batteries Generated by Applications

Application	2020	2021	2022	2023	2024	2025	CAGR
Others	11,861	13,335	15,433	17,539	20,232	23,959	15%
Stationary Storage	2,274	3,127	4,142	5,366	6,970	11,216	37%
e-Mobility	77,862	117,051	167,146	258,517	367,534	481,196	45%
Consumer Product	161,534	165,211	166,845	169,963	178,681	188,374	3%
Total	253,531	298,724	353,566	451,385	573,417	704,745	21%

The end-of-life batteries had generated USD 1,092 million in revenue by recycling the valuable raw material and reuse in the market. It is estimated to increase to USD 1,960 million in 2025 with a CAGR of 13 percent; most revenue is contributed by the key raw materials Cobalt, Nickle, and Lithium. The contribution of the valuable raw material is demonstrated in Figure 7 and Table 5. (*LITHIUM-ION BATTERY RECYCLING - MARKET UPDATE*, 2020)

(Unit: USD Million)

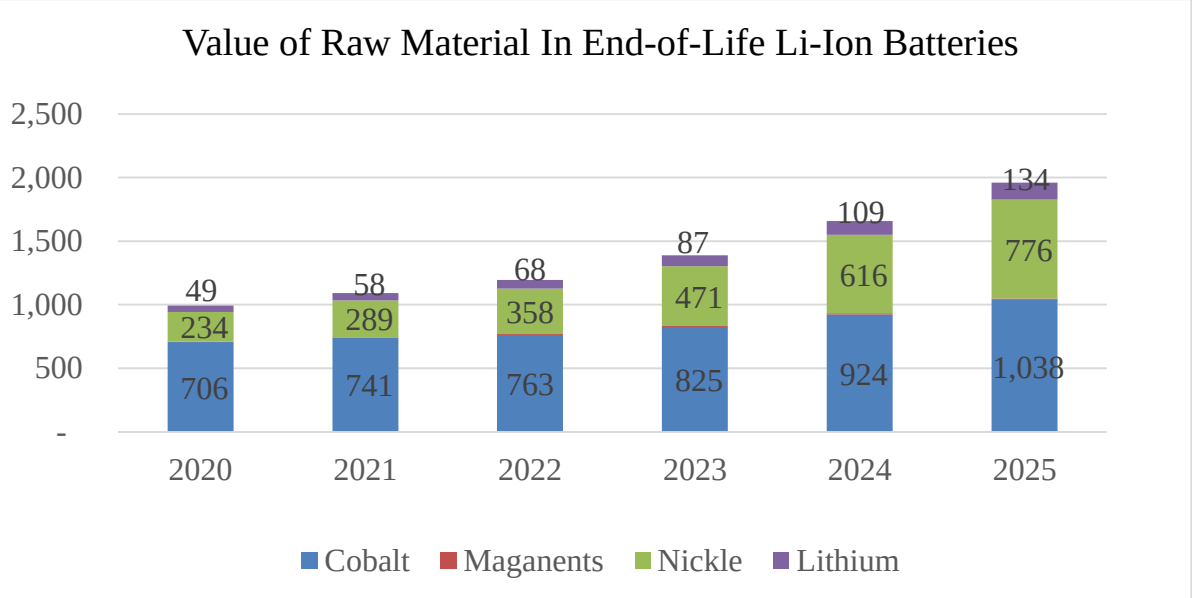

Figure 7 – The Contribution of the Valuable Raw Material in the Recycling Market.

DOI:10.6814/NCCU202101276

Table 5 - The Contribution of the Valuable Raw Material in the Recycling Market

Material	2020	2021	2022	2023	2024	2025	CAGR
Cobalt	706	741	763	825	924	1,038	7%
Magnets	4	4	6	7	10	12	26%
Nickle	234	289	358	471	616	776	26%
Lithium	49	58	68	87	109	134	21%
Total	993	1,092	1,195	1,390	1,659	1,960	13%

3.2. The Recycling Methods

Before knowing how to recycle end-of-life batteries, it is essential to understand the knowledge of the manufacturing process of the battery packs. The key raw materials are majority mined in Congo, Africa; these elements will be transported to the material processing factories before delivered to the cell manufacturers. Once the battery cells are output, they will be delivered to the pack assembly house and distributed to the users, such as Apple and Tesla, and then start their energy servicing life.

The recycling process is reverses engineering; the recyclers collect the battery packs waste from the users, categorize the batteries, disassemble them into cells, and eventually take the physical and chemical methods to separate and refine the valuable raw material. The refined raw material will be sold back to the cell makers and used for electrode manufacturing, in order to reduce cost and creating a circular economy. The circular flow can be illustrated in Figure 8 image, from material extraction, cell and pack manufacturing, battery usage, recycling as second-life, and refining as the raw material for next round production.

DOI:10.6814/NCCU202101276

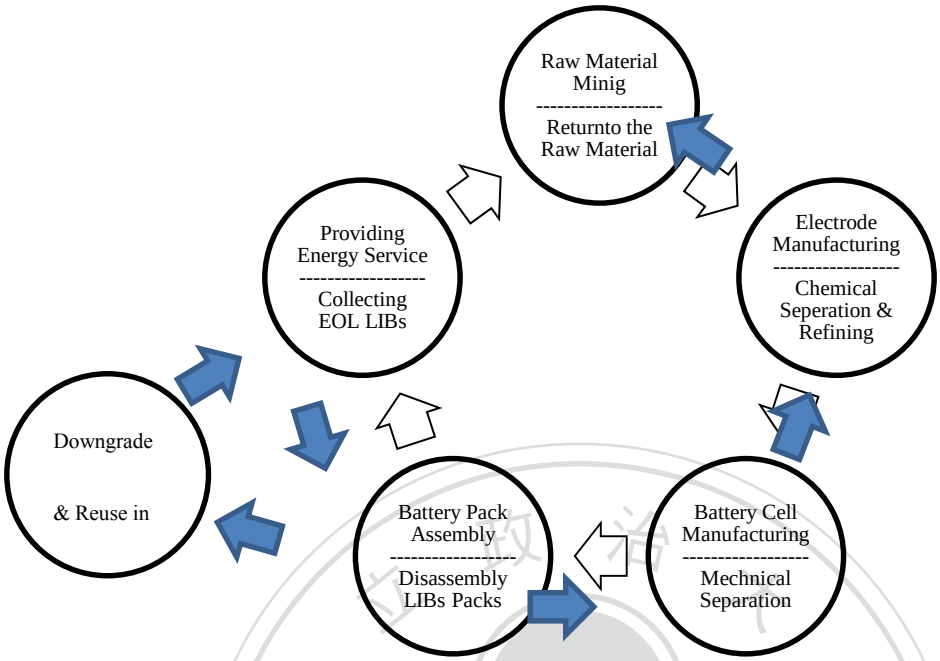

Figure 8 - Circular Economy Flow of Lithium-ion Battery

There are two existing solutions to handle batteries at end-of-life; the first solution is called "mechanical pretreatment." The recyclers would evaluate the batteries' capacity and decide to downgrade the serviceable packs and reuse them in different applications as the second-life. An Electric Vehicle comprises an average of 7,000 lithium-ion batteries cells, which can provide at least 5 to 10 years of power. However, most of the batteries still have 70 to 80 percent capacity when the vehicles reach end-of-life. These retired batteries can be reused in the EV charging stations, energy storage systems, base stations, backup power systems, and low-speed vehicles.

