Analysis of significant parameters the development of rechargeable electric energy storage (REES) national recycle standards

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Abstract. The growth in using battery-based electric vehicles (EV) in the world increased significantly last ten years. This trend was to achieve the global target of reducing the negative impact of conventional vehicles. Simultaneously, in reverse, the waste of Rechargeable Electric Energy Storage (REES) of EV escalated. Sources for REES material were limited, but the demand predicted to mount up in the next decade, so recycling is an option to overcome this problem. However, there are still no standards related to REES recycling of electric vehicles in Indonesia, so preliminary data is required in determining parameters associated with REES recycling standards. The parameters were collected by questionnaire from research-based units or producers in government and private institutions in Indonesia as the baseline of this discussion. The respondents stated that REES recycling has three significant parameters: raw material, process, and product. There were seven parameters in raw material, six parameters of the process, and the product comprises four parameters. Further research and discussion against stakeholders are needed to achieve exemplary implementation of REES recycling standards.

1. Introduction
The growth in using electric battery-based vehicles worldwide continues to increase during the 2010-2019 period. The IEA noted that 4.79 million electric vehicles have been circulating the world, China dominates half of which. This trend has implications for the demand for battery materials that are at the core of electric vehicle performance, especially in Nickel Cobalt Aluminum Oxide (NCA), Nickel Manganese Cobalt Oxide (NMC), and Lithium Ferro Phosphate (LFP) batteries. It predicts the demand for materials to increase cobalt, lithium, manganese, and nickel by three times by 2030 compared to 2019 [1].

Electric vehicle technology is in demand to meet global targets of reducing greenhouse gas emissions, improving air quality, and fulfilled consumer needs. Still, it presents severe challenges of battery waste management [2]. It is estimated that by 2025, the electric vehicle Rechargeable Electric Energy Storage System (REES) of electric vehicles will reach 340,000 metric tons by 2040 [3], consisting of 6,500 tons of lithium, 20,000 tons of aluminum, 26,400 tons of copper, 40,800 tons of manganese, and the rest is others materials [4]. REES, usually a Lithium-Ion Battery (LIB) in electric vehicles, has not been officially classified in Indonesia as B3 waste in [5]. However, previous studies have shown that Li-ion battery waste has elements that exceed
Figure 1: Research respondent data (a) Distribution of respondents; (b) the respondent’s recycling field

the Toxicity Characteristic Leaching Procedure (TCLP) threshold in this parameter. Co, Cu, Ni, and Pb in landfill [6]. The application of good waste management is one of the options in overcoming the problems of using REES, starting from preventing damage to recycling use. For this reason, it is necessary to find and use sustainable materials and durability in the recycling process. The key remains in the recycling development industry [1, 2].

The management of EV battery waste in Indonesia is contained in [7], namely in Chapter VI concerning the Protection of the Environment. This article explains that electric vehicle battery waste must be recycled and other processing. The handling of this waste is carried out by institutions, the battery-based EV industry, and the domestic battery-based EV component industry with a battery waste treatment permit from EV under the provisions of laws and regulations in waste treatment. Unfortunately, there are no standards related to battery recycling at the national and international levels. Regulatory support that can be accepted by all parties will have an impact on the increasing use of electric vehicles. REES recycling standards need to be examined in terms of the parameters used, starting from raw materials, processes, and handling, which are the first steps in the REES application study.

2. Methods
The data were collected using an online Google form questionnaire with a purposive sampling technique because few respondents understood REES recycling [8]. Selected respondents were identified with a connection with REES recycling, which focuses on developers and several companies assumed to know the recycling process. A total of 20 respondents were obtained.

Respondents were dominated by government agencies on research and development related to electric vehicles, with 67% Figure 1 of respondents having been involved in REES recycling. We focused on the R&D because we wanted to examine the parameters that should be considered in REES recycling as a baseline in the discussion. Descriptive analysis methods were used to compile, change, and interpret data to make it easier to explain the information descriptively or simplify the data. It shows that in Figure 2, the significant parameters in REES recycling and study literature will also support data analysis in the discussion.

3. Results and Discussion
3.1. Raw material
3.1.1. Types of batteries, basic components, and elements. The variation of the metal would depend on the battery to be recycled. The type of battery follows the cathode (positive electrode used) as one of the battery’s essential components, an anode (negative electrode) and electrolyte. Respondents considered these components because they determine the elements that will be obtained from the recycling process [9].

NCA / LiNiCoAlO2 dominated the batteries that were currently being developed by respondents for recycling (36%), and NMC / LiNiMnCoO2 (21%) Figure 3 with the acquisition
of batteries or materials got from China and domestic. Using NMC and NCA batteries in recycling is possible because of the effect on the use of industrial materials in the manufacture of REES, which in the early stages were dominated by using these batteries in the manufacture of commercial REES. Companies such as Tesla use NMC in the early stage development of electric vehicles because they have the highest energy density than other LIBs. In contrast, additional electric vehicle manufacturers tend to use NCA in obtaining a more extensive life cycle [10]. NMC and NCA batteries’ cobalt content is also an interesting attraction because it has a high price because of its natural resources mostly deposited in the African Congo region with a production of 59% [11].

