THE EFFECTS OF END-OF-LIFE ELECTRIC CAR LITHIUM BATTERIES

ON THE WASTE STREAM, EPR PROGRAMS,

AND THE REVERSE SUPPLY CHAIN

by

Katelynn Badger

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Project Approved:

Joe Roh, Ph.D.
Department of Information Systems and Supply & Value Chain Management
(Supervising Professor)

Laura Meade, Ph.D.
Department of Information Systems and Supply & Value Chain Management

Keith Whitworth, Ph.D.
Department of Sociology and Anthropology

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INTRODUCTION

The purchasing habits of electronics consumers combined with the decreasing life span of electronics have led to an increasing amount of electronic waste generation each year. Electronic waste (E-Waste) describes “unwanted or obsolete electronics” such as refrigerators, washing machines, mobile phones, personal computers, printers, and television sets (Zhang, Schnoor & Zeng, 2012). Data released in 2011 by the U.S. Environmental Protection Agency Office of Resource Conservation and Recovery states that 40 million tons of e-waste enters the global waste stream each year (“Electronic Waste Management”, n.d.). This disposal represents a 122% increase since 1999. Of the disposed tons, only 25% entered a recycling or refurbishing program (“Electronic Waste Management”, n.d.). The generation of e-waste contributes to the risk of exhausting available landfill space. Additionally, the toxins and heavy metals such as lead, mercury, and arsenic found in electronic products pose health and safety risks to the environment and humans. Approximately 80% of waste generated in developed countries is sent abroad, causing social outcries as well (Zhang et al., 2012).

As the economic, environmental, and social impacts of waste disposal become increasingly prevalent, stakeholders place more emphasis on sustainable business practice and waste reduction. One initiative aimed at waste reduction that has gained momentum over the past several years is take-back legislation. The fundamental purpose of take-back legislation “is to lower the environmental impact by reducing the amount of waste sent to landfills” (Atasu & Van Wassenhove, 2012). Take-back programs facilitate the collection of end-of-life products in order to prevent the products from entering the waste stream. The ultimate goal is to design an infrastructure that allows for the recycling or refurbishing of goods in order to reclaim the valuable metals and natural resources contained within the goods.

Extended producer responsibility (EPR) systems are a particular type of take-back program that place the responsibility of take-back on the manufacturer. In an EPR system, manufacturers are required to "provide a system or financial means of collecting and processing the waste stream of used products to control environmental pollution" (Atasu, Van Wassenhove & Sarvary, 2009). In an EPR system, aspects of the traditional take-back initiative are managed by the manufacturer, and the goal is to "provide producers with incentives to design greener products" in addition to reducing the amount of waste sent to landfills (Atasu et al., 2012).

This manuscript will focus specifically on the lithium battery waste generated by electric vehicles. Based on the prominence of e-waste take-back programs in other nations, and the negative consequences that arise from improper disposal, it is likely that national take-back legislation for electronic goods will eventually come to fruition in the U.S. Due to the 10 year life span of these batteries, the U.S. has yet to reach a point in which the generation of lithium batteries from end-of-life electric vehicles is steady and high (Kanter, 2011). It is estimated that by the early 2020s, 500,000 electric car batteries will enter the U.S. waste stream each year (Kanter, 2011). Only one company within North America has the technological capability of recycling lithium electric car batteries, but they lack the physical capacity to meet the future recycling needs of the U.S. The recycling limitations are a contributing reason to why the U.S. presently lacks a national take-back program.

The lithium electric car batteries have several unique characteristics that differentiate them from other forms of e-waste, and these qualities will serve as the driving force behind the type of take-back system that is put in place. Characteristics such as the size, volume, visibility, and reactivity will influence which stakeholders will manage and control each aspect of the future take-back initiative (Refer to Table 1 for a listing of lithium electric car battery characteristics). The supply chain activities for the various stakeholders involved will be affected by the take-back program, regardless of the specific design and structure of the system. The manuscript will provide hypotheses on how the unique battery characteristics will drive how they are disposed of, the type of EPR program put into place, as well as how supply chain activities for the various stakeholders will be affected.

RESEARCH QUESTION

The paper will seek to answer the question of how recycling lithium batteries from electric cars will affect the waste stream, EPR program design, and the reverse supply chain.

Due to the infancy of the lithium electric car industry, national take-back legislation for the batteries is non-existent in the U.S., as is research on the implications of a take-back program. The manuscript will propose how the nature of the batteries will affect disposal as well as the creation of an EPR system. The end goals is to aid supply chain leaders in their planning activities required to effectively respond to this new supply chain challenge. The environment and safety risks that arise from failing to recycle the batteries drive the creation of a national take-back program, as does the “green” nature of the car. The future implementation of a take-back program in the U.S. is extremely likely; taking this into consideration stakeholders should begin the process of understanding how the battery as well as take-back legislation will affect their various supply chain activities.

Solutions to the research question will be provided through a series of hypotheses defending the impact of the battery characteristics and the government on disposal, EPR system structure, and supply chain operations. The proposed hypotheses will be defended through academic research on the drivers behind traditional e-waste recycling procedures as well as a look at the various types of take-back programs implemented around the world. The research will create an understanding of how recycling lithium batteries will impact the supply chain operations of the involved stakeholders. This ultimately will allow for predictions as to which type of take-back structure will prove most effective for the recycling of lithium electric car batteries and which stakeholders should have the responsibility of managing each of the supply chain activities.

