Today the United States is heavily reliant on the lithium-ion battery as most portable devices and electronics run on it. Current innovations are also looking on how to maximize it on the grid and transportation. This paper will look at three sovereign states and their current initiatives on Li-ion battery recycling: US, European Union, and China. The term initiative is used loosely as the information is not permanent in most policies or plans. Li-ion battery recycling initiatives are crucial to look at because used and wasted Li-ion batteries can disrupt public health and Li-ion batteries are expected to be a factor for effective material supply for future battery production especially in transportation, like the Tesla Roadster.

Introduction

The digital revolution is the shift from analog technology to digital technology. The Internet and the continuous use of electronics can characterize it. Most personal electronics are portable and run on lithium ion batteries. Portable electronic devices, like the laptop, have given people easy access to connect to each other anytime, anywhere. The Internet has given birth to a new form of communication through social media and a new way for data collection and record keeping. With the age of sustainability and the marketability of greener products from media like Youtube, consumers are shifting to buy products like hybrid cars and organic food. Due to this, the consumer demand for lithium ion batteries has increased dramatically.

In 2012, about 27% of the global lithium consumption came from rechargeable batteries while it was only 15% in 2007 and only 8% in 2002. The world lithium consumption from 2000 to 2008 had a steady 10% rate increase. According to signumBOX, the demand for energy storage and transportation will have at least a projected 20% annual growth rate until 2025. Table I shows the breakdown.

| Application/Tonnes Lithium Carbonate Equivalent (LCE) | 2011 | 2025 | CAGR 2011-2025 |
|--------------------------------------------------------|------|------|----------------|
| Batteries for Portable Devices                         | 30,416 | 111176 | 9.7%          |
| Batteries for Grid                                     | 500 | 7500 | 21.3%        |
| Batteries for EV and Hybrid                            | 6967 | 204901 | 27.3%        |
| Other                                                   | 91400 | 174994 | 4.7%          |
| Total Li Demand                                        | 129,283 | 498571 | 10.1%        |

Some estimates suggest that by 2020, electric vehicles with lithium batteries are more likely to account for most electric vehicles. Consequently, questions about lithium consumption and availability of these batteries have slipped into energy conversations in recent years. This paper will present and summarize some current international initiatives surrounding battery recycling, and if possible lithium ion batteries in the US, Europe, and China. It is important to look at these initiatives as it concerns the growing number of wasted and unused batteries, which in the future will most likely be lithium ion batteries. While the US, Europe, and China may not agree on how to recycle, the initiatives give an idea of how the wasted batteries will be utilized to avoid a potential health hazard. Having these initiatives allows the world to become accountable for a sustainable path. Europe, USA, and China are simply a few players in this path.

Lithium Ion Battery Background

The lithium ion battery is found in many electronic devices. It is favored due to their high energy density, long run time, handle of discharge/charge cycles, and stable power. Lithium is a highly reactive element because it is an alkali metal. It enables technologies that can store large amounts of electrochemical energy. This battery is heat sensitive and extreme heat can induce degradation. On very rare occasions, the battery can burst into flames due to overheating and short-circuiting. Voltage estimation for the Li-ion battery can be established by a sound battery model, which addresses chemical, electrical, and physical properties of the battery and can be used to predict battery performances in different environments. However, the data is experimental and is not necessarily the most precise tool.

With all these consequences, lithium-ion batteries that are tossed in a landfill can be a health concern. The highest level measured in lithium batteries comes from cobalt at 278000 mg/L with the regulatory threshold for hazardous waste at 8000 mg/L. The research group concluded that the lithium-ion battery is associated with portable electronic products as potential sources of hazardous metal pollutants in the environment particularly...
in regions lacking infrastructure in solid waste collection, sorting, and recycling.\(^4\)

Most lithium ion battery packs have the same components. They can consist of a metal cylindrical shell, voltage converter and regulator circuit, voltage tap, and a battery charge state monitor.\(^5\) The metal case holds the anode and cathode. The question of recyclability starts from here and demonstrates some obstacles found from varying manufacturers as how they make it is usually kept under wraps.

### Lithium Ion Recycling Challenges

Not all recycling processes are created equally. Recycling is useful to alleviate material scarcity, reproduce cheaper materials with old components, reduce energy and emissions, and to create a more sustainable process. With Li-ion batteries, the chemical compositions of the active materials vary and are unstandardized. The common cathode used in consumer electronics is LiCoO\(_2\), but it is also costly. Other combinations are available and used differently by manufacturers depending on the lower raw material cost.\(^6\)

Due to this, the best solution may be to allow the processes for recycling tailored to the specific battery type. Along with different solutions for recycling, there are some growing concerns over the availability of lithium. Some demonstrated that the lithium demand can be met and battery material shortages are unlikely assuming that recycling will mitigate the potential scarcity.\(^7\)

Most of the world’s lithium production is found in Bolivia, Chile, Argentina, and China.\(^1\) These countries can potentially play a huge role in the market and cycle, especially China since it makes its own Li-ion battery as well.