3.1.2. State of Charge (SOC), current, voltage, and battery resistance. Respondents suggested the electrical parameters as a battery safety measure in the EOL stage. When the battery reaches EOL, it is better if the battery capacity condition is carried out by monitoring battery performance because it will also affect waste management. In determining this, the battery is usually monitored online to see a graph of the voltage, current, and state of charge (SOC) or state of health (SOH) of the battery. SOC is a measure to get the battery charging condition based on the relationship between the battery’s open-circuit voltage and the battery capacity. At the same time, SOH is the ratio between the old battery’s maximum charge capacity and the charge capacity of the new battery [2]. While charging, the full battery may be limited to less than 100%, and the minimum may be limited to more than 0%. It aims to improve safety and save battery life, so there needs to be a standard for the empty level of batteries to be recycled [12]. Also, the battery during the EOL period can be seen from its resistance because an aging battery has increased internal resistance due to Li + ions being unable to intercalate the graphite in the battery that is already covered with a layer of electrochemical reaction results [13]. However, the exact value of those parameters wasn’t stated clearly by
respondents. Recyclers are generally not aware of the condition of a SOH or SOC battery. Only vehicle manufacturers or dealers the only could check the state of the battery by a specific code. There has been no defined and recognized definition and standard to classify the purpose of reuse batteries. All stakeholders in the supply chain didn’t clearly understand the performance of batteries reused or recycled [14]. We also suspect the respondents chose these parameters to carry out testing/monitoring of the EOL battery to make it easier for the recycling process.

3.2. Recycling Process
3.2.1. Quantity, raw materials, chemicals, and efficiency. The number of raw materials from the REES cycle at the end of their life will affect the continuous recycling process. In carrying out the recycling, the industry needs an optimal supply of raw materials from users. If the REES EOL quantity is not sufficient, it will hamper the collection of existing battery waste sustainably because this quantity economically must be fulfilled, namely to get investment returns [15]. This condition was encountered by respondents and influentially the implementation of the recycling industry. The raw materials’ characteristics will also affect the metal recovery results, as discussed in the previous section. Each type of battery’s different composition will affect the material yield from the metal extraction carried out. Suppose you look at the NMC and NCA types of batteries. In that case, they have more appeal for the industry to be recycled because they contain relatively high cobalt, which is in line with the current development carried out in Indonesia. The purity of cobalt, nickel, and copper can affect the battery recycling process’s economic value. Still, the recovery of all other battery components, especially lithium, should also be a concern in waste recycling efficiency [16]. In line with the development of recycling carried out by respondents, it shows that the development of metal extraction methods is dominated by hydrometallurgy (42%) Figure 4. The same thing is shown internationally regarding REES recycling research, which uses the hydrometallurgical method because it has the highest efficiency than other methods and could recover various metals in REES electrodes [17]. The dominance of the hydrometallurgical method’s use causes one parameter related to chemical process materials to be important in obtaining maximum results in terms of the efficiency of the chemicals used.

3.2.2. Safety and sanitation. REES has elements that vary depending on the type, but all contain heavy metals harmful to humans. Using chemicals for the extraction process or electrolytes from batteries can be dangerous for personnel safety. The safety and sanitation aspects of the factory from this exposure are essential. Case studies on the recycling of lead batteries, orientation, and lead absorption can include inhalation, ingestion, and skin contact. Personnel can inhale dust in the shelter or contaminate food, and tend to accumulate on the body [18]. Contamination in REES was also found in landfills, which were confirmed to cause pollutants to the environment, especially for Co, Cu, and Pb metals [6]. The safety aspects for personal and environmental needs to be considered in the development of recycling standards, including sanitation of the industrial environment, to create pleasant working conditions [15].

3.3. Product
3.3.1. Metal Quality, Purity, and Processing Method. The metal recovery results from recycling should have high efficiency and excellent quality, namely from the metal’s purity. Still, this quality must be adjusted from the post-destination of the recycled material. The processing method also plays a role in the output of recycled metal to get a high purity of up to 99% is required in the material recovery process, which is intended for REES raw materials. However, the only method to acquire that quality by using hydrometallurgy that viable at best is the respondent’s lab-scale. The industry could also take advantage of each method’s benefit in pyrometallurgy and hydrometallurgy, namely in facilitating the initial
Figure 4: The distribution of the development of recycling methods carried out by respondents

process in separating battery components by pyrometallurgy and high material recovery from hydrometallurgy. The challenges that may arise from the quality issue of recycled battery materials emphasize the importance of developing cost-effective recycling technologies with efficient material recovery processes for traction batteries and the development of a timely functional recycling infrastructure [19].

