J. Inf. Technol. Appl. Manag. 30(1): 1~9, February 2023
https://doi.org/10.21219/jitam.2023.30.1.001
ISSN 1598-6284 (Print)
ISSN 2508-1209 (Online)

전기차와 ESS용 이차전지 시장의 현재와 미래에 대한 기술경제적 분석

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Techno-economic Analysis on the Present and Future of Secondary Battery Market for Electric Vehicles and ESS

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Abstract

Interest in the future of the battery market is growing as Tesla announces plans to increase production of electric vehicles and to produce batteries. Tesla announced an action plan to reduce battery prices by 56% through 'Battery Day', which included expansion of factories to internalize batteries and improvement of materials and production technology. In the trend of automobile electrification, the expansion of the battery market, which accounts for 40% of the cost of electric vehicles, is inevitable, and the size of the electric vehicle battery market in 2026 is expected to increase more than five times compared to 2016. With the development of materials and process technology, the energy density of electric vehicle batteries is increasing while the price is decreasing. Soon, electric vehicles and internal combustion locomotives are expected to compete on the same line. Recently, the mileage of electric vehicles is approaching that of an internal combustion locomotive due to the installation of high-capacity batteries. In the EV battery market, Korean, Chinese and Japanese companies are fiercely competing. Based on market share in the first half of 2020, LG Chem, CATL, and Panasonic are leading the EV battery supply, and the top 10 companies included 3 Korean companies, 5 Chinese companies, and 2 Japanese companies. All-solid, lithium-sulfur, sodium-ion, and lithium air batteries are being discussed as the next-generation batteries after lithium-ion, among which all-solid-state batteries are the most active. All-solid-state batteries can dramatically improve stability and charging speed by using a solid electrolyte, and are excellent in terms of technology readiness level (TRL) among various technology alternatives. In order to increase the competitiveness of the battery industry in the future, efforts to increase the productivity and economy of electric vehicle batteries are also required along with the development of next-generation battery technology.

Keywords : Cost Analysis, Secondary Battery, Electronic Vehicles, ESS(Energy Storage Systems), Next-generation battery technology, Case study

Received : 2023. 01. 05. Revised : 2023. 02. 07. Final Acceptance : 2023. 02. 15.

※ This research was supported by the Academic Research Fund of Hoseo University in 2022"(202202180001).
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1. Introduction

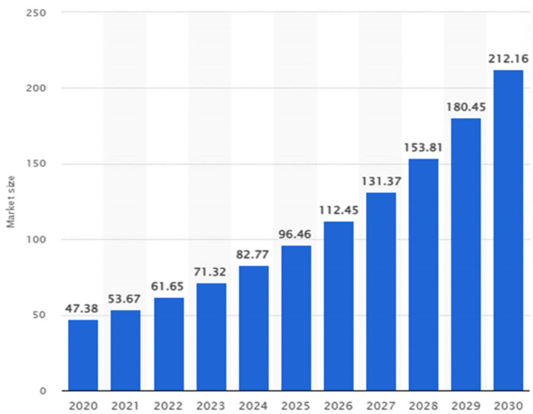
Interest in the future of the battery market is increasing as Tesla recently announced an action plan for increasing the production of electric vehicles and self-production of batteries. Tesla's CEO Elon Musk announced at the 'Battery Day' event held in September 2020 that he would cut battery prices by 56% and bring a $25,000 electric vehicle to the market by 2022 [Kim, 2020]. Tesla has announced that it will maintain its sales target of 500,000 units this year despite the aftermath of the coronavirus, and has pledged to secure production capacity of 500,000 units in Fremont, USA, 250,000 units in Shanghai, China, and 80,000 units in Berlin, Germany in 2021.

Tesla expressed its will to internalize batteries by acquiring and producing battery materials and battery pack-related companies, and is expected to spark a chicken game in the battery industry in the future. It seems that it is trying to transform from a differentiated strategy of performance and technology superiority to a cost advantage strategy by reducing the cost of 56%, reducing design and process by 32%, and releasing a public car worth 25,000 dollars. If the target value of 56% reduction is applied to the battery pack price of $156/kWh in 2019, it is $70/kWh, but there is a point that the gap is significant from the industry analysis of $100/kWh.

