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REPLACING LITHIUM-ION BATTERIES WITH GRAPHENE BATTERIES

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ABSTRACT

This paper first deals with how the lithium-ion batteries work and then goes on to explain their shortcomings and disadvantages while also discussing the factors making lithium-ion batteries unsuitable for the future. Then it states the properties and advantages of one of the most viable replacement options for lithium-ion batteries – GRAPHENE; discussing the advantages of graphene batteries over lithium-ion batteries and then states why graphene batteries are still not used today. It then talks about 3-D printing that is potentially the most suitable way to mass produce graphene thus making commercial production of graphene batteries economical and effective so that they can then be used in various industries and fields of science possibly leading to various revolutions.

Keywords: Lithium-ion batteries, discharge, efficiency, endurance, graphene batteries, 3-D printing

Introduction

Today is the age of batteries. The most widely used type of battery is the lithium-ion battery used in several industries ranging from mobile phones to space. Lithium-ion is the best kind of battery available for use today vastly more efficient than any previous kind of battery like a lead- acid or a nickel-based battery. This has led to its dominance in almost every concerned industry. But lithium-ion batteries are not ideal and are not sustainable as well as suitable for our future needs. But we first need to understand the lithium-ion battery and then discuss its disadvantages and the perfect replacement for it – the Graphene Battery.

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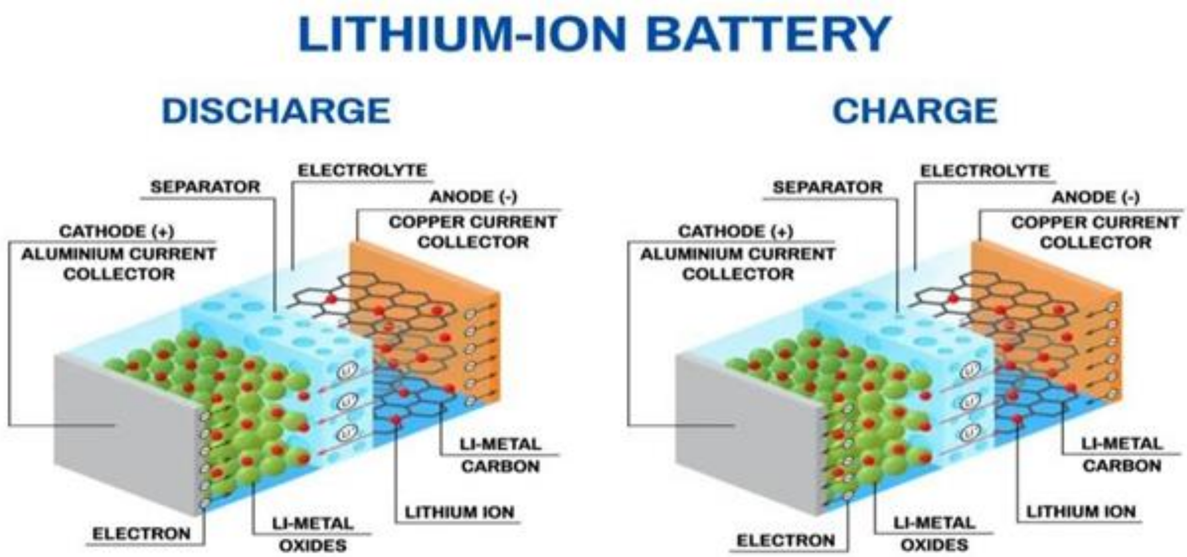

States of a battery

1.1. The Cell

A lithium-ion battery is a relatively simple battery with a simple structure. The cell, serving as the energy-storage unit of the battery, is one of the most critical and sensitive components of the battery.

The cell is comprised of the following battery materials:

- The two battery ends are known as the electrodes. The positively charged one is the anode whilethe negatively charged one is the cathode.
- The anode houses the lithium and is typically made from carbon.
- The cathode, that also stores the lithium, is typically made from a metal oxide.
- The separator is there to block the flow of electrons inside the battery but
- The electrolytic liquid sits between the two electrodes. It carries the positively charged lithium ions from the anode to the cathode and vice versa, powering the device or recharging the battery, de- pending on whether the battery is discharging or charging.