If the batteries are not available for downgrade market, the second solution is to recycle the malfunctions packs by hydrometallurgical and pyrometallurgical methods to refine the valuable elements like copper, aluminum, lithium carbonate, cobalt sulfate, and nickel sulfate. My research will focus on the market value generated from the hydrometallurgical and pyrometallurgical methods.

DOI:10.6814/NCCU202101276

The Pyrometallurgical Recycle Process

The pyrometallurgical process is also known as the thermal process. The recyclers will start by removing the plastic label and steel containers before heating the cathode and anode to smelt the valuable metals.

The process starts with heating in a low-temperature furnace, from 150 to 500˚C, to remove electrolytes and organic solvent. Afterward, using a high-temperature treatment from 1,400 to 1,700˚C to form alloy Co, and Slag Li2O and Li2CO3 products. Along with the thermal process, the carbothermal reduction of a spent lithium battery can be activated by slag composed of Al2O3, CaO, MgO, and SiO2. The below table summarizes the pyrometallurgical recycling of the LIBs. The process of recycling lithium-ion battery is demonstrated in Figure 9.

DOI:10.6814/NCCU202101276

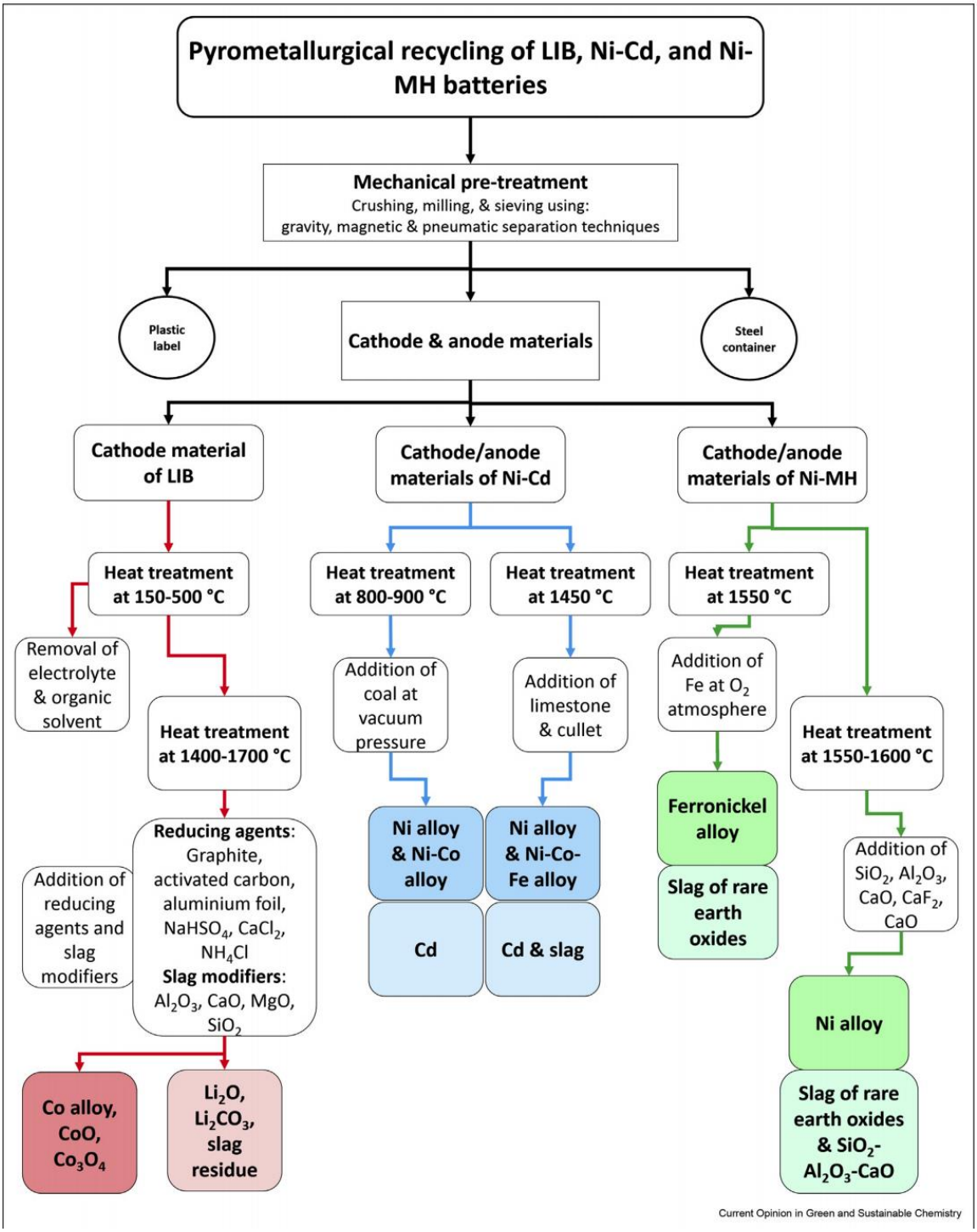

Figure 9 – The Process of Recycling Lithium-ion Battery

DOI:10.6814/NCCU202101276

4. Overview of Current Lithium-ion Battery Recycler Situation

Mentioned in the previous chapters analyze, the end-of-life lithium-ion batteries will reach the first peak in 2030, the majority generated by the retired EV and Hybrid EV (HEV) markets . Therefore, the global recyclers have been aiming at the huge battery market and cooperating with key cell manufacturers and automotive brands to create a closed-loop industry to secure their business.

4.1. The Major Lithium-ion Battery Recyclers

Brunp Recycling Technology is currently the largest battery recycler in world. It was established in 2006, as a subsidiary company by a leading lithium-ion battery maker, ACTL; it recycles various battery types, including lithium-ion nickel-hydrogen and nickel-cadmium batteries. Its plants in Hunan province can generate a capacity of 100,000 tons and its plant in Guangdong can generate 120,000 tons of battery recycling business with a 99.3 percent metal recovery rate of nickel, cobalt, and manganese.

American Battery Technology Company (ABTC, formerly American Battery Metals Corporation) is an American-owned company established in 2011. ATBC focuses on a clean-technology platform that effectively produces metal used in EVs and HEVs by closed-loop batteries recycling process. It recovers the valuable battery materials and advances them to be functional status that can be sold back to the new production. As a result, ATBC now can support recycling 200,000 tons of batteries waste per year.

DOI:10.6814/NCCU202101276

Li-Cycle is a Canadian-based company founded in 2016, and they invest 175 USD million in two recycling plants in Rochester, New York, which are the largest recycling plants in North America that can recycle 10,000 tones from all kinds of end-of-life lithium-ion batteries and recover the material and reintroduce them back to the supply chain.

Northvolt is a Swedish startup recycling company formed by the former Tesla executives Peter Carlsson in 2016 with a 40 percent stake held by Volkswagen. Its recycling plant has a capacity of 8,000 tons and will open in 2021 in Norway. Northvolt has an ambitious goal to cover 25 percent of the battery recycling market in Europe by 2030, in which recycled batteries will generate 50 percent of new battery material. Their product will be launched in drones before 2024 and penetrate to EVs in 2025.

Umicore N.V is a leading recycling company which was formed in 1989 and the headquarter is located in Brussels, Belgium with 11,000 employees globally. Their main business is refining and recycling valuable metals, and it starts providing recycling polymer lithium-ion batteries service in 2006 from all possible applications across the countries. The recycling capacity for its Hoboken, Belgium plant is 7,000 metric tons per year, representing 35,000 units of EVs, 2 million units of electric bikes, and 250 million units of mobile phones.