As far as trading peak oil for peak lithium, the lithium production market is still a fairly new market, so predictions of when peak lithium is reached are premature. Although, the world will reach a peak at some point, even though some may not agree. Recycling lithium and only requiring a fraction of annual use to be mined can avoid it. Even as the lithium reserves and resources increase with the market demand.

Recycling can help each nation to have its own supply without having to rely on other nations.\(^5\) Of course, each nation has its own plans to deal with wasted batteries, which is why taking a look at their initiatives is important for the long-term goal.

### A. Europe Initiatives

In 2006, the European Union set up the Battery Directive, which is meant to regulate and recycle batteries overall. It was created for the European Member States to set up national laws on batteries under Art. 26 due to the approximate 800 tons of automotive batteries, 190 tons of industrial batteries, and 160 tons of consumer batteries of all types entering the European Union each year.\(^8\) With this, the EU legislation acknowledged the battery waste and holds itself accountable. The Battery Directive is intended for the EU to contribute to the protection, preservation and improvement of the quality of the environment by minimizing the negative impact of waste batteries. Among them, waste lithium ion batteries were taken as part of this responsibility.\(^8\)

According to the European Portable Battery Association (EPBA), the collected batteries are recycled to reuse and recover contained metals rather than to dispose them. However, batteries must be separated by their metal origins before the process can continue. For most lithium ion rechargeable batteries, they are processed to recover elements like cobalt, iron, and other metals.\(^9\)

Due to this document, Europe is leading the sustainable battery development and recovery industry over the US. The directive is part of the EU Sustainable Development Strategy to build a future without jeopardizing the ability of future generations to meet their own need.\(^10\)

The initiative is also utilized for energy storage with positive consequences across different fields. With energy efficient equipment that is a direct result of lithium ion recycling, portable appliances are more cost effective. This can be implemented in industries like the food industry. Machinery used for frozen foods packaging, farming/agriculture, and food processing for the supply chain of any major part of the food industry can have lower energy costs and emissions.

Ideally, the batteries of a given type will be standardized once the next best generation battery chemistry is established.\(^7\)

### B. China Initiatives

In September 2015, China released regulations on Recycling of Motive Lithium Ion Batteries.\(^11\) It is the first explicit regulation to Li-ion batteries on how wasted batteries can be utilized. With this, Chinas lithium market can become the equivalent to Saudi Arabias oil market with its own control of the lithium production and manufacturing of the Li-battery. This is especially important to pay attention because most likely transportation will rely heavily on Li-ion batteries. Ziejian Li predicts the unique growth that China has over the industry especially in the electric vehicle business and eco-innovation in his study.\(^12\) By creating a system of production, consumption, and recycling, China can control the lithium ion battery market cycle in transportation.

### C. USA Initiatives

Currently, the U.S. Environmental Protection Agency (EPA) does not regulate the disposal of batteries in small quantities. However, large quantities are regulated under
the Universal rules of Hazardous Waste regulations (40 CFR PART 273). Lithium-ion batteries do not fall under it, and are not collected by manufacturers for recycling currently as well. As such, large quantities of lithium batteries are sent to the incinerator at a hazardous waste facility.\textsuperscript{13}

The US is attempting to put forth some type of regulation. The EPA is conducting a partnership with a screening-level life-cycle assessment (LCA) of currently manufactured lithium-ion (Li-ion) battery technologies for electric vehicles, and a next generation battery component (anode) that uses single-walled carbon nanotube (SWCNT) technology.\textsuperscript{14} Furthermore, other researchers are conducting research on recycling lithium batteries.

### Future Technology

As of 2015, some thoughts have been placed on the rechargeable nonaqueous lithium-air battery (Li-O\textsubscript{2}). A group found that a reduced graphene oxide electrode, the additive LiI, and the solvent dimethoxyethane could reversibly form and remove crystalline particle (larger than 15 micrometers) during the discharge and charge cycle. The chemical nature has an impact on battery performance with an energy efficiency rate of 93.2\% and 0.2 voltage gap. The technology has some promising results as the next generation energy storage, but the efficiency rate hasn't reached above 99.9\% for a reliable long cycle life.\textsuperscript{15} As the shift from lithium-ion batteries happens, the initiatives in place for lithium can also apply to new technologies in energy storage that also rely on lithium. Lithium scarcity is possible and these initiatives lay the foundation for future policies should the need for it arises out of concern for health or limited lithium.

### Final Thoughts

Currently, there are a lot of buzzwords and promises in the media and Internet. There has not been an explicit regulation (besides China) imposed yet for Li-ion batteries simply because of the newness of the battery and market itself. The demand for the lithium ion battery will continue to grow.

With research ongoing, electric vehicles will rely heavily on Li-ion batteries unless another option is found. So, it is interesting to see what sort of regulation and policies will be implemented in the near future. There needs to be some sort of standard for these specific wasted batteries as this can impact cost, raw materials, emissions, energy storage, the grid of the future (smart grid), consumers, and maybe future industries. There may be materials and other development under wraps, but there is more information needed to expand on such an idea. The incentive is to have an innovative and adaptable battery for energy storage and to lower the overall cost of transportation, not create another scarcity issue. Recycling can be the answer to it.\textsuperscript{16}

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