2. Related Research

2.1 Lithium-ion battery-based Electric Vehicle Case

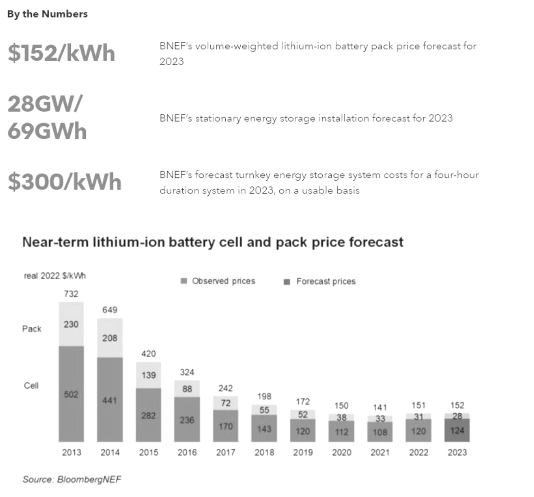
With rapid progress in automobile electrification, the expansion of the battery industry, which accounts for about 40% of electric vehicle costs, is inevitable [Seok, 2020]. According to environmental regulations, the proportion of electric vehicles (BEV, PHEV) and hybrid vehicles (HEV) is increasing, and the capacity of batteries installed in one electric vehicle is also increasing to increase the mileage. For example, the battery of the first generation of Nissan Leaf, the first mass-produced electric vehicle, was 24kWh, but then gradually expanded to 40kWh and 60kWh [d'Aprile, 2016]. The global electric vehicle battery market has more than doubled from $15 billion in 2016 to $38.8 billion in 2019, and is expected to reach $93.9 billion in 2026, a 526.7% increase from 2016. Global electric vehicle battery market size is shown in ⟨Figure 1⟩ below [Mathilde, 2022].



⟨Figure 1⟩ Global Electric Vehicle Battery Market Size (in billion U.S. dollars)

With the development of battery materials and process technology, energy density increases and prices decrease [Iclodean et al., 2017]. Soon, electric vehicles and internal combustion locomotives are expected to compete on the same line. As high-capacity batteries with increased energy density are installed, electric vehicle mileage is approaching that of internal combustion locomotives

〔Frankel and Wagner, 2017〕. The energy density of lithium-ion battery cells has improved from 130Wh/L in 2013 to 800Wh/L now (US DOE). Electric vehicle mileage reached 647km, the level of an internal combustion engine vehicle from 134km in 2016 (Tesla). The Tesla Model S Long Range Plus improved its mileage to 402 miles (647km, EPA standard) with an update in June 2020. The price parity of an internal combustion locomotive is gradually becoming a reality due to the decline in the price of electric vehicle batteries. The average price of an electric vehicle lithium-ion battery pack has fallen from $1000/kWh in 2010 to $156/kWh in 2019, and is expected to fall below $100/kWh around 2024, which will be similar to the maintenance cost of an internal combustion engine vehicle 〔Lee and Han, 2020〕. Near-term lithium-ion battery and pack price forecast is shown in 〈Figure 2〉 〔Bloomberg NEF, 2023〕.



〈Figure 2〉 Annual Average Price of Electric Vehicle Battery Packs

2.2 Electric Vehicle Battery Company Case

Currently, in the electric vehicle battery market, Korean, Chinese, and Japanese companies are fiercely competing. Based on market share in the first half of 2020, LG Chem, CATL, and Panasonic are leading the EV battery supply, and the top 10 companies included 3 Korean companies, 5 Chinese companies, and 2 Japanese companies 〔Son, 2020〕. In Korea, LG Chem (No. 1), Samsung SDI (No. 4), and SK Innovation (No. 6) accounted for a combined 34.5%, and in China, CATL (No. 2), BYD (No. 5), and AESC (7). 5 companies, including above) and CALB (9th), accounted for a combined 36.8%, and in Japan, two companies, Panasonic (3rd) and PEVE (8th), took a combined 22.5%. Despite the corona 19 pandemic, three Korean companies, including LG Chem, are doing their best by raising their market share from LG Chem to 24.6% from 10.4%, Samsung SDI from 3.4% to 6.0%, and SK Innovation from 1.8% to 3.9%.

