HYBRID-CAR BATTERY WASTE MANAGEMENT TOWARDS CIRCULAR ECONOMY IN THAILAND

Wanida SURIYANON[1,2,3], Napat JAKRAWATANA[2] and Nakorn SURIYANON [3*]

1 Graduate school, Chiang Mai University, Thailand

2 Faculty of Engineering, Chiang Mai University, Thailand

3 Faculty of Engineering, Rajamangala University of Technology Lanna, Thailand; pinkenv@gmail.com (Corresponding Author)

ARTICLE HISTORY

Received: 29 September 2023 **Revised:** 11 October 2023 **Published:** 27 October 2023

ABSTRACT

Electric and hybrid cars are becoming increasingly popular in Thailand, following global trends. This study uses Material Flow Analysis (MFA) to track the flow and inventory of nickel in the Ni-MH battery supply chain in Thailand. In 2022, there were ~302,000 HEV/PHEV vehicles in Thailand, up 10x since 2012, and the government's campaign could mean up to 895,420 hybrid cars. Expired nickel-metal hydride batteries are disposed using the 3R method. The following are the recommended guidelines to manage Ni-MH batteries sustainably: 1) Develop a market for secondary materials. 2) Promote circular economy practices for Ni-MH batteries. 3) Establish a supply chain. 4) Create a second life for batteries. 5) It is recommended to define a minimum cycle number for batteries. This helps to reduce environmental loads. Batteries with high energy density and long lifespan produce less environmental harm. Therefore, it's important to support products and technologies that can improve energy density and lifespan. 6) It is crucial to separate secondary batteries from municipal garbage and to treat different types of discarded batteries separately. 7) Thailand should build its own recycling factory instead of shipping materials to Japan for recycling. This will lessen the cost and reduce the greenhouse effect.

Keywords: Nickel Metal Hydride, Hybrid Electric Vehicle, Plug-In Hybrid Vehicle, Material Flow Analysis, Circular Economy

CITATION INFORMATION: Suriyanon, W., Jakrawatana, N., & Suriyanon, N. (2023). Hybrid-Car Battery Waste Management towards Circular Economy in Thailand. *Procedia of Multidisciplinary Research, 1(10),* 25.

INTRODUCTION

In modern times, we have witnessed significant advancements in the fields of economy, science, technology, industry, invention, and innovation. However, these advancements are not in sync with environmental development. For instance, the rise in vehicle production and usage leads to an increase in fuel consumption and emissions from engine combustion, which poses a grave threat to the environment (Rasul et al., 2006). The United Nations Framework Convention on Climate Change (UNFCCC) fights harmful climate interference with the goal of stabilizing greenhouse gas levels in the atmosphere. Signed by 154 countries at the 1992 Earth Summit in Rio de Janeiro (Kuyper et al., 2018). The world is transitioning to eco-friendly energy and reducing carbon emissions to net zero. The car industry is moving from ICE to EV, reducing the use of fossil fuels.

There are four types of batteries commonly used: Lead acid, Ni-MH (Nickel metal hydride), NiCd (Nickel Cadmium) and Li-Ion (Lithium-Ion). In Thailand, most vehicles (around 40 million) use internal combustion engines (ICE) that require lead acid batteries (Kanchanapiya et al., 2013). However, in the past decade, hybrid vehicles have been imported into the country. There are two types of hybrid vehicles: hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV).

Hybrid electric vehicles combine an ICE system with an electric propulsion system. They use the ICE as the primary system and the electric motor as the secondary system to drive the vehicle. In contrast, PHEVs are HEVs with rechargeable batteries that can be restored to full charge by connecting a plug to an external electric power source (Green et al., 2011). HEVs, on the other hand, cannot be recharged by connecting a plug to an external electric power source. PHEVs can use energy from both sources simultaneously, which allows the vehicle to run at higher speeds and extended distances using only electricity. Hybrid vehicles use Ni-MH batteries, and currently, there are roughly 320,000 HEVs and PHEVs in Thailand. One of the policies in the Thai national Energy Plan is to shift towards using electricity or green energy for transportation.

In order to analyze the current status of nickel management and find ways to improve towards a circular economy, this study applied Material Flow Analysis (MFA) to trace the flow and stock of nickel in the Ni-MH batteries supply chain in Thailand. The study uses data on the number of vehicles expected in 2022. The aim of this study is to explore ways of improving the circularity of nickel in Ni-MH batteries waste (which is used in hybrid vehicles). The objective of this research is to use applied material flow analysis as a tool to trace the flow and stock of nickel in the supply chain of Ni-MH batteries in Thailand. This will help to analyze the current status of nickel management and identify ways for improvement towards a circular economy.