1.2. The Battery Pack

The battery pack, which holds the lithium-ion cells, operates much like the brain of the battery. It contains the following:

- Temperature sensors to monitor the battery’s temperature.

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- Voltage converters and regulator circuits that focus on keeping the voltage and current at safe levels.
- A Euro connector, overseeing the movement of power and data in and out of the cell.
- Voltage stabiliser to oversee and maintain voltages of the cells present in the battery pack.
- A battery monitoring system, acting like the manager of the battery that oversees the whole batteryand ensures the safety of the user as well as the battery.

1.3. Movement in the Cell

The movement of energy is a lithium-ion cell is extremely simple. When you plug the battery into any device, the positively-charged ions flow from the anode to the cathode making the cathode more positively charged than the anode. Thus, the cathode attracts the charged electrons to itself.

The separator present in the battery pack has electrolytes present in it that form a catalyst. The movement of the ions through the electrolyte solution is what causes the electrons to move through the device thereby powering it and discharging the battery.

Lithium-ion batteries are rechargeable. While recharging, the lithium ions go through the same process, but in the opposite direction, restoring the battery again for any use.

1.4. Battery Management System (BMS)

The battery management system plays an integral role in making sure the battery cell works at its highest levels of safety and efficiency at all times by regulating how the battery functions andalso offering several protections and features as safeguards.

- It monitors currents and voltage to keep both at safe levels. Dendrites begin to form in the cell if voltages drop too low which can short the cell, so it is important that a lithium-ion battery pack has a system to monitor this
- There is no “memory” built into the pack, so partial discharges do not hurt the battery on a noticeable level.
- Controllers are built in to prevent overcharging and avoid harm to the battery.
- It also balances the charges inside a cell thus preventing the need of equalization charges.
- The BMS also allows the tracking of the battery health through onboard computers that send vitaldata to through cloud-based service.

Pioneer work with the lithium battery began in 1912 under G.N. Lewis but it was not until the early 1970s when the first non-rechargeable lithium batteries became commercially available. lith- ium was the lightest of all metals, had the greatest electrochemical potential and provided the

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largest energy density for weigh.

Attempts to develop rechargeable lithium batteries failed due to safety problems. Because of the inherent instability of lithium metal, especially during charging, research shifted to a non-metallic lithium battery using lithium ions. Although slightly lower in energy density than lithium metal, lithium-ion is safe, provided certain precautions are met when charging and discharging. In 1991, the Sony Corporation commercialized the first lithium-ion battery triggering a massive revolution in major industries that required mobile battery packs.

Despite its several advantages, lithium-ion has its drawbacks. It is fragile and requires a protection circuit to maintain safe operation. Built into each pack, the protection circuit also limits the peak voltage of each cell during charge and prevents the cell voltage from dropping too low on discharge. The performance is also often limited to keep the battery at healthy temperature levels so as to keep it functioning properly.

Aging is becoming one of the most serious concerns with lithium-ion batteries and many manufacturers still do not address this possibly failure-inducing issue in an adequate manner. Capacity deterioration is noticeable after one year, whether the battery is in use or not, putting the device at a huge disadvantage. The battery frequently fails after 2-3 years even if it is taken good care of. It should be noted that other chemicals, both external and internal, also have age related degenerative effects leading battery degeneration over a period of time.

The most economical and commercially-used lithium-ion battery in terms of cost-to-energy ratio is the cylindrical 18650 (size is 18mm x 65.2mm). This cell is used in mobile computing and other applications that do not demand ultra-thin geometry. These cells come at a higher cost in terms of stored energy. The above factors along with the conditions required for the lasting of a lithium-ion battery do not make it a viable option for the future where it will be required to work under heavy loads and critical conditions. Lithium-ion batteries have also been involved in some dangerous and famous incidents over the many years they have been in use.