Battery Resourcers is a startup recycling company founded in 2015 in Worcester, Mass. It focuses on recycling lithium-ion batteries and manufactures the valuable NMC cathode. It collects the scraped batteries from manufacturing factories as raw materials and directly uses them for new products; that process recovers over 90 percent of all the material from scrapped batteries and uses less energy than regular cathode that generates zero toxic waste.

DOI:10.6814/NCCU202101276

4.2. The Cost Structure for EV Used Lithium-ion Battery

U.S Department of Energy (DOE), the leading federal agency, is in partnership with the U.S automobile industry and FreedomCAR Partnership. To assist the industrial developers in overcoming the cost barriers, service life, and abuse tolerance so that the lithium-ion technology can be rendered practical for use in EVs applications under this association, DOE and Vehicle Technology Office sponsored the Advanced Technology Department (ATD), included 5 national laboratories' engagement.

According to their research and analysis that the cost for the 25-kW minimum power-assist and 40-kW maximum power-assist for the EVs are USD 300 and USD 478 separately; the cost structures are listed as Table 6.

Table 6 – The Cost strucre of 25KW and 40KW Power-Assist Battery

		25-kW Minimum Power-Assist Battery		
Type of Material		Quantity (Kg)	Unit Cost ($/Kg)	Cost ($)
Cathode	Active Material	3.643	13.00	47.33
	SFG-6	0.228	15.00	3.42
	Carbon Black	0.228	6.82	1.55
	PVDF Blinder	0.445	10.00	4.55
	NMP Blinder Solvent	3.337	3.18	10.61
Anode				
	Active Material	3.139	10.00	31.41
	Rubber Blinder	0.292	6.00	1.75
	Aqueous Solvent	2.141	-	0
Aluminum Foil Current Collector		20.04m^2	1.00m^2	20.04
Copper Foil Current Collector		21.65m^2	2.00m^2	43.33
Separator		44.64m2	2.00m^2	89.27
Electrolyte		2.93L	16.00L	47.04
Total Material Cost				**300.30**

DOI:10.6814/NCCU202101276

		40-kW Minimum Power-Assist Battery		
Type of Material		Quantity (Kg)	Unit Cost ($/Kg)	Cost ($)
Cathode	Active Material	5.859	13.00	76.17
	SFG-6	0.366	15.00	5.49
	Carbon Black	0.366	6.82	2.50
	PVDF Blinder	0.732	10.00	7.32
	NMP Blinder Solvent	5.371	3.18	17.08
Anode				
	Active Material	5.004	10.00	50.04
	Rubber Blinder	0.465	6.00	2.79
	Aqueous Solvent	3.409	-	-
Aluminum Foil Current Collector		32.25m^2	1.00m^2	32.25
Copper Foil Current Collector		34.51m^2	2.00m^2	69.01
Separator		70.67m2	2.00m^2	141.34
Electrolyte		4.67L	16.00L	74.479
Total Material Cost				**478.46**

As the cost structures are shown, the active material from Cathode, which includes the critical, valuable materials cobalt, lithium, and manganese, takes a significant 15% allocation. It creates a business incentive for the recyclers.

4.3. The Evaluation for the Revenue of Recycle Valuable Material

Nickel, Cobalt, and Manganese are the key raw material used in the cathode formula and are the key elements that the recyclers anticipate gaining value from:

Cobalt is the most valuable material used in lithium-ion battery products. It is majority mined by Congo by 77.7% as 100,000 tons which 16.5 times compared to the second large output country, Russia. Table 7 and Figure 11 demonstrate the production, share, and allocation of the top cobalt suppliers globally.

DOI:10.6814/NCCU202101276

Table 7 - The Top Cobalt Suppliers Globally

Item	Country	Production	Share
1	Congo	100,000	77.7%
2	Russia	6,100	4.7%
3	Australia	5,100	4.0%
4	Philippines	4,600	3.6%
5	Cuba	3,500	2.7%
6	Madagascar	3,300	2.6%
7	Papua New Guinea	3,100	2.4%
8	Canada	3,000	2.3%
Total		**128,700**	**100.0%**

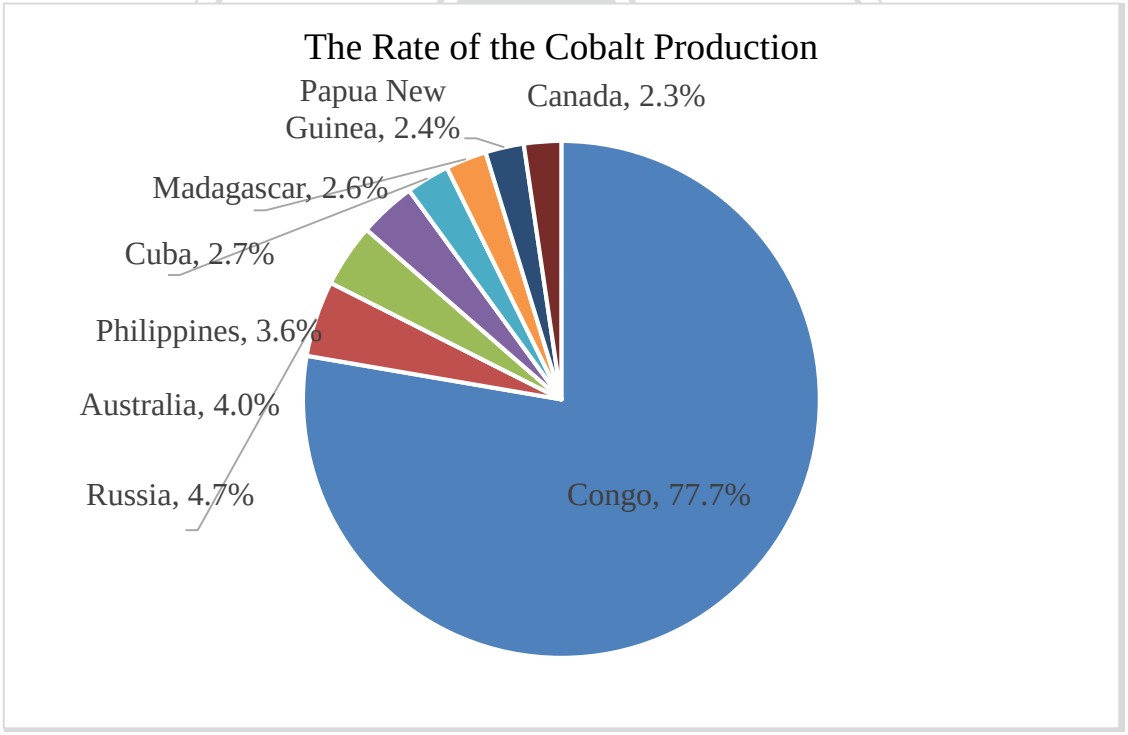

Figure 10 – The Allocation of the TOp Cobalt Suppliers Globally

According to London Metal Exchange's (LME) record, its price has increased 55.8 percent in the past decade; from USD 31,500 per ton at the beginning of 2011 to USD 49,072 per ton in May 2021, with an average price of USD 43,650 per ton.

DOI:10.6814/NCCU202101276

Based on Crux Investor, an England-based found company's data, the revenue of cobalt global market would be USD 1,585 billion in 2021 and increase to USD 5,140 billion in 2025. The cobalt historical supply/pricing trend and the expected revenue in the recycling market are listed in Figure 11 and Table 8.