Korea, which has secured competitiveness led by large corporations, China, which enhances competitiveness through state-led investment, and Japan, based on the technology tradition in the rechargeable battery field, have similar competitiveness. Similar to the case of semiconductors, Korea has secured competitiveness through technology development and investment centered on conglomerates, while China, a latecomer, is improving its competitiveness thanks to state-led investment and growth in domestic electric vehicle sales. China accounts for 82% of the world's distribution of cobalt, a core material for electric vehicle batteries, and 59% of the world's distribution of lithium. Since 2005, it has been receiving full support from the country by investing in resources in Africa and South America to secure raw materials. Japan has the first commercialization and long-term delivery of lithium-ion batteries leading to Sanyo-Panasonic, but its market share has declined somewhat as Japanese automakers focus on hybrid vehicles over electric vehicles. Top 10 EV Battery Manufacturing Companies in 2022 is shown in <Table 1> below [Globalevehicleinfo, 2022].

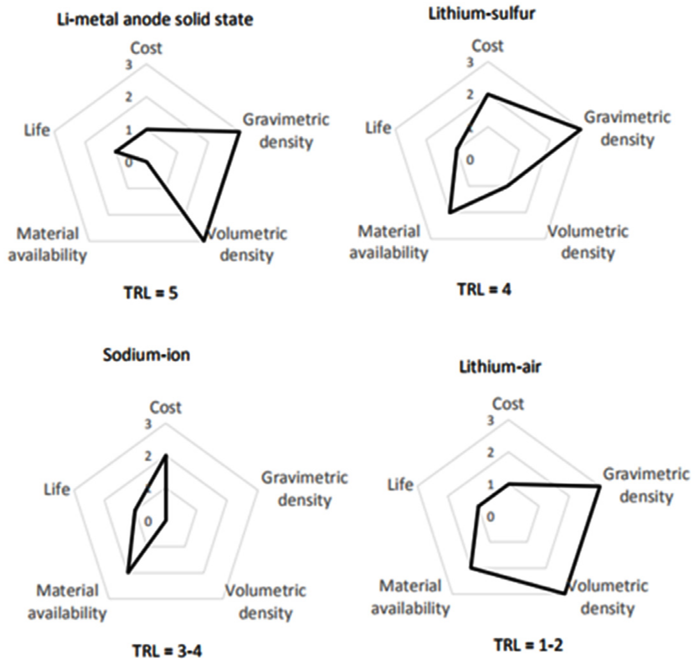
<Table 1> Top 10 EV Battery Manufacturing Companies in 2022

rank	companies	2022 market share	country
1	CATL	34%	China
2	LG Energy Solution	14%	Korea
3	BYD	12%	China
4	Panasonic	10%	Japan
5	SK On	7%	Korea
6	Samsung SDI	5%	Korea
7	CALB	4%	China
8	Guoxuan	3%	China
9	Sunwoda	2%	China
10	SVOLT	1%	China

*Referred from Globalevehicleinfo [2022] and modified.

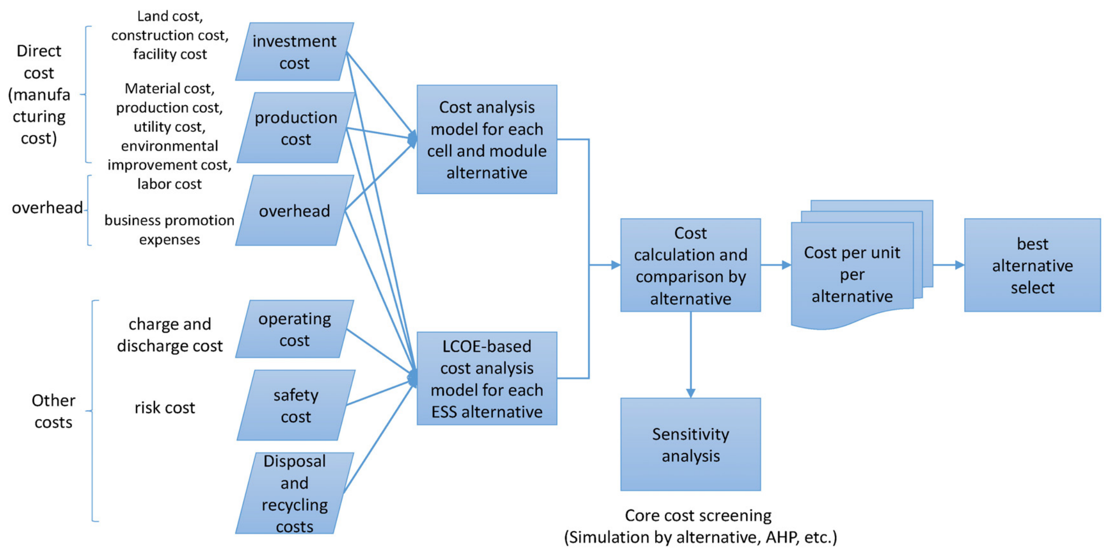
2.3 Next-generation Electric Vehicle Battery Case