REVIEW OF LITERATURE

Understanding Waste

The characteristics of a waste product determine the structure and limitations of the take-back program. Therefore, a comparative examination of lithium battery attributes with other waste products will precede a thorough understanding of the type of EPR alternative needed for lithium recycling as well as the alternative’s affect on stakeholders.

Beverage Containers

In 1930, long before the presence of mass-produced consumer electronic goods, the first steel beverage can entered the market and revolutionized the way beverage companies bottled and sold drinks. Since then, bottles and cans have entered the waste stream in high numbers and account for 40-60% of litter annually (*Bottle Bill Resource Guide*, n.d.). Consumers today dispose of 2.5 million plastic bottles every hour and 80 million cans a day (Robertson, 1991). The first piece of recycling legislation for these glass, plastic, and aluminum containers came into existence in 1971 in the state of Oregon (*Bottle Bill Resource Guide*, n.d.). Ten more states followed suit and enacted state-wide container deposit laws that require bottling companies to recycle returned containers. Upon returning an empty container to a redemption operation or retailer, consumers receive a monetary reward directly from the retailer typically valued around 5-10 cents. The retailer receives re-imbursement from the bottler once returning the empty containers (*Bottle Bill Resource Guide,* n.d.). Sorting poses the most significant challenge to recycling beverage containers, particularly when the label is missing. Common costs to the manufacturer in a take-back system for bottles includes additional warehouse space construction, additional delivery truck usage, and R&D depending on the manufacturer's level of involvement.

E-Waste

As previously discussed, a high volume of e-waste enters the waste stream every year. The following section will provide a more in-depth look at e-waste, it's end-of-life value, and how it is recycled.

EPR legislation for electronics is currently present in the European Union and several Asian countries on a national level. The United States does not have a national take-back program for electronic waste, but 24 of the 50 states have implemented state-wide programs. Refer to Table 2 for a listing of the states.

In Europe, the Waste Electric and Electronic Equipment (WEEE) organization is a not-for-profit organization begun in 2003 that requires its 31 member countries to meet annual recycling quotas (Khetriwal, Widmer, Kueher & Huisman, 2011). The organization is the largest multi-national e-waste recycling program in existence and the various manufacturers hold the responsibility of funding and implementing end-of-life product recycling with the help of the government and 3rd party facilitators ("Taking on Europe's Electronic", n.d.).

EPR systems exist only in the more developed countries of Asia such as Japan, Korea, and Taiwan. However, developing nations such as Thailand, Vietnam and Malaysia are in the process of drafting take-back legislation as well (Akenji, Hotta, Bengtsson & Hayashi, 2011). Japan has implemented two take-back laws: The Specified Household Appliance Recycling Law (SHAR) in 2001 and the Law for Promotions of Efficient Utilization of Resources (Akenji et al., 2011). The SHAR law focuses on the recovery of televisions, air conditioners, refrigerators, freezers, washing machines, and dryers, whereas the other program specializes in the collection of personal computers (Akenji et al., 2011). The SHAR law requires the end-user to pay a disposal fee to assist with the cost of collection and recycling. The fee goes into a centralized pool for the funding of supply chain processes needed for electronics recovery (Atasu & Van Wassenhove, 2012). In Taiwan, manufacturers absorb the costs associated with collection and recycling electronic equipment in addition to contributing to a national recycling fund that facilitates the various supply chain functions in a centralized manner.

Lithium Electric Car Battery Waste

Lithium rechargeable batteries are used in several devices such as cameras, laptops, and cell phones (Egbue & Long, 2012). The clear performance advantages these batteries have over other battery technologies have led to their use in the electric automobile industry (Egbue & Long, 2012). The typical lithium electric car battery weighs approximately 550 pounds and is much larger than gasoline powered cars. The larger size is needed to compensate for the lack of fuel (Kanter, 2011). The average life span is 10 years, although current research is looking for ways to re-harness the leftover energy in order to increase the lifespan (Egbue & Long, 2012). The composition includes a steel casing made from iron, chromium, nickel, or aluminum. The battery's anode contains both carbon and aluminum and the cathode is composed of lithium, cobalt, nickel, manganese, iron and copper. Other materials include plastics, lithium salts, and organic solvents. Although these components would prove harmful to humans and the environment if disposed of improperly, they are not as toxic as heavy metals such as lead and mercury found in traditional batteries (Egbue & Long, 2012).

The recycling capability for lithium batteries, especially those used to power vehicles is almost non-existent (Ziemann, Weil & Schebek, 2012). Toxco, located in British Columbia, is the only North American company with the capability of recycling lithium batteries from electric cars (Hamilton, 2009). The only other company with the capability is Umicore in Hoboken, Belgium (Kanter, 2011). The Department of Energy (DOE) has granted $9.5 million to Toxco to build a plant in Ohio specializing in the recycling of lithium car batteries that will be able to support the upcoming demand (Kanter, 2011).

The recycling process at the sole lithium battery plant, Toxco, involves the storing of the waste in earth covered concrete storage bunkers after being inventoried in order to prevent harmful explosions from occurring. Large amounts of energy remain stored in the end-of-life batteries which could deliver harmful shocks or pose a fire hazard if not handled properly (Kanter, 2011). Residual electrical energy is then moved through Toxco's patented cryogenic process. The process involves the cooling of the battery down to 325 degrees Fahrenheit. Although explosively reactive at room temperature, Lithium is inert at this particular temperature. The batteries are then shredded upon the cooling process and the materials are separated. The materials extracted during the recycling process have less value than the by-products extracted from recycling traditional e-waste. ("Lithium Battery Recycling," n.d.). The value of lithium is less than that of heavy metals such as lead or the cobalt and nickel present in lithium electric batteries. Thus, current recycling programs focus mainly on "recovering battery materials such as cobalt and nickel that are considered more valuable than lithium" (Dewulf, Der Vorst, Denturck & Van, 2010). With only one recycling facility and no national take-back legislation, car manufacturers are going their individual ways when it comes to end-of-life disposal of lithium electric car batteries. Some batteries are sent abroad illegally, some are sent to power companies to develop ways of reusing old batteries, some manufacturers defer recycling altogether, and then some end up at Toxco for recycling (Kanter, 2011).