LITERATURE REVIEWS

Nickel-Metal Hydride Batteries (Ni-MH)

Nickel-metal hydride batteries were developed in 1989 and are known for their high electrochemical capacity, long lifetimes, safety, good environmental compatibility, wide temperature range, and low self-discharge rates (Lin et al., 2016). Before the era of Ni-MH batteries, NiCD batteries were commonly used. However, Ni-MH batteries have several advantages over NiCD batteries, such as being more environmentally friendly, having efficient charging, and providing better power. As a result, since 1999, the sales and usage of Ni-MH batteries have steadily increased in the global market (Rydh & Svärd, 2003). In the automotive industry today, Ni-MH batteries are commonly used in hybrid electric vehicles worldwide (Pradhan et al., 2022). Ni-MH batteries consist of a nickel-metal hydride cathode and metal hydride anode. Equations 1 and 2 represent the chemical reactions occurring at the cathode and anode of a Ni-MH battery (Chen et al., 2015).

Cathode reaction: $NiO(OH)+H_2O+electron \rightarrow Ni(OH)_2 + OH^-$ (1)
Anode reaction: $MeH+OH^- \rightarrow Me +electron + H_2O$ (2)

Nickel products are typically classified as either class I or class II. Class I products have a nickel content of more than 99% and can take the forms of cathodes. The class I nickel is commonly referred to as nickel metal. On the other hand, Class II products have a nickel content of less than 99%. Both class I and class II nickel are used in the production of batteries (Schmidt et al., 2016). A process chain diagram for the primary production routes of Class I nickel is shown in Figure 1.