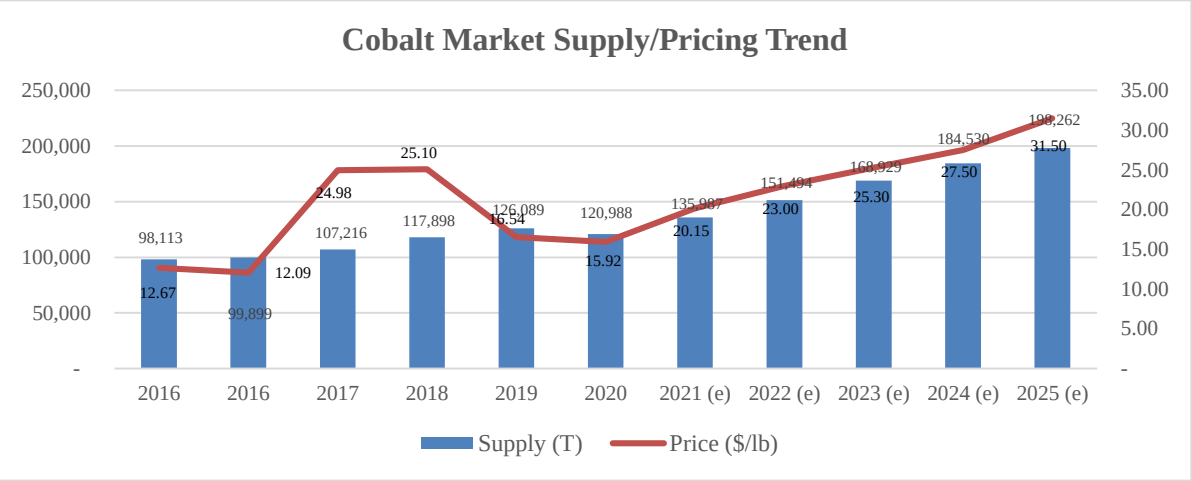

Figure 11 – The Cobalt Market Supply / Pricing Trend

Table 8 – The Expected Revenue of Cobalt Recycling Market

Year	2016	2016	2017	2018	2019	2020	2021 (e)	2022 (e)	2023 (e)	2024 (e)	2025 (e)
Supply (Ton)	98,113	99,899	107,216	117,898	126,089	120,988	135,987	151,494	168,929	184,530	198,262
Price ($/lb)	12.67	12.09	24.98	25.10	16.54	15.92	20.15	23.00	25.30	27.50	31.50
Revenue (BUSD)	**1,023**	**994**	**2,204**	**2,435**	**1,716**	**1,585**	**2,255**	**2,868**	**3,517**	**4,176**	**5,140**

Nickel is the key material to activate the cathode. To provide higher electric intensity, the weight of lithium now reaches 80% in the chemical formula in the EVs product. Lithium is majority supplied by Indonesia and Australia, which allocates 28.3 percent and 27.0 percent separately. The Table 9 lists the top nickel suppliers globally

DOI:10.6814/NCCU202101276

Table 9 - The Top Nickel Suppliers Globally

Item	Country	Production	Rate
1	Indonesia	21,000,000	28.3%
2	Australia	20,000,000	27.0%
3	Brazil	16,000,000	21.6%
4	Russia	6,900,000	9.3%
5	Cuba	5,500,000	7.4%
6	Philippines	4,800,000	6.5%
Total		**74,200,000**	**100.0%**

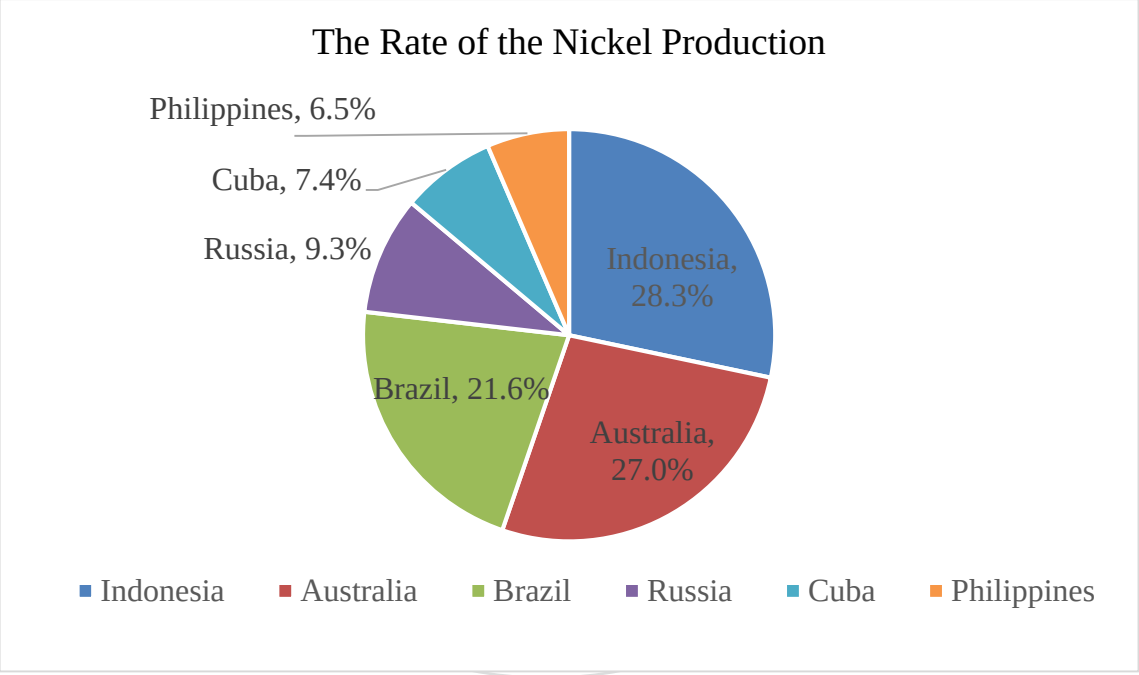

Figure 12 - The Allocation of the Top Nickel Suppliers Globally

According to the LME historical data, the nickel price has increased 90 percent in the past decade, from USD 8,660 per ton at the beginning of 2016 to USD 16,450 per ton in May of 2021. Follow to Crux, and Statista's data, the revenue of the nickel market will be estimated to reach 5,920 million USD in 2021 and 13,030 million in 2025. Figure 13 and Table 10 illustrate the market supply/pricing trend and the estimated revenue in the nickel recycling business.