Large amounts of energy remain stored in the end-of-life battery which could deliver harmful shocks or pose a fire hazard if not handled properly (Kanter, 2011). Regardless of the final destination of the battery, safe storage and transportation must take priority due to the reactive nature of the batteries.

EPR Alternatives

As previously explained, take-back legislation aims to close the supply chain loop by promoting the collection and eventual recycling of end-of-life products. EPR systems hold the OEM responsible for the end-of-life goods they produced. Legislation diversity exists not only between the different nations, but among the various municipalities and states within a nation as well. The following text will outline the differentiating factors among the various EPR alternatives and provide examples of current systems in existence. Understanding the different EPR alternatives is the initial step in hypothesizing the type of structure required for lithium electric car battery recycling. When designing an EPR system, four main implementation components exist: program management, collection method, payment, and recycling cost distribution (Atasu & Van Wassenhove, 2012). These components are discussed in further detail below.

Program Management

The foundational difference between the various alternatives is whether or not the program embodies a collective or individual management structure. In collective systems, products are collected and recycled jointly either by the state (monopolistic) or by individual 3rd party systems (competitive). Collective systems typically embody the following three qualities: a) all producers are required to join in, b) costs are shared on producer’s market shares rather than actual production returned volume, and c) recycling cost variations for different brands and product types are ignored (Atasu & Van Wassenhove, 2012). Collective systems allow for economies of scale to occur but they allow for free riders in the system and provide little incentive to improve operations effectiveness and efficiency (Atasu & Van Wassenhove, 2012). Of the many WEEE member states, all participants utilize a collective operation scheme as do the majority of established Asian programs. However, producers in the United Kingdom and Germany have developed their own collection systems while still participating in the collectively managed WEEE system (Atasu et al., 2009). Although producers within these two nations individually control collection, the systems still fall under a collectively managed system since the producers do not facilitate recycling. Producers in these two nations still participate in the collective WEEE program but only incur the portion of the shared costs associated with their own returned products. In the United States, collective systems dominate as well. The Extended Producer Responsibility Act of Maine is centrally run by the government who then invoices manufacturers for the cost of the collection and the cost of the transportation to recycling facilities performed by municipalities (Webster & Mitra, 2007). The same is true for the rest of the U.S. with take-back legislation except for Washington state, which gives its individual municipalities the option of choosing to implement collective or producer operated systems (Atasu & Van Wassenhove, 2012).

Manufacturers collect and recycle their own goods in producer operated systems. Within this type of operation, manufacturers must create or outsource an individual logistics system for the collection and recycling of their returned products (Atasu & Van Wassenhove, 2012). One drawback of this particular type of management is the loss of scale economies that are achieved in collective systems. The OEM has more control in this type of system, which results in the absorption of costs directly relating to capital expenditures on initial system infrastructure set-up (Karakayali, Emir-Farinas & Akcali, 2007). The most appealing aspect of the system is the achievement of fair cost allocation based on individual producer's actual returned product count (Atasu & Van Wassenhove, 2012).

Collection

The collection method serves as the second factor driving the EPR alternative structure. Individual collection systems are developed by producers and allow for easier product sorting. Shared collection systems require producers to use municipal collection points or retailers for the collection of waste. The type of collection system often coincides with the management structure. Centrally managed systems typically have a shared collection system except for in the case of the UK and Germany as discussed above.

The method of collection varies from program to program. While the Japanese utilize the postal service for PC collection and retailers for the SHAR program, the United States and Europe more often use collection centers, local consolidators, municipality run logistics systems or retailers (Atasu & Van Wassenhove, 2012).

Funding

The funding for a take-back system is provided either by the producer, as is true in an EPR program, or by the end user. Costs can be assigned to the end user in the form of an Advance Recycling Fee (ARF), which is charged to the consumer at the time of sale. The method charges the end-user with the cost of recycling and the fees are used to undertake the recycling operations system (Atasu et al., 2009). Either the producer or 3rd party conducts the recycling process and receives a subsidy from the government to cover the cost of each recycled good. A standard recycling target is set by the government and normally reflects a proportion of the products produced annually. The ARF structure has been implemented in the Japanese SHAR program discussed above (Akenji et al., 2011) as well as in Taiwan and California (Lee, Chang, Wang & Wen, 2000). California's Electronic Waste Recycling Fee requires retailers to collect from consumers a fee on certain electronic devices to "cover the net cost of a state authorized collector who collects, consolidates and transport electronic wastes" (Webster & Metra, 2007).

Cost Allocation

Lastly, allocation of recycling costs must be distributed amongst the various producers in the EPR system. Cost allocation is most fair and accurate in individual producer operated systems since the producer only absorbs the costs associated with their retuned products. In collective systems, cost allocation becomes more challenging, especially since costs must be shared among producers. WEEE member states have made producers "jointly responsible for the collection and recycling of all producers' products" regardless of the individual producers' actual return volumes (Atasu & Van Wassenhove, 2012). They typically disregard variations in recycling costs among brands and product categories but simply assign costs based on market share or a percentage of last year's sales numbers (Atasu & Van Wassenhove, 2012).