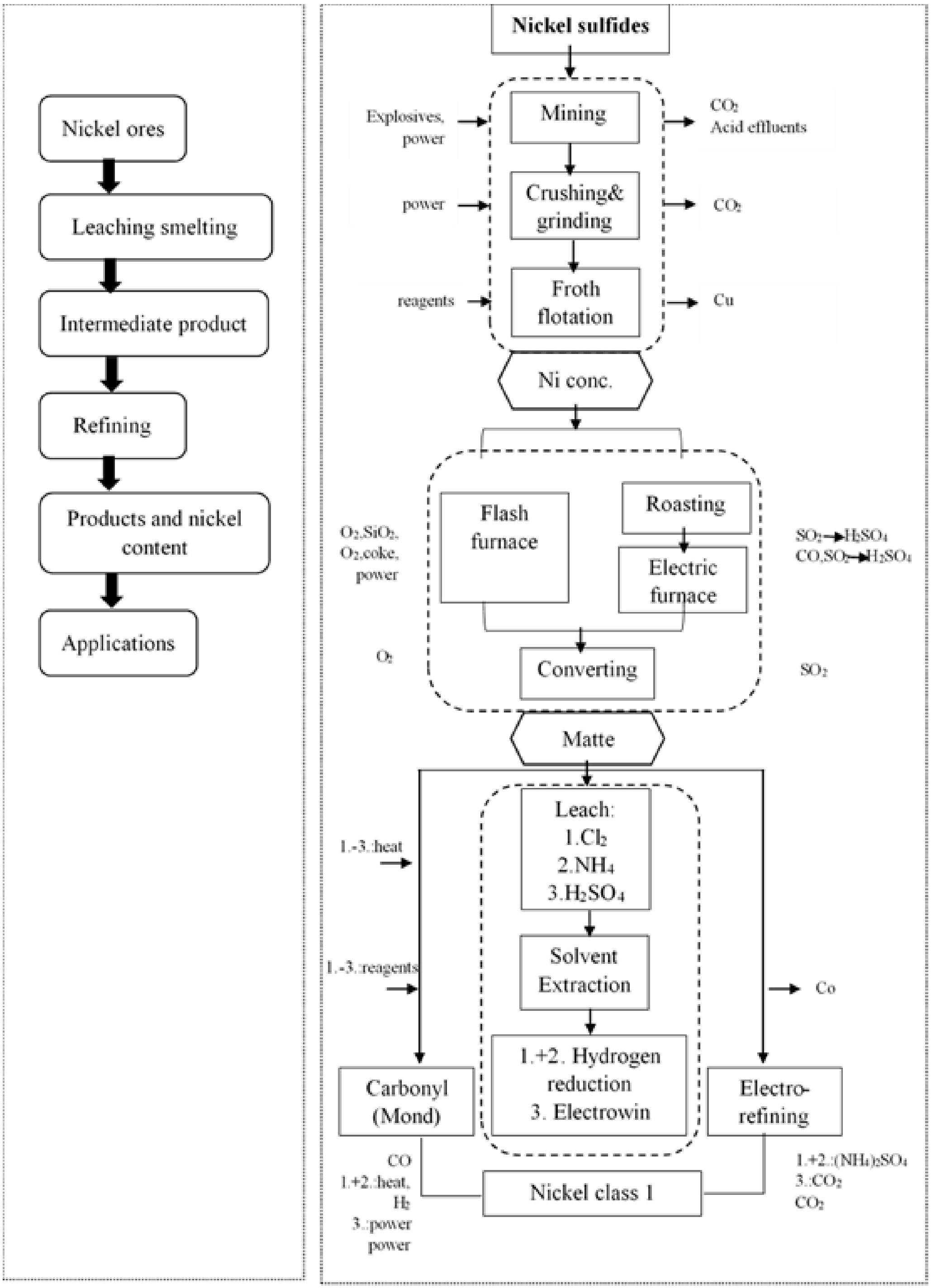

Figure 1 A process chain diagram for the primary production routes of Class I nickel

Material Flow Analysis (MFA)

Material flow analysis is a methodical assessment of the movement and amount of materials within a defined system over a specific period. It is a valuable tool employed in managing resources, waste, and the environment. It is used to 1) evaluate the significance and relevance of material movement and quantity, 2) regulate the flow and amount of materials to support specific objectives such as sustainable development, 3) evaluate resource utilization and environmental impact, 4) establish long-term environmental policies and resource management strategies, and 5) comprehend and regulate the movement of heavy metal-containing batteries (Suriyanon et al., 2021).

METHODOLOGY

In this study, MFA was used as a tool to systematically assess the flows and stocks of materials within a specified temporal and spatial system. The research methodology for this study can be broken down into four steps as follows:

1) Setting the scopes of the analysis study, identifying the system boundary and components

The scope of this study was to establish the material flow system of nickel in Ni-MH batteries, with a focus on Thailand as the spatial boundary and the year 2022 as the temporal boundary. The life cycle of nickel in Ni-MH batteries was divided into three stages: product manufacturing, product use, and waste management. It is worth noting that there is no lead mining in the life cycle chain of Thailand. Nickel, a raw material for battery production, is obtained through import and recycling only.

2) Data collection

To collect secondary data, we searched the official websites of various governmental offices, including the Department of Land Transport and the Office of Industrial Economics. Additionally, we reviewed articles published in local languages and Thai. The official websites of governmental offices were also used to gather data on the quantity of Ni-MH batteries in Thailand.

3) Schematic modeling and balance for material flow system framework

In this step, we create a system that utilizes the data we have collected earlier. In case some data is missing, we can use mass balance or mass conservation principle, which means that the mass-in is equal to mass-out to balance the materials. To analyze the current situation, we have utilized the STAN software to perform Material Flow Analysis.

4) Interpreting MFA result for lead in lead acid battery

In this step, the results of the MFA for nickel in Ni-MH batteries were interpreted to find the appropriate method for managing battery waste in Thailand.

RESULTS

The Number of Hybrid Electric and Plug-in Hybrid Electric Vehicles from 2014 To 2022

Data from the Department of Land Transport indicates that there will be a growing number of HEV/PHEV vehicles in Thailand from 2014 to 2022, with the number expected to range from 62,726 to 302,008 (Statistics of Department of Land Transport, 2020). Figure 2 depicts the number of registered hybrid cars in Thailand during the period from 2014 to 2022.

