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BATTERY TECHNOLOGY: THE FUTURE FOR SUSTAINABLE INDUSTRIAL AND ECONOMIC GROWTH

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ABSTRACT
Depleting oil reserves and environmental concerns on emission have heightened the search for alternative energy sources and efficient electrochemical energy systems through renewable energy sources. Technological advancements in the field of automation, robotics, communication, nanotechnology, electrification and hybridization of vehicles as well as the push for renewable energy sources have broadened the scope of opportunities for Electrochemical Energy Storage Systems (ESS). These new technologies place a growing demand on compact, safe and higher capacity batteries to enable functionality. Battery technologies for different needs and application have become an indispensable aspect of sustainable development in the quest for renewable energy and global sustainable carbon emission reduction. This paper briefly looks at the integrated nature of batteries to human day to day activities, the current state and impact of battery technology, future of energy storage systems and an analysis of battery storage systems for sustainable industrialization.

Keywords: Energy storage systems, sustainable Industrialization, Renewable energy, Future batteries.

INTRODUCTION
Battery powered electric vehicles possess the potential to becoming the most disruptive technologies of the 21st century which can alter the economy of two of the worlds' largest industries: automobile and petroleum (Sprague, 2015). Although vehicle electrification does not provide the ideal solution to societal concerns on depleting fossil reserves and emissions, it does provide a road map towards addressing the aforementioned concerns. However, the challenges hindering the success and acceptance of the electric vehicle are tied to but not limited to the following;

- *Cost and energy density*: compared to the internal combustion engine, electric vehicles are very expensive to procure while the energy density that can be stored onboard is still very limited (Brennan & Barder, 2016). To increase this density based on current battery technology will result in increased cost, charging time and size/weight.
- *Travel range*: the maximum range that can be gotten from a full charged electric vehicle is limited even after driving under optimal conditions. This discourages drivers.
- *Infrastructure and charging* time: Unlike petrol station which are readily available and require but a short time to refill the tank, electric vehicle charging stations are largely unavailable and will require about an hour to fully charge in a fast charge outlet.
- *High risk potential*: current onboard battery chemistry have the potential of exploding if they over heat due to either excessive demand or ineffective management strategy.

Although this paper is not focused on electric vehicle, it is worthy of note that the challenges outlined are but a magnification of bottle necks faced by the battery industry leading to wide areas of research for battery technologies that are safer in operation, store larger energy in shorter charge time and be made of materials that are abundant to reduce cost.

This paper will explore the battery technology as an integral part of day to day activities, a leading force in technological advancement, and state of battery technology, its current impact, the future of batteries as an Energy Storage System and an analysis of battery technology for sustainable industry.

Battery Fundamentals and History
Comfort, convenience and technological advancement are the trends in the 21st century that have been made possible by improvements in battery technology. Battery technology represents the force behind the paradigm shift of possibilities driving today's society. Batteries as energy storage devices are widely and easily used for activities that could cause one to casually dismiss the importance of their effect. They have enabled numerous industries where there is a significant dependence on electric storage mechanism such as the cell phone industry, portable electronics and computing, robotics and the automobile industry to mention a few (Sprague, 2015). Without the storage of energy, devices will still be tethered to a continuous power supply in order to function.

The battery is the heart of any electrical system. It is plugged into the systems circuit and releases a flow of electron through the circuit thus converting chemically stored energy to electrical energy. The conversion is made possible due to the reaction taking place between the electrode (anode and cathode) material and electrolyte/electrolytic solution in Figure 1 (Pratik et al., 2015). This chemical process forms the principle of battery technology and shows that even with a vast array/types of batteries, they basically store electricity in the same way. Batteries are made of cells consisting of pair electrodes; negative terminal-anode and positive terminal-cathode, electrolyte and casing (Sprague, 2015).