DOI:10.6814/NCCU202101276

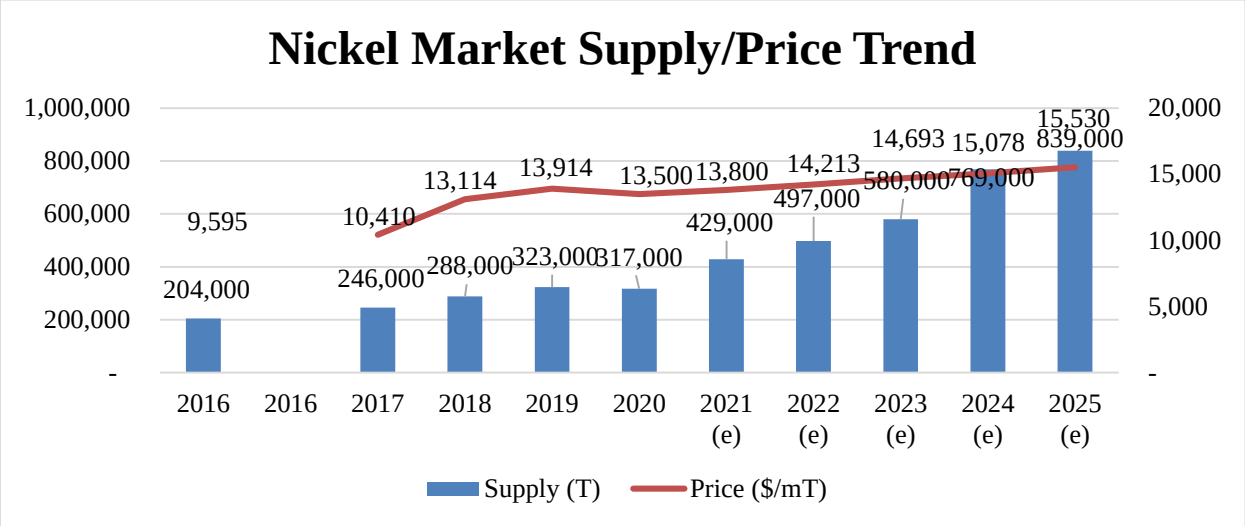

Figure 13 - The Cobalt Market Supply / Pricing Trend

Table 10 - The Cobalt Market Supply / Pricing Trend and the Estimated Revenue

Year	2016	2017	2018	2019	2020	2021 (e)	2022 (e)	2023 (e)	2024 (e)	2025 (e)
Supply (T)	204,000	246,000	288,000	323,000	317,000	429,000	497,000	580,000	769,000	839,000
Price ($/mxT)	9,595	10,410	13,114	13,914	13,500	13,800	14,213	14,693	15,078	15,530
Revenue (MUSD)	1,957	2,561	3,777	4,494	4,280	5,920	7,064	8,522	11,595	13,030

DOI:10.6814/NCCU202101276

5. The Challenge for the Lithium-ion Battery Recycling Market

Follow by the rise of environmental awareness, several European countries have announced to stop selling gasoline motor vehicles from 2025 to 2030; Japan will prohibit selling gasoline motor vehicles in the 2030s; California, USA will stop selling the same products in 2035. Meanwhile, in Asia, the Indonesian government also issues the policy to prohibit selling gasoline motor vehicles in 2040, and China is promoting the domestic EV market, estimated to reach 700 million EVs before 2050.

According to the International Energy Agency, US Department of Energy prediction, there are 140 million EVs will put on the road globally by 2030, facing the great potential of the growth of the market, maintaining a steady supply, and the price becomes the critical strategy that all the lithium-ion batteries manufacturers searching and devoting to the recycling business.

5.1. The Market Entry Barriers

Less than 5 percent of end-of-life lithium-ion batteries are recycled globally in recent years; This is because the current recyclers have yet to develop the technology to extract the components from a formed pack in large scale, the second reason is that the suppliers don't have ability to collect the enough quantity of the malfunction batteries that can help the firms reach the economically. (*It's Time to Get Serious about Recycling Lithium-Ion Batteries*, 2019)

5.1.1. Market Selecting and Penetrating

Electric vehicle market is becoming the largest battery waste source. A typical electric vehicle can have around 7 thousand battery cells, roughly equivalent to 10 kilograms of lithium in it,

DOI:10.6814/NCCU202101276

selecting the most demanding of EVs countries will help those recyclers to gather the material and entry the business. Table 11 and Figure 14 list the most EV-demanding market and the market share of individual areas globally.

Table 11 – The Most EV-Demanding Market in the World

Item	Region	Country	Unit (in Thousand)
1	APAC	China	133.1
2	North America	United States	59.1
3	EMEA	Germany	52.8
4	EMEA	France	40.0
5	EMEA	United Kingdom	33.6
6	EMEA	Norway	23.3
7	EMEA	Sweden	18.6
8	EMEA	Netherlands	12.2
9	APAC	South Korea	11.5
10	EMEA	Italy	8.5
11	EMEA	Switzerland	5.5
12	EMEA	Portugal	4.8
13	EMEA	Finland	4.7
14	EMEA	Denmark	4.2
15	EMEA	Iceland	1.4
16	APAC	Hong Kong	1.4

DOI:10.6814/NCCU202101276

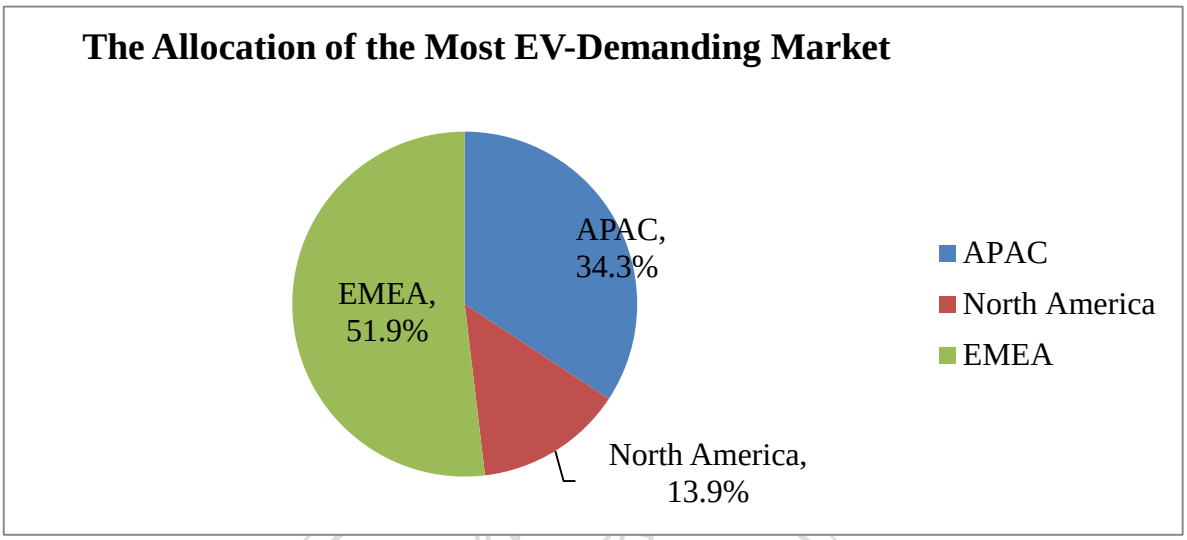

Figure 14 – The Allocation of the Most EV-Demanding Market Globally

According to McKinsey's research, the EMEA region has the strongest EVs demand with 221.1thounsand units; the APAC region has 146.0 thousand units of demand; North America has 59.1 thousand units of demand in 2020. These three regions are domaining the lithium-ion battery market, which builds the entry barriers to overseas players to run the recycling business in their own countries and compete with the existing local key recyclers.

5.1.2. Lithium-ion Battery Shipping Regulation

The lithium-ion battery is highly reactive, and its storage conditions are sensitive. In addition, high environmental temperatures, over 20 percent charging voltage, and short circuits can stimulate the batteries that cause an exothermic reaction and inflames. Therefore, the International Air Transport Association (IATA) and International Maritime Organization (IMO) have listed the lithium-ion battery as the class 9th dangerous goods, which required the specified certification UN Transport Testing (UN DOT 38.3) before loading. This regulation has become a problem for the recyclers during the delivery.