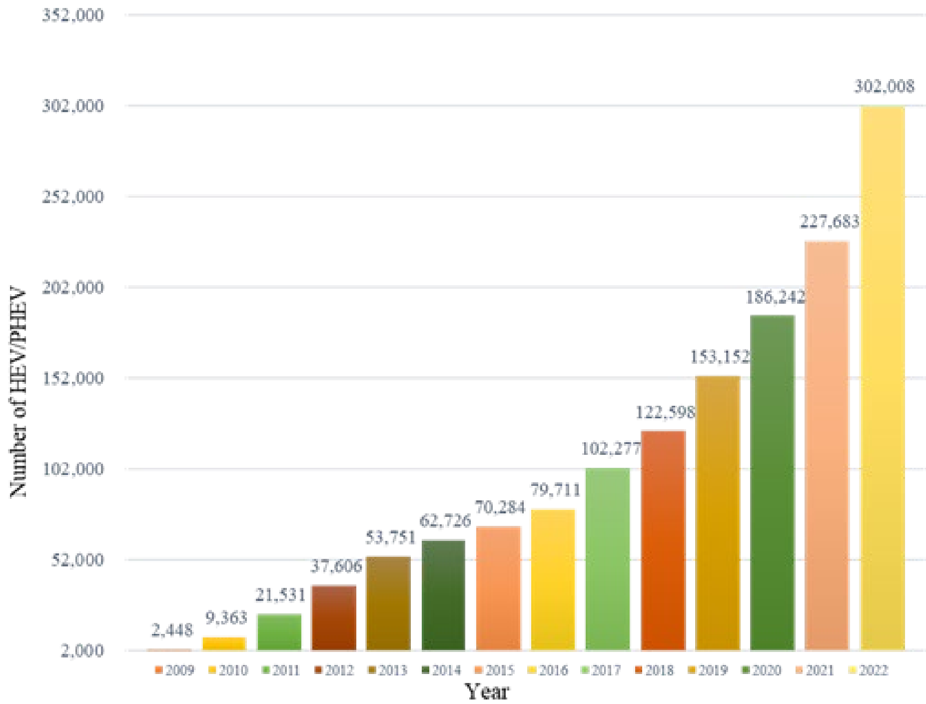

Figure 2 The number of registered hybrid cars in Thailand during the period from 2009 to 2022.

Material Flow Analysis (MFA) of Ni-MH Batteries

According to data from the Department of Land Transport, in 2022 there were 302,008 HEV/PHEV vehicles which used nickel-metal hydride batteries containing nickel minerals. This amounts to approximately 13,076 tons of nickel per year, assuming an average battery weight of 300 kilograms per vehicle (equivalent to 43.3 kilograms of nickel).

Thailand was found to be the pioneer in the first generation of HEV cars, specifically the TOYOTA Prius, as per the results of the MFA study on nickel minerals in batteries. At present, there are many brands of HEV cars available. The lifespan of this type of battery is around 8 years.

According to Figure 3, Thailand imports 13,077 tons of virgin cell every year to be used in car factories. Once the batteries reach the end of their useful life, they are collected by the Collector who checks their performance. If the batteries have an efficiency of over 80%, they are repacked and accounted for 2,615 tons per year. The batteries with efficiency ranging from 60-80% are reused, accounting for 1,569 tons per year. The batteries with efficiency less than 60% are taken for recycling, which amounts to 8,892 tons per year. Since there is no recycling factory in Thailand, the batteries are sent for recycling abroad. The batteries that are reused in Thailand are sent to Energy Storage, but once they have expired, they are also sent abroad for recycling. The recycling process has an efficiency rate of approximately 95%, and 9,938 tons of ore are recycled back into the battery pack factory process. Recycling helps to reduce the import of virgin material, especially nickel ore, which is considered a hard-to-find mineral.