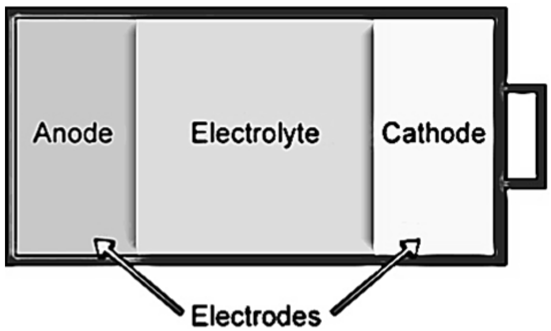

Figure 1: Battery Cell Parts (May et al., 2018)

American scientist and Inventor Benjamin Franklin first used the term "Battery" in 1749 while conducting experiments on electricity with linked capacitors. However, Italian physicist Count Alessandro Volta is credited to have been the first to discover the electrochemical reaction process of battery operation in 1799. He created a simplified battery from metal plates (copper and zinc discs as seen in Table 2) separated by clothes soaked in salty water (brine) to serve as electrolyte. This resulted in a voltaic pile that sustained electricity. This was a refinement of the discovery. This idea of electrochemical energy storage in 1789 by Scientist Luigi Galvani when he noticed that the legs of a frog began to twitch when it came in contact with two different types of materials. Ever since, Scientists have improved upon Volta's design to create batteries from different materials and in various sizes (Marshall et al., n.d.; Pratik et al., 2015). The standard construction of a battery consists of two metals with different electrochemical potentials that are separated by a porous insulator commonly referred today as microporousity. The electrochemical potential of a metal is the tendency of the metal to loose electrons. The potential is the energy stored in the atoms and bonds of the compounds, which is then imparted to the moving electrons, when these are allowed to move through the connected external device.

Primary vs. Rechargeable Batteries

Primary Batteries**:** These are non-rechargeable batteries because the electrochemical reaction that brings about flow of electrons cannot be reversed. The battery is flat and disposed when one of the reactants is consumed. Today primary batteries are commonly zinc-carbon separated by an alkali electrolyte because it causes the battery to last longer. The challenge of being non-reusable especially as the need for larger capacity batteries necessitated the invention of rechargeable batteries (Alarco & Tabolt, 2015; Jose & Peter, 2015).

Rechargeable batteries**:** Successfully developed in 1859, the Lead-Acid battery ushered rechargeable batteries and it is still commonly used today. It has a nominal cell voltage of 2.1V and a charge/discharge efficiency of 50 to 95%. Although it has a very low energy to weight ratio, its ability to supply a high surge of current over a short period and low cost makes it most desirable for automobile applications as it eliminated the hand crank method of starting a car (May et al., 2018). However, the 30 – 40 Wh/kg specific energy of Lead-Acid batteries is very low hence limits its application. This cannot be overlooked in the face of rapid advancement in technology. Some of the most common rechargeable batteries are described in the following section.

Nickel cadmium (NiCd) battery**:** This battery is made up of nickel and cadmium based electrodes of which an ionic conductor serves as its electrolyte. While reacting, it undergoes dissolution/precipitation mechanism while charging/discharging on the cadmium electrode. The electrolyte of this battery also participates in the reaction thereby varying its amount based on the state of charge. This situation leads to the "*memory effect*" of NiCd batteries. A phenomenon which takes place when the battery is partially charged or discharged over several cycles because unused cadmium grains gradually become coarse when surface area remains inactive (Noréus, 2000). NiCd batteries need intermittent maintenance (full discharge and charge cycles) in order to optimize their useful life (Michael, 2000).

Table 1: Characteristics of Commonly used Rechargeable Batteries (Battery University, 2017)

	Lead Acid	NiCd	NiMH	Li-ion
Gravimetric energy density (Wh/kg)	30-50	45-80	60-120	110-160
Life cycle (to 80% of initial capacity)	200 to 300	1500	200 to 300	500 to 1000
Fast charge time (hrs.)	8-16	1	2-4	2-4
Overcharge tolerance	High	Moderate	Low	Very Low
Self-discharge per month at room temperature (%)	5	20	30	10
Cell voltage (V)	2	1.25	1.25	3.6
Battery cost ($)	25	50	60	100

Nickel-metal hydride (NiMH) battery**:** This battery was developed in 1989 because of its higher specific energy, recyclability and safety (Jose & Peter, 2015). This battery systems have been used for the propulsion of the successful Toyota Prius Hybrid Electric vehicle (HEV), powering small electronic gadgets like laptops and wireless communicators, but are now commonly used for satellite applications (Michael, 2000). Although it has a very short life cycle to NiCd, they do

not suffer any memory effect and need not to be full discharged before recharging to enhance their useful life.