The U.S. typically uses return shares, which is the percentage of total goods returned by a specific company. Return share cost allocation charges each producer a final cost proportional to their actual collected volume of used product. However, the return share allocation system contains flaws as well, for a true count of returned goods is often impossible due to product diversity (Atasu & Van Wassenhove, 2012). Usually only a sampling of waste is used to identity individual producers' waste return.

In addition to costs, collection targets must be set and allocated to the various producers in order to encourage, monitor, and enforce participation. The majority of EPR programs implement weight-based metrics to monitor and control collection. WEEE member states do not set individual collection targets for individual producers or individual categories of waste (Atasu et al., 2009). Member states under the WEEE hold the responsibility of ensuring a minimum collection target of 4 kg of waste collected per capita per year. Because this goal must only be met on a national level, producers are often not held accountable on an individual basis.

The Implications of E-Waste Characteristics on EPR Alternatives

Take-back legislation for e-waste poses an extensive list of complications due to the unique characteristics of electronics.

Low Visibility Leads to Illegal Disposal

E-waste goods have low visibility for they enter the waste stream through multiple avenues. In his article, *Extending Producer Responsibility up and Down the Supply Chain, Challenges and Limitations*, Jan-Willem Scheijground explains how "smaller items of WEEE with a market value also find their way to different channels such as brokers, illegal export, or incorrect disposal". As Scheijground describes, the two characteristics driving the improper disposal of e-waste is its size and end-of-life value.

The small size of electronics drives incorrect disposal. Consumers can discard of electronic waste into the city's solid waste services which eventually leads to final disposal into a landfill. Small electronics have the ability to be improperly stored by consumers, such as in closets, drawers, etc.

The second component contributing to the low visibility of e-waste is the high end-of-life market value that drives disposal in illegal avenues. Small electronics such as computers or cell phones have an end-of-life value that can be extracted by individuals for a profit. This profit provides the incentive for illegal disposal such as exportation to a foreign country or sale to a broker. Products whose value cannot be easily extracted by individuals are more often returned to producer schemes (Scheijground, 2011).

Diversity Challenges OEM Identification

A "widespread challenge to the functioning of EPR systems is the difficulty of identifying the producer" which is a precondition for implementing a true EPR program (Akenji et al., 2011). With electronics, identification issues are more diverse and vary between countries. In Europe's WEEE program, the main factors affecting identification include: diversity and heterogeneity of products, variations among product types within one product group, variations among brands over time due to innovations, time gaps between market entrance and appearance in the waste flow, and the large number of producers in the sector (Rotter, Chancerel & Schill, 2011). These issues, common to the majority of developing countries, differ from those identification issues present in developing countries. The EPR programs of nations in Asia particularly struggle with identification issues derived more from the numerous independent producers and repair shops. Assembly of electronics by small shops is prevalent in developing nations and thus several non-branded products exist. Small shops have also led to the creation of a large second-hand market repair business in which brand names and logos displayed on the original parts are often replaced. The presence of imitation products complicates identification of goods as does bankruptcy in which the manufacturer no longer exists to bear responsibility (Kojima, Yoshida & Sasaki 2009).

Fair Cost Allocation

As discussed earlier, the inability to accurately assign every good to its rightful owner is a challenge present in many existing EPR programs. The issue has forced existing EPR systems to assign costs based on market shares or a simple sampling of the goods returned, regardless of the OEM's actual product return volumes (Atasu & Van Wassenhove, 2012). Producers must also share recover costs with any free-riders present in the system.

Collection Challenges

The process of securing the end-of-life product from the consumer presents a challenge for take-back system operators. The "effectiveness of incentive mechanisms used to facilitate the collection of used products is crucial to the success of a product recovery program" especially when dealing with small household electronics (Karakayali et al., 2007). Without incentive, the goods will more likely enter the waste stream through the various harmful or illegal entrances. The fines distributed to OEMs who fail to meet take-back quotas provide motivation for OEMs who in turn motivate the consumer to recycle.

Reverse Supply Chain Uncertainty

The recovery process of goods involves two markets, both a “disposer market” where goods are set free by consumers and a “reuse market” with demand for recovered goods (Fleischmann, Beullens, Bloemhof-Ruwaard & Van Wassenhove, 2001). Between these two markets is a network of processes known as the reverse supply chain (RSC), which involves five sequential steps: product acquisition, reverse logistics, inspection and disposition, reconditioning, and distribution and sales (Guide & Van Wassenhove, 2002). Refer to Figure 1 for a depiction of the forward and reverse supply chain. These recovery steps give rise to a “coordination issue concerning supply and demand” (Fleischmann et al., 2001). The “mismatch between supply and demand with respect to timing and quantity” can create complications for the recovery of end-of-life goods (Fleischmann et al., 2001). It is this uncertainty of the quantity and quality of goods entering the reverse supply chain that complicates the EPR system. The uncertainty impacts the determination of appropriate metrics and targets for collection.

The uncertainty also prevents the reverse network from having the ability to predict the type and amount of services that will be needed. Due to the many household electronics that enter the waste stream, a variety of recycling and end-of-life treatments exist based on product value and composition. Thus, the final destination of any given electronic is dependent on its quality and material composition. This variety of recycling processes combined with the uncertainty of disposal timing and levels, challenges management's ability to proactively prepare to meet reverse demand (Fleischmann et al., 2001). Ultimately, the lack of a demand signal leads to high costs for the involved stakeholders with little gain if returns exceed or fall behind forecasted demand (Koccabasoglu, Klassen & Prahinski, 2007).