DOI:10.6814/NCCU202101276

5.1.3. The Insufficient Government Incentive Policies and Subsidies

To stimulate the penetration of electric vehicles in the domestic market, many countries have published subsidy policies to encourage drivers to switch types of gasoline vehicles to electric vehicles; among the subsidy policies, for instance the Chinese government offers the highest subsidy to a maximum of USD 7,800 to relieve buyers switching cost. The USA, Japan, France, and German have issued different subsidy policies separately, which success-driven the growth rate of the EV market. Meanwhile, the import tax reduction attracts car manufacturers and importers to launch more promotions to the market.

In contrast, with incentive policies and subsidies that promote the market to switch the types of vehicles, there is no relevant incentive strategy to encourage users to manage the end-of-life vehicles yet. Majority of owners sell the malfunctioning vehicles to the general recyclers at a low price; the valuable components will then be disassembled and sold to the second-hand market. The non-profitable parts will be disposed to land fields, including the complex and hazardous lithium-ion batteries.

5.2. Cost-Effectiveness between Mining and Recycling Raw Materials

According to the United Kingdom-based automotive manufacturing and battery company, Warwick Manufacturing Group (WMP) research, the value of an end-of-life automotive battery pack is USD 3.92 per Kg. However, the UK-based recyclers are costing USD 3.57 to USD 9.51 per Kg for the entire recycling process, includes purchasing the wasted batteries, re-processing, storage, and sell back into the market.

DOI:10.6814/NCCU202101276

Each electric vehicle manufacturer selects different lithium-ion battery cells, from the most common cylindrical 18650 to the flat prismatic and polymer models. Their specific designed specifications for the battery packs provide the best performance. Unfortunately, the variety of pack sizes, cell models, and the cathode formula multiply the difficulties in the recycling process; therefore, the recyclers are required different disassembly procedures for different battery packs, resulting in the effectiveness of the recycling process decrease.

Although the forecast predicts that the demand and the price of the valuable raw metal materials cobalt, lithium, and manganese will keep rising continuously in the following years, the Roskill, a UK-based material supply chain intelligence, indicates that the total mining cost of the most valuable material, cobalt all-in-sustaining cost (AISC) will have 2 percent decrease in 2021, which is generated by the decreasing intermedia transportation cost in South Africa, and have the improvement of operational efficiency from the key miners.

These represent that the cost-effectiveness for the recycling business hasn't reach the economies of scale and there is still room for improvement.

DOI:10.6814/NCCU202101276

6. The Potential of Lithium-ion Battery Recycling Business in Taiwan

According to Boston Consulting Group's analysis, the total revenue of the recycling business for large-scale recyclers can generate USD 25 per kWh. The gross margin for the mainstream NCM and NCA automotive used batteries is USD 7.50 per kWh, and the EBIT margin is USD 3.75 per kWh, which is equivalent to 15 percent in the recycling business. (Nathan Niese, Cornelius Pieper, Aakash Arora, and Alex Xie, 2020)

Among the cost structure, the acquisition and transportation take the highest allocation of 30 percent, followed by labor and materials and energy, which take 20 percent of total cost individual. The D&G and SG&A take 15 percent among the cost.

Unlike foreign markets, Taiwan has no own electric vehicle brands, and most EVs rely on imports from overseas. However, Taiwan is devoting effort to declining greenhouse gas emissions in recent years. The government has published the incentive and subsidy to promote the EVs and e-scooter penetration in the local market. The potential growth of the lithium-ion battery recycling business is highly anticipated.

6.1. A Unique Geographic Scooter Market

Due to the high rate of urbanization and population density, Taiwan has the highest scooter usage globally, with a total number of 22.4 million registered scooter license plates in 2021, nearly everyone has one scooter.

DOI:10.6814/NCCU202101276

According to the Directorate General of Highways (MOTC) historical annual sale unit of gasoline-motored scooter and e-scooter, the penetration rate of e-scooter had a significant increase, from 0.9% in 2015 to 9.6% in 2019, and the high peak in 2019 with 19.2% because of the governmental high incentive and subsidy. The historical record of new license plates registered in Taiwan is listed in Table 12.

Table 12 – New License Plates Registered of E-Scooter in Taiwan

Year	2015	2016	2017	2018	2019	2020
e-Scooter	9,765	18,492	39,025	78,676	173,033	93,244
Total	1,126,974	1,291,994	1,444,278	855,397	902,289	966,748
Rate	0.9%	1.4%	2.7%	9.2%	19.2%	9.6%

Calculate with the minimum service life with 5 years for the lithium-ion battery, the end-of-life batteries will reach a high volume in 2025, and every battery pack can generate around 4 Kg.

6.2. A Growing Electric Automotive Market

Although Taiwan has no electric automotive manufacturers, consumers still have various options imported overseas, from high-end segments, for instance, Tesla, BMW, Porsche, Jaguar, Mercedes-Benz, and Audi to accessible segment like Nissan, Toyota, and Luxgen.

With the increasing availability of charging stations, more and more consumers prefer to purchase EVs and HEVs in the past three years. As a result, according to the Directorate General of Highways (MOTC), historical annual sale unit of the number of new registered private-compact plates of EVs and HEVs have significant growth, with CAGR 118.6 percent and 67.5 percent separately, compared to 30.2 percent of CAGR for the pure gasoline-motor vehicle. The historical record of new license plates registered for vehicles in Taiwan is listed in Table 13.

DOI:10.6814/NCCU202101276

Table 13 - New License Plates Registered of vehicle in Taiwan

Year	2018		2019		2020		CAGR
Category	Unit	Share	Unit	Share	Unit	Share	
EV	598	0.16%	3,361	0.87%	6,243	0.71%	**118.56%**
HEV	8,871	2.31%	26,713	6.95%	41,687	4.76%	**67.50%**
Pure Gasoline	374,787	97.54%	354,218	92.17%	827,955	94.53%	**30.24%**
Total	**384,256**	**100.00%**	**384,292**	**100.00%**	**875,885**	**100.00%**	N/A

Although the total registered license plates of EVs and HEVs are only represent 0.14 percent and 2.14 percent separately in the market 2020, the market predicts that the allocation of EVs and HEVs will dominate the market in 2030. Therefore, it is essential to invest more in R&D of lithium-ion recycling technologies and facilities to catch up the market trend to compete with the following upside demand.

6.3. The Currently Lithium-ion Battery Technology in Taiwan

Limited by the geographic resource, Taiwan lacks metal mining; hence all the valuable raw materials for the lithium-ion battery are imported. However, Taiwan has a mature experience of the lithium-ion battery supply chain including ODM/OEM assembly from upstream to downstream.

6.3.1. The Upstream Suppliers in Taiwan Market

Upstream covers anode, cathode, separator, electrolyte, and can. It covers more than 60 percent of the total lithium-ion battery production. Meanwhile, anode and cathode take 26 percent, separator takes 23 percent, and electrolyte takes 15 percent among of the 60 percent. Therefore, the material cost of the upstream suppliers will influence the entire cost of the battery products,

DOI:10.6814/NCCU202101276

whereas the most profitable segment in the supply chain. Table 14 shows the current Taiwanese firms that participated in upstream.

Table 14 – The Upstream Company Participated in Lithium-ion Battery Supply Chain

Item	Company	名稱	Item	Company	名稱	Item	Company	名稱
1	Yeongguan	永冠	4	TFC	尚化	7	CAEC	長圓科
2	Topco	崇越電	5	Coremax	康普	8	Long Time	榮炭
3	Bizlink	貿聯	6	Aleees	立凱	9	TienLi	天力離岸

6.3.2. The Midstream Suppliers in Taiwan Market

Midstream represents the battery cell manufacturers, which have the most difficult market entry barriers because of high capital investment, high technology requirement, high risk of flammability, and long-term cost amortization.