1.5. The famous Samsung Note 7 mobile phone incident

In September, weeks after the Note 7 launched, Samsung issued an initial recall of 2.5 million devices after several phones experienced overheating issues. By the time the US Consumer Product Safety Commission issued a formal nationwide recall two weeks later, nearly 100 dangerous battery incidents had been reported in the United States. Samsung had purportedly pinpointed the cause of the problem: It had used two sources for the Note 7 batteries, and the ones made by Samsung's own component division seemed to be faulty. Even after replacing several of the new phones those new "safer" replacement phones started overheating and catching fire. It even happened on an airplane when a replacement device was unplugged and

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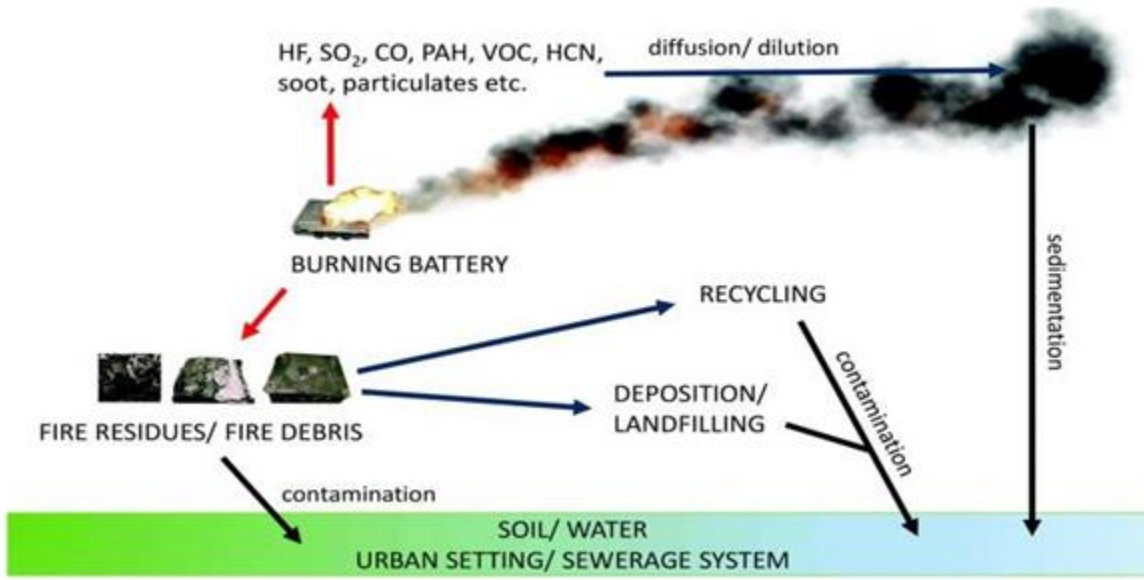
powered off which could have been a terrible accident.

The main reasons why lithium is not the perfect material for batteries are:

- It is fragile in nature and requires a protection circuit to maintain safe operation. Built into each pack, the protection circuit limits the peak voltage of each cell during charge and prevents the cell voltage from dropping too low on discharge keeping the battery at optimum levels.

- Lithium-ion batteries contain potentially toxic nickel, copper and lead compounds as parts of their battery chemistries.



Pollution due to Lithium-ion batteries

- Lithium-ion batteries are extremely sensitive to high temperatures and inherently flammable. These battery packs tend to degrade much faster than they normally would, due to heat. If a lithium-ion battery pack fails, it can burst into flames and can cause widespread damage.
- When disposed of improperly, used batteries can lead to an environmental disaster and if stored uncontrolled, they even become explosive which poses a fatal risk to anyone present in the vicinity.
- The supply of lithium-ion batteries is also often interrupted by several economic and political factors leading to shortage and thus adding to the need to look for a substitute that is more reliable.