HYPOTHESES

The research question addresses how these unique batteries will be dealt with upon reaching end-of-life. In this section, hypotheses are formulated on how the nature of the batteries will drive disposal, the creation of an EPR program, and supply chain activities for stakeholders. Refer to Figure 2 for an illustration of the hypotheses.

H1. Battery Characteristics Will Lead to Legal Disposal

There is a positive relationship between the lithium batteries' attributes and legal disposal for the following two reasons: battery size and low end-of-life value.

Battery Size

Since small size is a driver behind unaccounted for disposal and illegal exporting, the large size and weight of the lithium electric car batteries will reduce this type of illegal activity. Unlike cell phones or personal laptops, a consumer cannot dispose of a 500 lb. battery through their residential waste management system, nor can it be easily or inexpensively shipped to another country.

Low End-Of-Life Value

The low value of lithium extracted from end-of-life lithium electric batteries removes the incentive for consumers to dispose of the battery outside of the EPR system in order to achieve personal gain. The valuable heavy metals found in laptops, cell phones, and other household electronics are not present in lithium electric car batteries. Additionally, harvesting the leftover value from lithium batteries is an expensive process requiring patented technology and large capital investments. Therefore, it is impossible for the value to be extracted by any single consumer.

H2. The EPR Alternative Structure: Collective Management, Individual Collection, Manufacturer Funded, Return-Share Cost Allocation

The hazardous nature of the goods will lead to the creation of a collectively management EPR system with individual collection, funding by the manufacturer, and cost allocation based on return shares.

Collective Management

There is a positive relationship between the batteries' dangerous nature and a collectively managed EPR system. The reactivity of the batteries and their potential to explode allows for the argument to be made that a collective body should manage the EPR. Since the batteries can react and explode, a central party will need to oversee the collection process to help ensure public safety. One option would be for the government to serve as the overseer of the collection process to watch and ensure that proper care is taken by the party put in place to collect the goods.

Additionally, low value and homogeneous nature of the batteries supports the argument for a collectively managed system. In his article, *An Analysis of Decentralized Collection and Processing of End-of-Life Products*, Ibrahim Karakayali argues that the implementation of centralized systems should occur when the end-of life good is homogeneous, when the driver for the OEM is meeting collection targets, and when the salvage value of the entire good exceeds the salvage value of the particular component in question. End-of-life lithium batteries from electric vehicles meet the three criteria and should therefore undergo a EPR program performed collectively by an entity separate from the manufacturer. Unlike the variety of small household electronics, lithium electronic batteries are homogeneous goods that do not differ between the various manufacturer brands. Due to the low value of the metals extracted during the recycling process, the main motivation behind OEM take-back participation will be achieving the required targets set by the program manager. Lastly, the small value of the battery is less than the total salvage value of end-of-life cars (Karakayali et al., 2007).

Individual Collection by Producers

The collection of lithium electric batteries will most likely be conducted individually by each producer. The collection scheme will reflect the systems implemented in the UK and Germany. The size and reactivity prevents the use of municipal collection points, for consumers cannot separate the battery from the car themselves and safely transport it to the collection facility. Therefore, there argument is made that collection will occur at the dealerships of OEM's for ease to the consumer. Since consumer typically return cars to the source of purchase, this argument aligns with current disposal methods.

Manufacturer Funded

The take-back of lithium electric batteries will resemble a true EPR system and place the responsibility of environmentally friendly treatment of end-of-life products on the producer rather than the end consumer. This type of alternative is feasible due to the ability to identify manufacturers. The type of cost distribution system that will most likely be used is described below.

Return Share Cost Allocation

Manufacturers will pay for the costs only associated with their share of returned batteries. There will be no shared pool of costs and all costs will be based on actual returned batteries. This cost accuracy can be more easily achieved due to the fact that the identification issues that cause difficulty in assigning cost responsibility to small electronics manufacturers are eliminated by the lithium battery's unique visibility characteristic.

First, a much smaller pool of producers compete in the electric car industry. While this number is likely to increase, only 15 models are available in the U.S. currently and they are produced by 14 different manufacturers (*Plug-In America,* n.d.). The pool of potential responsible owners is significantly smaller than small electronic consumer goods.

Secondly, batteries are attached to an automobile, which has a VIN and license plate. Due to this visibility, it will be easier to track the end-of-life good and identify the OEM. The VIN allows for scanning and tracking capabilities which can aid in accuracy.

Third, the time gap between entrance into the market and entrance into the waste stream for lithium batteries will not play the same detrimental role as it does in the small consumer goods market. The innovations and changes made to car batteries will not significantly affect the overall appearance and recognition of the good as true with consumer electronics.

H3. Government Regulation Will Lead to Legal Disposal

The government's prohibition of certain avenues of disposal as well as their use of incentives will have a positive effect on legal return.

Due to the fact that the success of the EPR system is wholly dependent on the ability to secure the end-of-life product from the consumer, the government will determine the legal locations for disposal. As discussed in Hypothesis 2, collection will occur at the retailer's location. Thus, the argument is made that the government will use legislation to prohibit all other methods of disposal.

H4. The Government Will Select the EPR Alternative

Since the argument has been made that the EPR system will be implemented on a national level, it is also arguable that the U.S. government will serve as the selector of the supply chain alternative. The government will most likely select a collective EPR system based on realities derived from the nature of the battery.

Based on the batteries' dangerous reactive afterlife and the concern for the health and safety of the public, it is most likely that the government will choose a collective system in which products are collected and recycled jointly. The collection will occur either by the state (monopolistic) or by individual 3rd party systems (competitive).