3.3.2. Environmental safety. Environmental safety issues are becoming popular with the increasing trend of circular economy (CE). CE creates an economic cycle for the electric vehicle industry to be a closed system so that the waste generated will be processed into components for electric vehicles again. The CE LIB recycling system has been targeted at a broader spectrum to reduce the environmental impact associated with LIB production. Besides producing quality products, recycling also produces waste from destructive processes to the environment and humans, such as recycled chemicals and toxic gases. The agencies must carry out improvements from recycled or reusable waste in the recovery of other materials under CE principles. As has been done by several agencies in utilizing the remaining recycled waste, secondary recovery can be carried out to obtain additional materials used for the metal industry [20]. It is hoped that from this process, not only the cathode but also all the other components are considered new main ingredients. The environmental impact caused by battery waste could be reduced.

4. Conclusion
The significant factors that influence REES recycling consist of raw materials, process, and product results. The raw material parameters consist of 7 parameters, including the type of battery, elements, necessary components, state of charge (SOC), electric voltage, electric current, and battery resistance. The process parameters consist of 6 parameters, including quantity, raw materials, process materials, efficiency, safety, and sanitation. The product yield’s final parameters include quality, metal purity, processing methods, and environmental protection. These parameters could be used as a reference and illustration in the initial process of forming a standard development plan related to REES recycling in Indonesia. Further research and stakeholder discussions regarding parameters need to be carried out to validate these parameters or other parameters in the standard development process.

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References
[1] IEA, "Global EV Outlook 2020," 14 June 2020. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2020. [Accessed 4 July 2020].
[2] G. Harper, R. Sommerville, E. Kendrick, L. Driscoll, P. Slater, R. Stolkin, A. Walton, P. Christensen, O. Heidrich, S. Lambert, A. Abbott, K. Ryder, L. Gaines and P. Anderson, Nature, pp. 75-86, 2019.

[3] K. Richa, C. W. Babbitt, G. Gaustad and Xue Wang, Resour Conserv Recycl 83, p. 63–76, 2014.

[4] C. Xu, W. Zhang, W. He, G. Li, J. Huang and H. Zhu, Environ Sci Pollut Res 24, p. 20825–20830, 2017.

[5] "Peraturan Pemerintah Republik Indonesia Nomor 101 Tahun 2014 Tentang Pengelolaan Limbah Bahan Berbahaya dan Beracun," Jakarta, 2014.

[6] D. H. P. Kang, M. Chen and O. A. Ogunseitan, Environ. Sci. & Technol., pp. 5495-5503, 2013.

[7] "Peraturan Presiden No. 55 Tahun 2019 tentang Percepatan Program Kendaraan Bermotor Listrik Berbasis Baterai," Jakarta, 2019.

[8] R. Ciriminna, L. Albanese, M. Pecoraino, F. Meneguzzo and M. Pagliaro, Global Challenge, 3, 1900016, 2019.

[9] T. Elwert, D. Goldmann, F. Römer, M. Buchert, C. Merz, D. Schueler and J. Sutter, Recycling, 1, pp. 25-60, 2016.

[10] T. Or, S. W. D. Gourley, K. Kaliyappan, A. Yu and Z. Chen, Carbon Energy, pp. 6-43, 2020.

[11] M. Chen, X. Ma, B. Chen, R. Arsenault, P. Karlson, N. Simon, and Y. Wang, Joule, pp. 2622-2646, 2019.

[12] A. J. A. Burke and K. Kurani, Batteries for PHEVs: Comparing Goals and the State of Technology, in Electric and Hybrid Vehicles: Power Sources, Models, Sustainability, Infrastructures and the Market, G. Pistoia, Ed., 2010.

[13] M. Pagliaro and F. Meneguzzo, Heliyon, vol. 5, p. e01866, 2019.

[14] Kelleher Environmental, “Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles: The Technical, Environmental, Economic, Energy and Cost Implications of Reusing and Recycling EV Batteries,” Kelleher Environmental, Toronto, 2019.

[15] R. Danino-Perraud, “The Recycling of Lithium-Ion Batteries: A Strategic Pillar for the European Battery Alliance,” IFRI, Paris, 2020.

[16] T. Georgi-Maschler, B. Friedrich, R. Weyhe, H. Heegn and M. Rutz, J. Power Sources, vol. 207, pp. 173-182, 2012.

[17] X. Zeng, J. Li and N. Singh, Critical Reviews in Environmental Science and Technology 44, p. 1129–1165, 2014.

[18] WHO, Recycling Used Lead Acid Batteries: Health Considerations, Bern: WHO, 2017.

[19] S. Ziemann, D. B. Müller, L. Schebek and M. Weila, Resources, Conservation and Recycling, vol. 133, pp. 76-85, 2018.

[20] O. Velázquez-Martínez, J. Valio, A. Santasalo-Aarnio, M. Reuter and R. Serna-Guerrero, Batteries 5, 68., pp. 1-33, 2019.