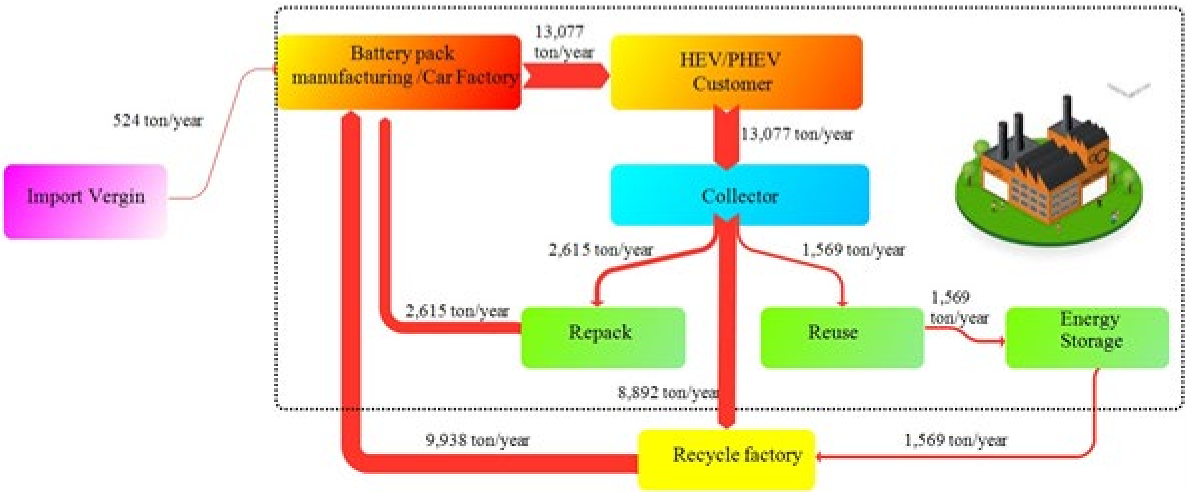

Figure 3 Material Flow Analysis of Ni-MH in Ni-MH batteries in Thailand 2022

DISCUSSION AND CONCLUSION

According to a study conducted in 2022, there were around 302,008 HEV/PHEV vehicles in Thailand. The number of hybrid vehicles has increased significantly since 2012, by approximately 10 times. Similarly, compared to the number of cars in 2009, the number of hybrid vehicles has increased by about 120 times. This indicates that HEV/PHEV cars are gaining popularity in the country. Furthermore, it is predicted that the number of hybrid cars will increase further in the future. By 2048, Thailand may have as many as 895,420 hybrid cars due to the government's campaign to promote the use of electric cars (Suriyanon et al., 2021). While hybrid cars are still more expensive than ICE cars, they are more affordable than electric cars. However, the trend in car production is moving towards greater use of electric cars, and the Thai government is supporting the production of more electric cars in the country. This may lead to a decrease in the price of electric cars in the future. Thailand has been using hybrid cars for some time, which sets them apart from EV electric cars that have only recently been introduced in the country. This has affected consumer trust and confidence in the performance of HEV/PHEV cars, which may lead to even higher production and sales of hybrid cars in the future.

In Thailand, the management of expired nickel-metal hydride batteries involves collecting and separating battery waste using the 3 R method, which stands for Reuse, Repack, and Recycle. Currently, the use of hybrid electric and plug-in hybrid electric vehicles (HEV/PHEV) is not very common in the country. Hybrid cars only arrived in Thailand around 2009, which means that there are still only a few of them, and their high cost makes them rare. However, as the battery life of these cars is only 10 years, the nickel-metal hydride batteries in them eventually wear out and become waste. The MFA of Ni-MH (Nickel-metal hydride) batteries in Thailand for 2022 is presented in Figure 3. The data for Import Virgin materials, Battery pack manufacturing, Car Factory, and HEV/PHEV, as shown in the figure, have already occurred in 2022. However, the subsequent data, from battery collection to recycling, will occur in 2032, when these Ni-MH batteries expire or deteriorate and become scrap batteries. If these used batteries are not managed properly, they could cause significant environmental pollution problems.

Currently, Thailand only manages the recycling of lead-acid batteries. Recycling of Ni-MH batteries is not yet managed (Suriyanon et al., 2020). When batteries are used, their performance declines. Until they can no longer be used in cars, there are mostly two types:

batteries that have reached the end of their useful life, and batteries that were damaged in an accident. In the case of batteries that have expired (the current average is about 10 years), there is still about 80 percent of the total battery capacity remaining. If it can be repaired, for example, in case some of the battery cells are damaged, the battery can be reused in HEV/PHEV. Alternatively, it can be repacked for another 4 and a half years. But if the battery cannot be repaired to capacity above 80 percent, it will be used as a stationary energy storage device for use in emergencies or to help add electricity to the system during periods of excessive electricity use. In such a case, it is called battery management, either reuse or recycling (Second Life). One of the advantages of repacking and reusing batteries is that it increases their overall value, even after they have reached the end of their useful life. This helps reduce the cost of batteries in hybrid and electric cars, making them more accessible to consumers. It's worth noting that when batteries are reused in these cars, even after they have expired, they still retain about 80 percent of their total capacity. To refurbish these batteries, they need to be charged up to 70 percent of their capacity and tested. Another benefit of reusing batteries is that they can be repurposed for stationary energy storage instead of using new lead-acid batteries. This reduces the energy used in the production of new batteries, which helps to combat climate change. In fact, reusing batteries can reduce energy use and the occurrence of global temperature change by 69 and 68 percent, respectively. However, if a battery cannot be reused due to damage from an accident, it will need to be taken apart and recycled. The raw materials obtained from recycling will be used to produce new batteries, while the parts that cannot be recycled will be sent to landfill according to the waste disposal process. It's worth noting that recycling batteries requires a lot of energy and chemicals, so it's important to consider all aspects of the recycling process. In the future, Thailand should build its own recycling factory instead of shipping materials to Japan for recycling. This will lessen the cost and reduce the greenhouse effect.