H5. The Battery Characteristics Will Affect All Supply Chain Operations

The characteristics of a waste product such as its size and value play a role in how supply chain activities for the various stakeholders will be affected through the collection and recycling process. An explanation of how supply chain operations will be affected by lithium battery attributes follows. Refer to Table 3 for a description of supply chain operations.

SC Operation: Collection/Forecasting

Collection and forecasting are affected by the battery's unique size and visibility. The issues relating to poor collection rates are reduced by the ability to track each good and trace it back to its OEM. The ability to track and identify the OEM affects collection by making the process more accurate and by allowing for costs to be based on actual return shares.

The visibility of the lithium batteries will provide the "demand" for the reverse supply chain. The access to information such as the VIN and the ability to track the end-of-life batteries will allow the battery recovery network to achieve a level of accuracy that is impossible in the recovery networks of household electronics. Additionally, sales data about electric vehicles provides an estimate for the number of batteries that will enter the waste stream annually starting in 2020. This ability to pre-determine the supply of used batteries entering the waste stream will allow for an improved ease of collection coordination.

SC Operation: Transportation

The battery's size and reactive after-life affects the transportation and storage of the collected waste. Unlike small electronics that can be transported relatively easy based on weight and size, special precautions will be required to ensure the safe transportation of the batteries. The vehicle types that can be potentially utilized to transport the batteries will be limited due to the battery's weight of 500 lbs. and reactivity.

SC Operation: Transformation/Recycling

Immature technology and the low value of the extracted metal components affect recycling in a negative manner. The lack of technology prohibits a high recycling rate while the low value of the extracted metals provides little incentive to recycle.

SC Operation: Hazardous/Non-Hazardous Material Rights

The comparatively low value of the components extracted from recycling will impact the size of the market created for the sale and re-use of valuable components extracted from the battery.

H6. Disposal Affects Collection and Transportation

Collection and transportation operations will be directly affected by the location as well as the process used for disposal. The nature of disposal impacts the collection and transportation network required to collect the goods upon their disposal.

SC Operation: Collection

Since collection is the process of securing the end-of-life good from the consumer, disposal and collection are directly linked. Additionally, the positive relationship between the electric car lithium batteries and legal disposal leads to a high rate of collection that cannot be achieved in the small electronic waste market. Returning the batteries to the OEM will positively impact the collection rates of the end-of-life batteries. In the WEEE program, recycling rates for industrial applications collected from OEMs rather than consumers exceed 90% whereas consumer good collection rates are much lower (Wilts et al., 2011).

Disposal at the manufacturer's retail location aids the collection process by providing the demand signal need to help with forecasting the number of waste products entering the reverse supply chain. Each manufacturer will have exact data on the end-of-life products present at their facility which can be combined to create total demand.

SC Operation: Transportation

Transportation is affected by disposal, for the number of disposal avenues determines the size of the transportation network. The argument has been made that the only site of collection will be the various manufacturers' dealership. Thus, this consolidation of disposal avenues will help to lower transportation costs as well as create a more simplified collection plan, unlike the logistics system required to pick up small electronic goods from a variety of collection centers and households.

H7: The Centralized ERP Alternative Affects the Transportation and Recycling Supply Chain Operations

SC Operation: Recycling

By implementing a centralized EPR system for the lithium electric batteries, the recycling processes will therefore be conducted centrally rather than through a variety of individual producer run programs. At the beginning, recycling will occur centrally at the Toxco plant for all batteries regardless of their producer. It should be noted that while technological barriers to entry currently exist in the small electric car lithium battery recycling market, market growth will lead to increased demand for recycling which will encourage competitors to invest market entry.

SC Operation: Transportation

Individual producers will not have the burden of establishing a logistics system for the transport of their batteries from collection point to recycling facility. Transportation will be sought out by the party centrally managing the EPR system. A single third party provider or multiple providers will conduct the movement of goods.

H8: The Government Affects All Supply Chain Operations in an EPR System

Due to the centralized alternative put in place, the supply chain operations in an EPR system will be the decision of the government.

SC Operation: Collection

The government will provide legislation declaring the disposal of all lithium electric batteries at the dealership. Rather than setting collection targets based on a market share or other percentages, the government will require close to total take back.

SC Operation: Recycling

The U.S. government has already invested $9.5 million in the development of the Toxco plant, and therefore has a monopoly over the recycling process. Under the centralized EPR, all recycling will occur initially through Toxco as required by the government.

SC Operation: Transportation

Under the centralized EPR system, the government will select the transportation providers to move the batteries from manufacturer to Toxco. The decision may be made on a city, state, or national level.

SC Operation: Hazardous/Non Hazardous Rights Management

As the regulator of the recycling process, the government will create legislation regarding the management of hazardous and non-hazardous materials. The government will create legislation regarding the safe transportation and discarding of the hazardous materials in order to protect the environment and communities.

DISCUSSION SECTION

From the analysis conducted, a conclusion can be drawn regarding which stakeholder (government, OEM, 3rd party private organization, etc.) will be responsible for each supply chain operation. Refer to Table 3 for an illustration of the responsibilities. It is argued that the government will absorb the majority of the responsibility in the collective EPR system.

It has been concluded that the nature of the batteries drive all decision regarding the collection and recycling process. A collectively managed system will be established to protect the health and safety of citizens. The responsibility of collection will fall on the manufacturer as will funding of the EPR program. Transportation will be facilitated by the government and most likely conducted through 3rd party companies who possess the ability to safely transport the large and dangerous batteries. Until competitors enter the market, recycling will occur at Toxco and will be overseen by the national government due to their investment in the recycling facility and technology.