The investment of a single production line can easily cost more than USD 36,000 dollar. Moreover, the certification of the facility requested by the customers normally takes one year, limiting the margin growth of the midstream suppliers; it is accounted for roughly less than 20 percent. Table 15 lists the current Taiwanese firms that participated in midstream.

Table 15 - The Midstream Company Participated in Lithium-ion Battery Supply Chain

Item	Company	名稱
1	Delta	台達電
2	CAEC	長圓科
3	SYNergy	興能高
4	TienLi	天力離岸

DOI:10.6814/NCCU202101276

6.3.3. The Downstream Suppliers in Taiwan Market

Downstream represents the assembly of battery cell and battery management unit (BMU) into the battery pack. The assembly battery packs will be eventually installed into the final products like automotive, e-scooters and bikes, energy storage systems, and consumer electrical products.

Taiwan is recognized by the abundant talented human resource for engineers and mature experience of the ODM and OEM services that provide the long-term battery packing service to the key battery suppliers like LG, SDI, Sony, Panasonic, BYD, and ACTL, as well as the end product customers like Apple, Lenovo, Samsung...etc. Taiwanese packers can generate 40 percent of net output value globally. Table 16 lists the current Taiwanese firms that participated in downstream.

Table 16 - The Downstream Company Participated in Lithium-ion Battery Supply Chain

Item	Company	名稱	Item	Company	名稱	Item	Company	名稱
1	Delta	台達電	5	Celxpert	加百裕	9	CAEC	長園科
2	Merry	美律	6	C-Tech	西勝	10	P-Duke	博大
3	Holy Stone	禾伸堂	7	Sysgration	系統電	11	GameCyber	天宇
4	Dynapack	順達	8	Simplo	新普	12	TienLi	天力離岸

6.4. Geographic Advantage and Marine Service for Taiwan

According to FutureBridge Analysis, around 14 GWh end-of-life lithium-ion batteries retired from the electronic vehicle market in 2020, equivalent to 102,000 tons. With the high adoption of EVs, the total amount of end-of-life EV batteries is expected to reach 7.8 million tons by 2040, and the entire market value will be worth USD 31 billion annually.

DOI:10.6814/NCCU202101276

APAC contributed USD 165 million in the battery market in 2019, driven by the largest lithium-ion users, China, Japan, and South Korea. Taiwan has the geographic advantage located at the center of the largest lithium-ion users, making it more convenient to access the battery waste.

The recycling business requests less safety regulation and efficiency, and the marine service is perfectly matched with the characters of low cost and mass loading capacity. Taiwan has a well-developed marine supply system and global famous marine service companies, Evergreen, YangMing, and WangHai, which takes the global market share of 5.3%, 2.6%, and 1.3% separately; the company's information is listed in the Table 17.

Table 17 - The Taiwanese Leading Marine Delivery Service Company

Item	Company	公司	World Rank	Market Share	Capacity (TEU)
1	Evergreen	長榮	7	5.3%	195
2	YangMing	陽明	9	2.6%	92
3	WanHai	萬海	11	1.3%	116

DOI:10.6814/NCCU202101276

7. Conclusion

The lithium-ion battery is a rechargeable powering system that is widely used nowadays. Its usage covers electrical products like laptops, cellphones, other mobile devices, the energy storage system (ESS), e-mobility, aerospace, and military equipment.

The key lithium-ion battery cell manufacturers are majority located in the Asia Pacific region because of the early development by Panasonic and its cooperating suppliers. Now Chinese (ACTL), Korean (LG Energy, SDI, and SK Innovation), and Japanese (Panasonic) enterprises have supply 80 percent of the demand globally.

The lithium-ion battery market is forecasted to reach USD 94.4 billion in 2025, with growth at a CAGR of 16.4 percent because of the high adoption of electric vehicles. The total capacity is expected to increase from 455 GWh in 2020 to 1,447 GWh in 2025 and 9,300 GWh in 2030.

Reflecting that the market has great growth, the cost of critical raw metal materials continues to increase, and the lead time of the delivery of all components becomes longer. Therefore, more and more battery manufacturers and brand makers have devoted themselves to the recycling business to maintain a stable material cost and supply.

There are two existing recycling methods of recycling the end-of-life batteries in the recycling business; the first one is to downgrade the batteries retired from the EVs market and reuse them as the energy storage system as the second life since the batteries still have at least 70 percent capacity. The second method is called the pyrometallurgical process is also known as the

DOI:10.6814/NCCU202101276

thermal process. The recyclers disassembly the battery packs and melt the valuable materials.

The end-of-life batteries are expected to peak at some 5 million tons in 2030, generate 18 billion USD dollar value to the recycling market. The key materials had generated 1,092 USD million in 2020 and are forecasted to increase to 1,960 USD million in 2025 in the recycling business.

The market entry barriers for the startups are critical, which causes a low recycling rate of 19.4 percent in 2020. The bottleneck is that the recyclers couldn't collect enough battery waste to reach the economies of scale to compete with the price of manufacturing new lithium-ion batteries.

EMEA, the United States, and the Asia Pacific regions have high potential growth of the EV market. The battery cell manufacturers and brand makers have already joint ventures with recyclers or direct investment to penetrate the recycling market. The leading recyclers include Brunp Recycling Technology, American Battery Technology Company (ABTC), Li-cycle, Northvolt, Umicore N.V, and Battery Resourcers. These companies cover China, North America, and Europe.

Rise with the awareness of reducing greenhouse gas emissions, European regions, Japan, Indonesia had announced policies to prohibit selling the new gasoline motor vehicles. China even issued the regulation to promote the electric vehicle, which gives the market blooming potential growth.

DOI:10.6814/NCCU202101276

Taiwan is located in the center of the APAC region, and it has unique conditions to develop the recycling business. E-scooters, e-bikes, and EVs keep growing in the domestic market, accompany by wide-established charging stations. The battery waste will keep growing domestically. Taiwan has expertise in assembly for ODM and OEM, and it has been cooperating with the worldwide key battery cell manufacturers and brand makers for decades, from upstream to downstream. The mature experience, technology, and close relationship would help the firms acquire the certifications and know-how to deliver the scraped batteries, disassemble the battery packs, and contribute to the recycling business. Taiwan also has world-leading marine delivery service companies that can provide sufficient capacity to deliver recycling materials.

Creating a circular economy is a terminal goal for all the players in the lithium-ion battery industry, and the foreign enterprises have already invested in the required facilities and technologies to explore the market. Although, according to my research, there are none of the lithium-ion battery recyclers in the Taiwan market yet, Taiwan has a talented human resource, technology, and an irreplaceable role in the international high-technology market; considering the penetration rate in this niche market domestically is yet low, the lithium-ion relative manufacturers and startups can still put the effort in the market and have expected revenue growth in the near future.