All-solid, lithium-sulfur, sodium-ion, and lithium air batteries are being discussed as the next-generation batteries after lithium-ion, among which all-solid-state batteries are the most active. In the all-solid-state battery, research is underway to improve stability and increase charging speed by replacing the liquid electrolyte and separator filled with a solid electrolyte layer to transfer lithium ions between the positive and negative electrodes of the existing lithium-ion battery. Sodium-ion batteries use low-cost sodium to lower manufacturing costs and ensure safety and long-term durability, so research is being conducted mainly on mid-to-large-sized battery applications such as energy stor-



*Gravimetric density: Weight density, Volumetric density: Volume density, Material availability: Availability of raw materials, numbers indicate superiority compared to lithium-ion batteries, 0 = inferior, 1 = similar, 2 = good, 3 = very good

<Figure 3> Comparison of Next-generation Battery Technologies



〈Figure 4〉 BESS's Cost Configuration

age systems (ESS). Lithium-sulfur batteries are batteries that use sulfur as a positive electrode material and lithium as a negative electrode material. In theory, they can realize higher energy density than lithium-ion batteries, and research to increase stability and lifespan is underway.

Among various technology alternatives, all-solid-state batteries currently occupy a relative advantage in technology readiness level (TRL) as shown in 〈Figure 3〉. TRL was defined on the IEA's innovation gap site (https://www.iea.org/reports/innovation-gaps) [IEA, 2020]. All solid batteries have very good weight density and volume density compared to lithium-ion batteries, and are mainly for Toyota. As a result of continuous research and development, the TRL level is relatively high. All-solid-state batteries are proposed by Toyota for mass production in 2025 and commercialization by Samsung SDI in 2027. After mass production, it will take some time to secure economic feasibility at the level of lithium-ion batteries.

3. Research Methodology

3.1 Necessity of Cost Analysis for Battery-based ESS

It is necessary to develop a secondary battery for ESS with high safety, long lifespan, and low price. Secondary batteries for ESS require three conditions: high safety, long lifespan (more than 15 years), and low price (installation and maintenance costs). Existing LiB-based ESS, Na-S-based ESS, and ZEBRA-based ESS have their own characteristics and limitations depending on their technical characteristics. It is necessary to develop a secondary battery for ESS that can be operated at a low price while having technical characteristics of high safety and long lifespan [Galloway and Dustmann, 2003; Li et al., 2014].

Demand forecasting of ESS by application and establishment of economic-based introduction strategy. Calculate the levelized cost of electricity (LCOE) for ESS by application, such as Grid, Commercial, Residential, Telecom, and Uninterruptible Power Supply (UPS). This study aims to develop an LCOE cost calculation and alternative comparison tool for ESS for each application and to conduct a sensitivity analysis for each cost item.

3.2 Levelized Cost of Electricity(LCOE)

The concept of life cycle cost (LCC) was used to calculate the cost of cells, modules and applications. As shown in ⟨Figure 4⟩, life cycle cost consists of investment cost, production cost (or battery, BMS/EMS, PCS purchase cost), operating cost (charging/discharging cost), safety cost (hazard cost), and disposal and recycling cost. To calculate the total cost over the life cycle, ALCC (annualized life cycle cost, \$/kW-yr) is equalized by year after time discount. Therefore, LCOE (levelized cost of electricity, \$/kWh) is obtained by dividing ALCC by annual discharge hours, and LCOS (levelized cost of storage, \$/kWh) is obtained by subtracting charging cost. LCOS(LCOE), which reflects the risk costs for the explosion of the existing BESS, and reflects the environmental costs such as eco -friendly processes and waste disposal, is the same as the formula below [Mongird et al., 2019; Zakeri, 2015].