Additional Avenues of Research

The paper address how end-of-life lithium batteries from electric vehicles will be collected and recycled through hypothesizing how the nature of the batteries will affect disposal, EPR implementation, and the reverse supply chain. The complexity and immaturity of the recycling process creates additional avenues for research needed to better understand the future implications of the recovery system.

Other areas of research include a deeper look into non-hazardous material rights and how the market for these valuable goods will be managed. Whether or not producers will earn profits from the value extracted from their returned products will be a valuable area of research. A look at whether or not this reward will incentivize producers to return batteries would prove beneficial as well.

Numerous parties are conducting research to test the viability of a "second life" for the batteries. The batteries are predicted to have the capability of storing energy from renewable energy sources such as wind and solar power as well as the ability to serve as backup power supplies during emergencies. If the "second life" can be achieved, the effects of this life extension on supply chain operations and take-back systems will need to be researched.

With the number of both domestic and international car manufacturers in the industry, the aligning of take-back legislation between nations could cause potential complications.

There is a need for a more in-depth look at how the low value byproducts of lithium battery recycling will affect the motivation behind recycling. This information would prove beneficial to ensuring end-of-life batteries reach the necessary disposal avenue, but also that the hypothesized lithium shortage is avoided or at least minimized.

Lastly, a common motivation with EPR programs is "providing incentives to manufacturers to incorporate environmental considerations into the design of their products" (Subramanian, Gupta & Talbot, 2009). A look at whether or not this motivation will exist in the lithium electric battery industry would give insight into the future value of the batteries as well as the design of the take-back system.

IMPLICATIONS

Knowing the implications of a future take-back system will provide benefits for the stakeholders that will be affected. Because take-back legislation is still in its infancy, any information provided at this point in time will help introduce stakeholders to territory they have not yet navigated. By providing knowledge now, before the lithium battery industry enters its growth stage, industry leaders, the government, and companies have the ability to proactively prepare for the future changes in their supply chains that will result from a national take-back system.

The findings in this manuscript identify the stakeholders that will be affected by a take-back system. As a country without a national take-back system of any kind, information that identifies the various parties, functions, and activities affected by a national recycling initiative proves valuable. Identifying the stakeholders helps to create a map of the widespread influence of a take-back system and provides a solid understanding of who will be affected and in what capacity.

Secondly, the manuscript highlights the areas of the system in which capital investments and expenditures will need to be directed. For example, the argument is made that transportation and recycling will not only generate high costs, but that they will also need to be performed centrally through a common carrier or party. Having a general idea of the cost structure of the take-back program will help with general planning and cost forecasting. Knowing which parts of the system will cost the most money can help the responsible party create a savings plan that will allow for the needed funds to be saved in advance.

Third, the findings provide information regarding the unique characteristics and attributes of lithium electric car batteries, which will serve as the most impactful information when designing and implementing a take-back system. It will be especially important to be aware of the reactive after-life of the lithium batteries, the value of the metal components within the battery, the limitations of its recycling process, and the visibility of its reverse supply chain. In addition, these characteristics help to differentiate the lithium electric car batteries from traditional e-waste. The identification of the similarities and differences between the two types of waste will pinpoint the aspects of current e-waste legislation that can and cannot be mirrored when creating a take-back system for electric lithium battery waste.

The information provided will aid the initial planning process for a take-back system. The relationships among the various supply chain functions and stakeholders are outlined and explained in order to serve as a foundation with which to build upon. Having basic information regarding who will need to facilitate each portion and who will have responsibility over the supply chain tasks will allow for more ease in the tailoring of aspects based upon specific needs. In addition, having an idea of what processes have been implemented in other countries gives the U.S. a starting point with which to begin creating the take-back system.

CONCLUSION

This paper highlights the health and safety concerns behind the increasing presence of e-waste take-back legislation and how the momentum behind the legislation will likely lead to the creation of take-back legislation for lithium electric car battery waste in due time. The unique attributes of the lithium battery waste produced serves as the main driver behind the structure of the take-back system that will be put in place.

The comparison of traditional household e-waste to the lithium battery waste provides insight on how the take-back program for lithium batteries will differ from the legislation for traditional e-waste. Many of the problems related to collecting end-of-life e-waste are eliminated through the attributes of lithium battery waste, such as its size and unique visibility. However, the lithium batteries will require special attention to address issues such as their dangerous after-life. Additionally, the infancy of the lithium battery industry creates the most complicated issues, for the U.S. does not currently have the capability to recycle the batteries on a large scale.

In addition, a look at the various take-back systems currently implemented across Europe and Asia on national levels, and in the U.S. on a state level, allows for a better understanding of the different alternatives to consider when implementing take-back legislation. The main differentiating factor among the EPR alternatives is program management. Programs can be managed collectively or individually. Collective management involves the collection and recycling of products jointly by the state or a 3rd party. Oppositely, individual producer run programs are operated by each producer, thus giving each producer more power and responsibility. EPR systems also vary based on who conducts the physical collection of the goods as well as who funds the initiative. Funding can either occur at the time of purchase by the consumer in the form of an Advanced Recycling Fee, or through producers. Lastly, the costs generated through an EPR system must be allocated to the various producers whose goods enter the waste stream. Costs can be allocated evenly among producers through return share numbers or estimated based on market share information or past sales data.