Another study found that spent Ni-MH batteries can be used to recover valuable metals, alleviating metal shortages. The process of recovering metals from spent Ni-MH batteries involves several steps. First, the remaining deposited energy is liberated, and then the collected electrode materials are crushed and calcined (Huang et al., 2011; Pinheiro et al., 2021). Next, chemical and metallurgical procedures, such as leaching and separation of recovered metals by precipitation and solvent extraction, are used. There are three main techniques for recovering metals from battery waste: pyrometallurgical, hydrometallurgical, and biometallurgical (Granata et al., 2012). Recycling methods and recovery processes each have their own advantages, disadvantages, and limitations. While some methods may have benefits such as lower energy consumption and reduced greenhouse gas emissions, as well as high recycling efficiency and lower operating costs, others may require expensive equipment and may not be cost-effective (Pradhan et al., 2022). Rodrigues discovered that sulfuric acid can be used to leach nickel from Ni-MH battery powder with an efficiency of up to 85% (Rodrigues & Mansur, 2010). Meanwhile, Perämäki found that dry chlorination process can also leach nickel from Ni-MH battery waste, achieving a leaching efficiency of as high as 87% (Perämäki et al., 2022). Therefore, it is crucial to continuously study and develop recycling processes in order to maximize the recovery of valuable metals at reasonable prices.

Previous research has highlighted various deficiencies in the current policies concerning the handling and disposal of batteries. These include: 1) The lack of clear provisions for historical and orphan batteries. 2) The absence of a target for battery collection. 3) The unclear definition of the scope of authority among various central and local agencies involved in the regulation of waste battery treatment. 4) The unclear requirements for data auditing and verification for tracking the entire life cycle of EV batteries. 5) The limited consideration of the challenges in ensuring stakeholder cooperation. 6) The absence of explicit specifications of the mechanisms for financing waste battery treatment (Li et al., 2021). Malinauskaite et al. (2021) and Yu et al.

(2014), they have come up with guidelines to manage Ni-MH batteries sustainably. The researcher analyzed existing research, summarized recommendations, and drew conclusions on sustainable Ni-MH battery management. The following are the recommended guidelines: The following are the recommended guidelines:
1) Develop a market for secondary materials.
2) Promote circular economy practices for Ni-MH batteries.
3) Establish a supply chain that includes collecting, sorting, dismantling, materials recovering, and remanufacturing, including reusing, upcycling, and downcycling.
4) Create a second life for batteries.
5) It is recommended to define a minimum cycle number for batteries. This helps to reduce environmental loads. Batteries with high energy density and long lifespan produce less environmental harm. Therefore, it's important to support products and technologies that can improve energy density and lifespan.
6) It is crucial to separate secondary batteries from municipal garbage and to treat different types of discarded batteries separately.
7) Thailand should build its own recycling factory instead of shipping materials to Japan for recycling. This will lessen the cost and reduce the greenhouse effect.

REFERENCES

Chen, X., Zhou, T., Kong, J., Fang, H., & Chen, Y. (2015). Separation and Recovery of Metal Values from Leach Liquor of Waste Lithium Nickel Cobalt Manganese Oxide Based Cathodes. *Separation and Purification Technology, 141*, 76-83.

Granata, G., Pagnanelli, F, Moscardini, E., Takacova, Z., Havlik, T., & Toro, L (2012). Simultaneous Recycling of Nickel Metal Hydride, Lithium Ion and Primary Lithium Batteries: Accomplishment of European Guidelines by Optimizing Mechanical Pre-Treatment and Solvent Extraction Operations. *Journal of Power Sources, 212*, 205-211.

Green, R., Wang, L., & Alam, M. (2011). The Impact of Plug-in Hybrid Electric Vehicles on Distribution Networks: A Review and Outlook. *Renewable and Sustainable Energy Reviews, 15*(1), 544-553.