$$LCOS' = \frac{\sum \frac{Capital_t + O\&M_t + Charge_t + Safe_t + Eco_t}{(1+r)^t}}{\sum \frac{MWh_t}{(1+r)^t}}$$

⟨Figure 5⟩ Suggested LCOS(LCOE) equation

3.3 Development of ESS Cost (LCOE) and Alternative Comparison Tools for Each Application

In order to calculate the cost of ESS for each application, cost calculations by base, cell, and module are required, and the accuracy of the cost of ESS depends on the accuracy of cost calculations for each stage. In order to increase the accuracy of ESS costs, we refer to experts in joint research agencies such as RIST, KEPCO, and PNNL, reports from professional research firms such as SNE Re-

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Cost Analysis for System**											
2	**Name**		**L105 cell-based**		**L90 cell-based**	**LiB(NCM)-base**	**LiB(LFP)-based**	**Na-S-based**	**Na-NiCl$_2$-based**			
3	Development stage	L1	L2	PP1						*Make or Buy*	*Source*	*Explanation*
4												
5	**Capacity**											
6	Charging capacity											
7	Discharging capacity											
8												
9	**Operation condition**											
10	SOC window lower bound					50				*Buy*	*RIST 및 전력연구소 전문가 추정치*	*ESS 화재 사고 이후 FR용도로 정상 상태를 10~90에서 변경*
11	SOC window upper bound					80				*Buy*	*RIST 및 전력연구소 전문가 추정치*	*ESS 화재 사고 이후 FR용도로 정상 상태를 10~91에서 변경*
12	Cycle life lower bound (cycle)					4,000				*Buy*	*RIST 및 전력연구소 전문가 추정치*	*제작사가 제시한 cycle life는 1C 충방전 조건에서*
13	Cycle life upper bound (cycle)					6,000				*Buy*	*RIST 및 전력연구소 전문가 추정치*	*제작사가 제시한 cycle life는 2C 충방전 조건에서*
14	Retention lower bound (%)					70				*Buy*	*RIST 및 전력연구소 전문가 추정치*	*제작사가 제시한 cycle life는 3C 충방전 조건에서*
15	Retention upper bound (%)					80				*Buy*	*RIST 및 전력연구소 전문가 추정치*	*제작사가 제시한 cycle life는 4C 충방전 조건에서*
16											*RIST 및 전력연구소 전문가 추정치*	*제작사가 제시한 cycle life는 5C 충방전 조건에서*
17	**Total Cost per MWh (\$/MWh)**	**144202.78**	**83200.19**	**72650.89**						*Buy*	*RIST 및 전력연구소 전문가 추정치*	*약 6~7억원/MWh, 6억원 기준 계산*
18												
19	**Total cost per package (\$/package)**	**96135.18**	**55466.79**	**48433.93**								
20												
21	**Direct cost per package (\$/package)**	**61801.19**	**35657.22**	**31136.10**								
22												
23	**Direct material cost per package (\$/package)**	**48067.59**	**27733.40**	**24216.96**								
24	Module	41213.81	23684.33	23947.39						*Make*	*호서대 경제성 분석팀의 추정치*	*Cell 단가 x 90*
25	Hot Box	132.13	132.13	132.13						*Buy & Make (강판구매 후 가공)*	*호서대 경제성 분석팀의 추정치 및 인터넷 조사*	*냉연강판(0.2mm이하) 1219mm*2438mm 구매시USD 1057 -> Hot Box 한개당 380*380 2개, 170*170 4개가 필요*
26	Module Separator	117.44	117.44	117.44						*Buy & Make (강판구매 후 가공)*	*호서대 경제성 분석팀의 추정치 및 인터넷 조사*	*냉연강판(0.2mm이하) 1219mm*2438mm 구매시USD 1057 -> Separator 380*170 4개가 필요*
27	BMS	6594.21	3789.49	10.00						*Make*	*호서대 경제성 분석팀의 추정치 및 인터넷 조사*	*전기차배터리의 경우 BMS비용은 배터리 비용의 약 16%*
28	Wire	10.00	10.00	10.00						*Buy*	*호서대 경제성 분석팀의 추정치 및 인터넷 조사*	*전기 배터리 와이어 개당 USD 1 -> cell간 연결하는 8개 및 in & out 역할을 하는 2개*
29												
30	**Direct process cost per application (\$/package)**	**13733.60**	**7923.83**	**6919.13**								
31	Wiring labor cost	6866.80	3961.91	3459.57							*호서대 경제성 분석팀의 추정치 및 RIST 전문가 집단의 추정치*	*재료비 : 생산비+간접비 = 1 : 1 (개별항목은 생산비+간접비의 1/7)*
32	BMS labor cost	6866.80	3961.91	3459.57							*호서대 경제성 분석팀의 추정치 및 RIST 전문가 집단의 추정치*	*재료비 : 생산비+간접비 = 1 : 1 (개별항목은 생산비+간접비의 1/7)*
33												
34	**Manufacturing indirect cost per package (\$/package)**	**34333.99**	**19809.57**	**17297.83**								
35	Indirect material handling cost (간접재료비)	6866.80	3961.91	3459.57							*호서대 경제성 분석팀의 추정치 및 RIST 전문가 집단의 추정치*	*재료비 : 생산비+간접비 = 1 : 1 (개별항목은 생산비+간접비의 1/7)*
36	Indirect labor cost (간접인건비)	6866.80	3961.91	3459.57							*호서대 경제성 분석팀의 추정치 및 RIST 전문가 집단의 추정치*	*재료비 : 생산비+간접비 = 1 : 1 (개별항목은 생산비+간접비의 1/7)*
37	Maintenance cost (정비비)	6866.80	3961.91	3459.57							*호서대 경제성 분석팀의 추정치 및 RIST 전문가 집단의 추정치*	*재료비 : 생산비+간접비 = 1 : 1 (개별항목은 생산비+간접비의 1/7)*
38	Depreciation cost (감가상각비)	6866.80	3961.91	3459.57							*호서대 경제성 분석팀의 추정치 및 RIST 전문가 집단의 추정치*	*재료비 : 생산비+간접비 = 1 : 1 (개별항목은 생산비+간접비의 1/7)*
39	Utilities cost (전기,가스비)	6866.80	3961.91	3459.57							*호서대 경제성 분석팀의 추정치 및 RIST 전문가 집단의 추정치*	*재료비 : 생산비+간접비 = 1 : 1 (개별항목은 생산비+간접비의 1/7)*