The manuscript proposes eight hypotheses on how the nature of the batteries and the U.S. government will affect disposal, the creation of an EPR system, and supply chain operations for the various stakeholders. The characteristics of lithium batteries will lead to legal disposal. The large size and visibility of the batteries will prevent illegal disposal or disposal in unaccounted for channels. The structure of the EPR alternative will resemble a collectively managed system with centralized collection and transportation. Funding will come from the producer rather than the consumer, and cost allocation will be based on a producer's share of returned goods rather than an estimate of their returned goods.

The hope is that the contribution of this manuscript can proactively make stakeholders aware of the type of EPR structure needed to successfully collect lithium electric batteries before the need arises.

APPENDIX

TABLE 1: Unique Attributes of Lithium Electric Car Batteries

Attributes of Lithium Electric Car Batteries		
Characteristic	**Details**	**What does this effect?**
Size	Bigger than traditional car batteries (~500 lbs.)	Challenge to transport, can't easily throw away
Volume	500,000 per year by 2020	"Demand" for reverse SC
Visibility	Attached to car (VIN, license plate, collateral value)	Easier to track and identify OEM
Low Value	Lithium electric car batteries do not contain as much of the rare and valuable metals as other e-waste (ex: lead)	Reduces motivation to dispose of illegally
Dangerous	Reactive at end of life cycle	Special transportation/storage considerations
Limited Recycling Technology	Recycling technology not yet developed on large scale	Cost, volume, and quality of recycle capability if limited and unknown

TABLE 2: U.S. States with Take-Back Legislation as of 2012

STATE
California*
Connecticut
Hawaii
Illinois
Indiana
Maine
Maryland
Michigan
Minnesota
Missouri
New Jersey
New York
North Carolina
Oklahoma
Oregon
Pennsylvania
South Carolina
Texas
Utah**
Vermont
Virginia
Washington
West Virginia
Wisconsin

*Advance Recycling Fee

**Manufacturing Education Law

(“State Legislation”, n.d.)

FIGURE 1: Supply Chain Operations:

Forward Supply Chain:

Plan → Source →Produce →Deliver→ Consumption

Reverse Supply Chain:

Consumption→ Collection/forecasting→ Transportation→

Storage→ Transformation/Recycling→Hazardous/Non-Hazardous Materials Handling

FIGURE 2: Hypotheses

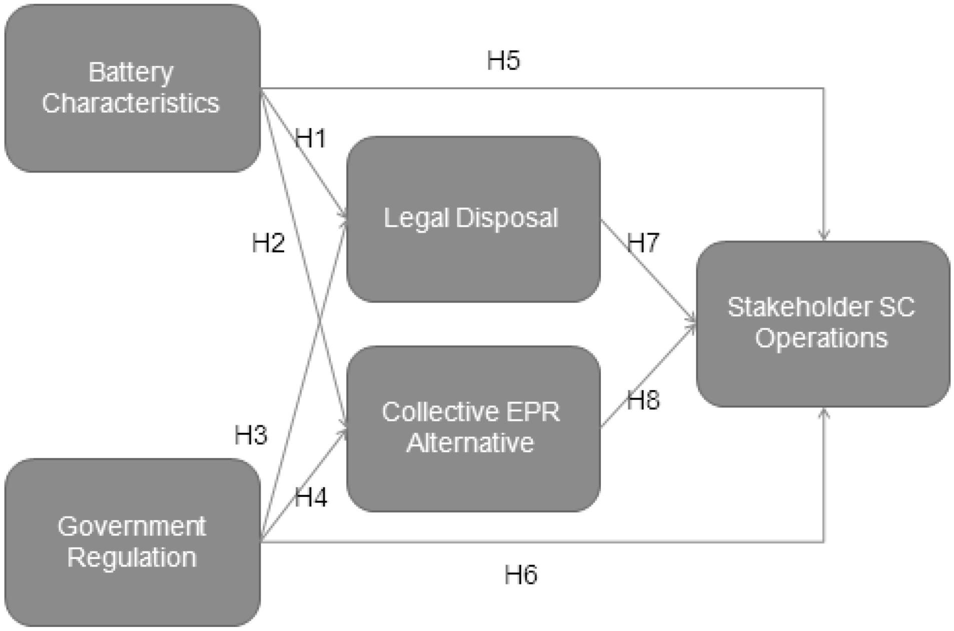

TABLE 3: Supply Chain Operations Analysis

Component	Supply Chain Ops Affected	SC Responsibilities for Alternative Take-back Programs
Battery Characteristics	1-5 (H5)	OEM, Govt., Consumer, 3rd Party
Consumer Disposal	1-2 (H7)	OEM, Govt., Consumer
EPR Alternative	1-2 (H8)	OEM, Govt., 3rd party
Government Regulation	1-5 (H6)	Government

Supply Chain Operations
1. Collection/forecasting
2. Transportation/storage
3. Transformation - recycling
4. Hazard Rights – removal service management
5. Non-hazardous Material Rights – re-sale and/or removal service management

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ABSTRACT

With the increasing concern for human and environmental health issues derived from electronic waste (e-waste) disposal, stakeholders have begun implementing recycling take-back programs. These take-back initiatives aim to reduce the number of electronics reaching landfills. One particular type of e-waste, lithium batteries from electric vehicles, still lies in its infancy. With numerous predictions estimating an annual disposal rate of 500,000 batteries per year by the early 2020s, there is a true need to begin proactively preparing for the handling of these waste products. The manuscript provides research on the unique attributes of these batteries and seeks to find an answer as to how the recycling of these batteries should be addressed. The research provides support for several hypotheses regarding the way in which these batteries and their attributes will affect disposal and the creation of a take-back system. The end goal is to provide stakeholders information on how supply chain operations will be affected by the implementation of a take-back initiative.