Huang, K., Li, J., & Xu, Z. (2011). Enhancement of the Recycling of Waste Ni–CD and Ni–MH Batteries by Mechanical Treatment. *Waste Management, 31*(6), 1292-1299.

Kanchanapiya, P., Utaka, J., Kittinan, A., Lecksiwilai, N., Kitpakornsanti, K., & Sudkla, B.. (2013). Life Cycle Assessment of Lead Acid Battery. Case Study for Thailand. *Environment Protection Engineering, 39*, 101-114.

Kuyper, J., Schroeder, H., & Linnér, B. (2018). The Evolution of the UNFCCC. *Annual Review of Environment and Resources, 43*(1), 343-368.

Li, W., Yang, M., Long, R., Mamaril, K., & Chi, Y. (2021). Treatment of Electric Vehicle Battery Waste in China: A Review of Existing Policies. *Journal of Environmental Engineering and Landscape Management, 29*, 111-122.

Lin, S., Huang, K., Wang, I., Chou, I., Kuo, Y., Hung, C., & Lin, C. (2016). Characterization of Spent Nickel-Metal Hydride Batteries and a Preliminary Economic Evaluation of the Recovery Processes. *Journal of the Air & Waste Management Association, 66*(3), 296-306.

Malinauskaite, J., Anguilano, L., & Rivera, X. (2021). Circular Waste Management of Electric Vehicle Batteries: Legal and Technical Perspectives from the EU and the UK Post Brexit. *International Journal of Thermofluids, 10*, 100078.

Perämäki, S., Tiihonen, A., Rajahalme, J., Larsson, S., Lahtinen, E., Niskanen, J., Budhathoki, R., & Väisänen, A. (2022). Dry Chlorination of Spent Nickel Metal Hydride Battery Waste for Water Leaching of Battery Metals and Rare Earth Elements. *Journal of Environmental Chemical Engineering, 10*(5), 108200.

Pinheiro, R., Michielin, L., Martins, T., Wildgrube, T., Tanabe, E., & Daniel, B. (2021). Application of Mechanical Processing Operations for the Recycling of Nickel Metal Hydride Batteries. *Journal of Material Cycles and Waste Management, 23*, 2148–2161.

Pradhan, S., Nayak, R., & Mishra, S. (2022). A Review on the Recovery of Metal Values from Spent Nickel Metal Hydride and Lithium-Ion Batteries. *International Journal of Environmental Science and Technology, 19*(5), 4537-4554.

Rasul, M., Faisal, I., & Khan, M. (2006). Environmental Pollution Generated from Process Industries in Bangladesh. *International Journal of Environment and Pollution, 28*, 144-161.

Rodrigues, L, & Mansur, M. (2010). Hydrometallurgical Separation of Rare Earth Elements, Cobalt and Nickel from Spent Nickel–Metal–Hydride Batteries. *Journal of Power Sources, 195*(11), 3735-3741.

Rydh, C., & Svärd, B. (2003). Impact on Global Metal Flows Arising from the Use of Portable Rechargeable Batteries. *Science of the Total Environment, 302*(1), 167-184.

Schmidt, T., Buchert, M., & Schebek, L. (2016). Investigation of the Primary Production Routes of Nickel and Cobalt Products used for Li-Ion Batteries. *Resources, Conservation and Recycling, 112*, 107-122.

Statistics of Department of Land Transport. (2020). *Department of Land Transport*. Retrieved from https://web.dlt.go.th/statistics/.

Suriyanon, W., Jakrawatana, N., & Suriyanon, N. (2020). Material Flow Analysis of Lead in Lead Acid Batteries Supply Chain Toward Circular Economy. *Thai Environmental Engineering Journal, 34*(3), 55-62.

Suriyanon, W., Jakrawatana, N., & Suriyanon, N. (2021). Material Flow of Nickel in Nickel Metal Hydride Batteries Waste and Possible Circularity Improvement in Thailand. *Clean Technologies and Environmental Policy, 24*, 887–899.

Yu, Y., Chen, B., Huang, K., Wang, X., & Wang, D. (2014). Environmental Impact Assessment and End-of-Life Treatment Policy Analysis for Li-Ion Batteries and Ni-MH Batteries. *International Journal of Environmental Research and Public Health, 11*(3), 3185-98.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.