⟨Figure 6⟩ Cost Analysis tool for each application search, and quotes from raw materials such as Alibaba, and battery cost literature. Target ESS applications were selected from GRID, Commercial, Residential, Telecom, and Unlimited Power Supply (UPS). The virtual scenarios were formed for installation and operation for each selected ESS application, and the cost of ESS was calculated for each scenario.

When calculating the ESS operating cost (charging and discharge cost), the LTNBB-based ESS reflects the effective driving section and the electricity fee based on the evaluation results of the latest cell/module developed by RIST. ZEBRA -based ESS calculated the effective driving section and electricity fee by reflecting the results of the cell/module evaluation of the relevant agencies. The LIB-based ESS reflects the actual operational data of the relevant agencies. When it is not a critical process, Processing Cost is the same as the material cost, and the environmental improvement cost in the Processing Cost is doubled with the general processing cost 〔Rahman, 2020; Zakeri, 2015〕.

Cost analysis tools for each application are developed based on Excel as shown in 〈Figure 6〉 with reference to BATPAC and ES-SELECT 〔Mongird et al., 2019〕.

4. Conclusion

In order to increase the competitiveness of the battery industry in the future, efforts to increase the productivity and economy of electric vehicle batteries are also required along with the development of next-generation battery technology. It is necessary to accumulate mass production know-how, such as reducing the price of electric vehicle battery materials, improving production efficiency, and improving yield, and to achieve economies of scale. It is also important to make technological efforts to reduce the share of cobalt, which is unstable in production, among lithium-ion battery materials. Domestic battery makers are trying to reduce the proportion of cobalt, such as mass production of NCM712 (LG), NCM811 (SK) and NCA (Samsung). Chinese companies such as CATL are also putting their efforts into lithium iron phosphate (LFP, LiFePO) batteries that do not use cobalt, and are trying to increase the price competitiveness of electric vehicles through this. LFP batteries have been mainly installed in electric buses for a long time due to problems such as low energy density and poor yield despite their long life and high stability, but recently, the low production cost has been highlighted as a weapon.

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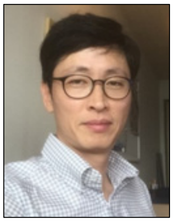
■ 저자소개



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