Lithium ion (Li-ion) battery: development started as far back as 1912 by G. N. Lewis because lithium is the lightest of all metals and has a very high electrochemical potential of 3.0401V (

Table 2). This makes lithium highly reactive to air and water in its pure form. In 1980, American physicist Professor John Goodenough invented the lithium battery in which the lithium (Li) could migrate through the battery from one electrode to the other as a Li-ion having discovered that lithium becomes stable when combined with a metal-oxide (Alarco & Tabolt, 2015). Sony Cooperation commercialized the Li-ion battery in 1991. Today, virtually all technological inventions, portable electric

gadgets and electric vehicles are powered by a Li-ion battery. This battery is however very expensive to develop due to its high risk of explosion due to *thermal runaway* when overcharged/discharged. Here, the battery heats up thereby disintegrating the electrolyte which causes short circuiting of the anode and cathode leading to explosion and fires sometimes witnessed in Laptops, mobile phones and electric vehicles. The lithium ion battery represents the first leap forward of battery technology.

Table 2: Electrochemical Series (Vanysek, 2000)

Name	Chemical symbol	Electrochemical potential (V)
Lithium	Li	3.04
Magnesium	Mg	2.37
Aluminum	Al	1.66
Zinc	Zn	0.76
Iron	Fe	0.44
Hydrogen	H	0
Mercury	Hg	-0.24
Copper	Cu	-0.34
Silver	Ag	-1.69
Fluorine	F	-2.8

The Future of Battery Technology

The Automobile Industry is and has always been the leading force in innovation as regarding battery research and design. In the quest to meet increasingly stringent legislations by government on emissions, billions of dollars are continually invested by cooperation's towards research and manufacturing that will tackle the challenge of range, safety, energy density to weight, charge time and cost which are currently associated with the Li-ion battery system (Walford, 2019). As such the future beyond Li-ion can broadly be categorized into the following;

1. **Lithium ion (Li-ion) vs. Solid state batteries (SSB)**: Solid State Lithium ion batteries are the most promising next generation battery technologies. The main difference between Li-ion and Solid state batteries is in the electrolyte. Li-ion batteries use liquid electrolyte solution which are flammable, while solid state batteries use a solid electrode made of glass, ceramic or lithium phosphate that are non-flammable (Schnell et al., 2018). In 2017, a company called Fisker patented and revealed an SSB having no liquid electrolyte and an energy density of over 400 Wh/kg. This battery has inorganic solid electrolytes that are non-flammable in increasing temperatures which make its application safe. More so, high-voltage high-capacity materials can be used to enabling denser, lighter batteries with improved safety performance and better shelf-life as a result of reduced self-discharge.
2. **Lithium-Sulphur (Li-S) Batteries**: Still in the research stage, the Li-S battery uses a very light active material; sulphur as the cathode and metallic lithium as anode. Unlike Li-ion batteries where the active materials are layered between the lithium ions in stable host structures during charge and discharge. In the Li-S batteries, there are no host structures. While discharging, the lithium anode is consumed and sulfur transformed into a variety of chemical

   compounds; during charging, the reverse process takes place. This is why its theoretical energy density is extraordinarily high: four times greater than that of Li-ion. It however needs further research and development work to improve its life expectancy and to continue to increase specific energy density (Schnell et al., 2018).
3. **Printed Batteries:** These are flexible and flat batteries, also known as flexible batteries. They can be thinner than a millimeter, weigh less than a gram and stretchable. They can supply power at the microwatt level, and are well suited for small devices, such as smart cards, sensors, medical devices and wearables, such as wristbands. Their innovative format opens up opportunities for a new generation of electronics, including electronic labels, packaging and posters and could help drive the 'internet of things', the network of devices and everyday objects which are connected up to the internet and powered by small batteries (Policy, 2018).

CONCLUSION

Battery technology holds the key to meeting the concerns in the society. There are numerous technological advancement being developed that have the potential to growing issues, but will remain in the Laboratory if battery technology does not advance along them. The field of possibilities will remain limited due to the limitation of energy storage systems. Issues relating to emission and renewable energy will be a thing of the past with highly efficient battery storage systems.

Multibillion dollar investments are channeled towards battery related research, design and manufacturing to bridge the gap currently facing technological growth. This shows the indispensable nature of battery technology to the growth and sustainability of any industry.

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