DOI:10.6814/NCCU202101276

8. Reference

2020 年全球動力鋰電池行業供需現狀與發展前景分析 出貨量保持 15%以上增長【組圖】原文網址：http://read01.com/kz8aeJg.html. (2020, November 24). 前瞻網經濟學人. https://read01.com/zh-tw/kz8aeJg.html#.YNsvnRMzbJx

2020 年全球鋰電池行業市場現狀與發展前景分析 規模超 400 億美元. (2020, June 6). 每日頭條. https://kknews.cc/zh-tw/finance/pb2qznz.html

Access to this page has been denied. (2021, March 3). Matt Bohlsen. https://seekingalpha.com/article/4411026-2021-looks-likely-to-be-great-year-for-evs-especially-battery-manufacturers

Class 9A: Lithium Batteries. (2021). Global Transport and Logistic. https://www.dsv.com/en-gb/support/faq/transporting-dangerous-goods/9-classes-of-dangerous-goods/class-9a-lithium-batteries

Economic Challenges of Li-Ion Battery Recycling from End-of-Life Vehicles. (2019). Elsevier B.V. https://www.nrel.gov/docs/fy19osti/71350.pdf

EV battery recycling: cost and components. (2020a, November 16). Automotive Manufacturing Solutions. https://www.automotivemanufacturingsolutions.com/emobility/ev-battery-recycling-cost-and-components/41287.article

EV battery recycling: cost and components. (2020b, November 16). Automotive Manufacturing

DOI:10.6814/NCCU202101276

Solutions. https://www.automotivemanufacturingsolutions.com/emobility/ev-battery-recycling-cost-and-components/41287.article

Global EV Outlook 2020 – Analysis. (2020, June). IEA. https://www.iea.org/reports/global-ev-outlook-2020

Harper, G. (2020, January 21). *Recycling lithium-ion batteries from electric vehicles*. Nature. https://www.nature.com/articles/s41586-019-1682-5?error=cookies_not_supported&code=544bd5f2-1f7a-4462-9243-f1c5e7a40bd9

It's time to get serious about recycling lithium-ion batteries. (2019, July 14). Mitch Jacoby. https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28

Jamasmie, C. (2019, October 31). *Recycled lithium batteries market to hit $6 billion by 2030 — report*. MINING.COM. https://www.mining.com/recycled-lithium-batteries-market-to-hit-6-billion-by-2030-report/

Johnson, S. K. (2020, September 24). *Here's what Tesla will put in its new batteries*. Ars Technica. https://arstechnica.com/cars/2020/09/heres-what-tesla-will-put-in-its-new-batteries/

Leighton, M. (2021, January 7). *The Ultimate Guide to the Cobalt Market: 2021 - 2030 | Crux Investor Articles*. Morgan Leighton. https://www.cruxinvestor.com/articles/the-ultimate-guide-to-the-cobalt-market-2021-2030f

DOI:10.6814/NCCU202101276

Lightening Global. (2019, June). *Lithium-ion Batteries Part I: General Overview and 2019 Update*. https://www.lightingglobal.org/wp-content/uploads/2019/06/Lithium-Ion_TechNote-2019_update.pdf

The lithium-ion battery end-of-life market – A baseline study. (2020). Hans Eric Melin. http://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf

LITHIUM-ION BATTERY RECYCLING - MARKET UPDATE. (2020). Yole Développement. http://www.yole.fr/Li-ionBatteryRecycling_MarketUpdate.aspx

Lithium-ion Battery Recycling Market & Technology Trends 2020. (2020). Dr. Shalu AGARWAL, Dr. Milan ROSINA,. https://s3.i-micronews.com/uploads/2020/07/YDR20092_Li-ion_Battery_Recycling_Trends_2020_Sample.pdf

A Look into Electric/Hybrid Cars from an Ecological Perspective. (2015, January 1). ScienceDirect. https://www.sciencedirect.com/science/article/pii/S2212017315000638

MarketsandMarkets. (2020, April). *Lithium-Ion Battery Market by Type, Power Capacity, Industry, Voltage, Region – Global Forecast to 2025* (No. 5730647). https://www.reportlinker.com/p05730647/Lithium-Ion-Battery-Market-by-Type-power-Capacity-Industry-And-Region-Global-Forecast-to.html?utm_source=PRN

DOI:10.6814/NCCU202101276

Materials Cost Evaluation Report for High-Power Li-Ion HEV Batteries. (2002, December). . L. Henriksen, K. Amine, J. Liu, and P. A. Nelson. https://publications.anl.gov/anlpubs/2003/01/45346.pdf

McKinsey Electric Vehicle Index: Europe cushions a global plunge in EV sales. (2021, April 15). McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/mckinsey-electric-vehicle-index-europe-cushions-a-global-plunge-in-ev-sales

Nathan Niese, Cornelius Pieper, Aakash Arora, and Alex Xie. (2020, September). *The Case for a Circular Economy in Electric Vehicle Batteries*. Boston Consulting Group.

Pyrometallurgical recycling of Li-ion, Niâ“Cd and Niâ“MH batteries: A minireview. (2020, August 1). ScienceDirect. https://www.sciencedirect.com/science/article/abs/pii/S2452223620300067

Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries. (2019, October). Mengyuan Chen, Xiaotu Ma, Bin Chen, Renata Arsenault, Peter Karlson, Nakia Simon, Yan Wang. https://doi.org/10.1016/j.joule.2019.09.014

RECYCLING OF LITHIUM BATTERIES. (2019, May). Tamás Pusztai , Zoltán Szamosi. https://doi.org/10.26649/musci.2019.049

DOI:10.6814/NCCU202101276

SK Innovation to invest W1.3tr in 3rd EV battery plant in Hungary. (2021, January 29). Yonhap. http://www.koreaherald.com/view.php?ud=20210129000127

Top electric vehicle markets dominate lithium-ion battery capacity growth. (2021, February 16). Alice Yu, Mitzl Sumangll. https://www.spglobal.com/marketintelligence/en/news-insights/blog/top-electric-vehicle-markets-dominate-lithium-ion-battery-capacity-growth

The Who's Who of Lithium-ion Battery Recycling. (2021, March 3). Edis Osmanbasic. https://www.engineering.com/story/the-whos-who-of-lithium-ion-battery-recycling

Wikipedia contributors. (2021, June 22). *List of electric-vehicle-battery manufacturers*. Wikipedia. https://en.wikipedia.org/wiki/List_of_electric-vehicle-battery_manufacturers

台. (2020, November 27). 如果納入電池生命週期評估，電動車還有環保優勢嗎？. The News Lens 關鍵評論網. https://www.thenewslens.com/article/142204

台灣鋰電池產業物質流布分析及管理策略. (2021, March 5). 王立邦、張添晉、翁國釗、邱少鈞、洪毅翔. https://www.materialsnet.com.tw/DocView.aspx?id=45772

廢棄鋰電池背後的暴利產業：預計到 2030 年僅回收市場就達 180 億美元_IT 之家 - MdEditor. (2020, December 23). IT 之家. https://www.gushiciku.cn/pl/g2B6/zh-tw

新車領牌數. (2021). 交通部公路總局. https://stat.thb.gov.tw/hb01/webMain.aspx?sys=100&funid=11200

DOI:10.6814/NCCU202101276

機動車輛登記數. (2021). 交通部公路總局. https://stat.motc.gov.tw/mocdb/stmain.jsp?sys=100&funid=a3301

臺灣網路科教館. (2019). 洪為民. https://www.ntsec.edu.tw/ErrorPage.aspx?cat=6838&a=6829&fld=&key=&isd=1&icop=10&p=1&lsid=16318

財團法人車輛研究測試中心，提供車輛測試、檢測、驗證、外銷、先進系統研發、試車場等服務。. (2011). 孔慶玲. https://www.artc.org.tw/chinese/03_service/03_02detail.aspx?pid=1846

陳. (2021, April 24). *車業 30 強》台達電吃全球電動車動力系統 10%市占！第一家攻入特斯拉動力核心的護國先鋒｜數位時代 BusinessNext*. 陳映璇. https://www.bnext.com.tw/article/62054/delta-electric-car

DOI:10.6814/NCCU202101276