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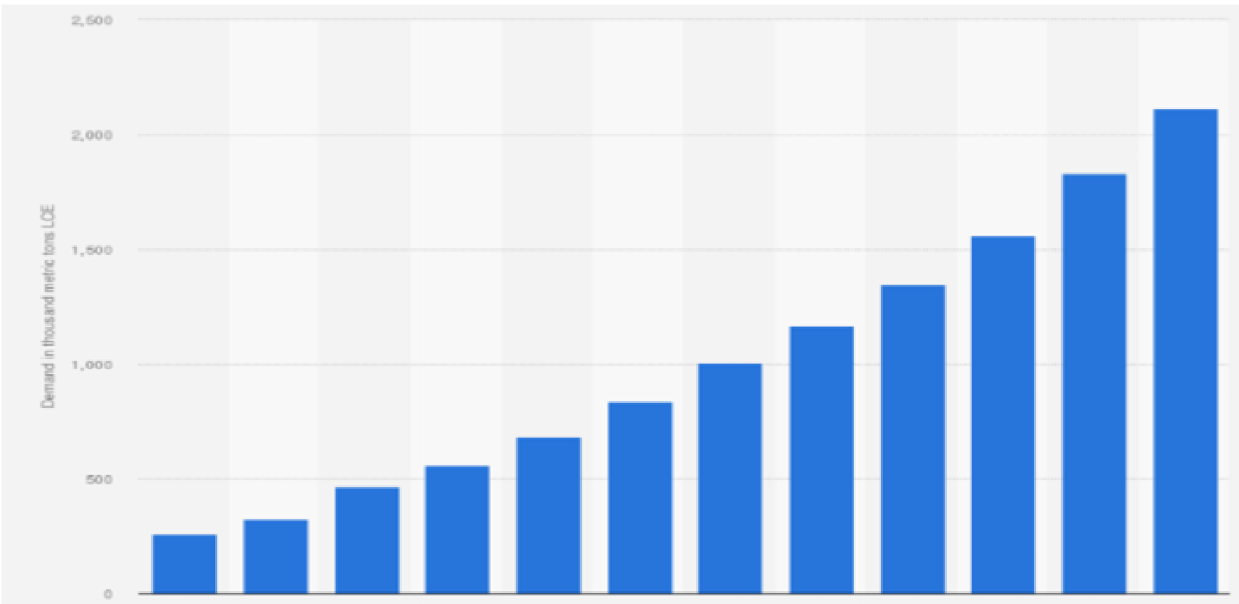
- The severe lack of lithium, as a mineral, in the world means that we cannot depend on it for the future because of the limited reserves and the manifold increasing demand that will eventually lead to a shortage of lithium hence, lithium-ion batteries are not the ultimate solution for human requirements in multiple fields.
- The lithium-ion batteries are not environment-friendly and cause pollution because they contain potentially toxic materials.



Increasing consumption of lithium

The above chart represents the increasing demand for the lithium which will ultimately grow so much that the supply will not be able to keep up with the demand, hence causing global shortage of lithium-ion batteries and problems in several industries like the smartphone and many others since they all depend heavily on lithium-ion batteries for production of their respective products. The above factors together make the lithium-ion a very unreliable and, more than often, an uncertain type of battery.

Materials and Methods

2.1 Material: Graphene

2.1.1. Introduction of Graphene

Graphene is an allotrope of carbon consisting of a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice nanostructure. The name is derived from "graphite" due to

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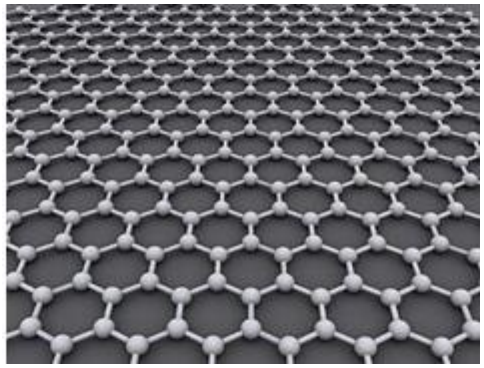
structural and some characteristic similarities and the suffixene, that is used in organic chemistry to show the presence of double bonds in the structure.



Lattice structure of grapheme

Each carbon atom in a graphene sheet is connected to its three nearest neighboring carbon atoms by strong sigma bonds and shows sp2 hybridisation. This is the same type of bonding seen in carbon nanotubes and polycyclic aromatic hydrocarbons, and (partially) in fuller- enes and glassy carbon. Charge carriers in graphene show linear, rather than quadratic, dependence of energy on momentum, and field-effect transistors with graphene can be made that show bipolar conduction. Graphene, conducts heat and electricity very efficiently along its plane, holding great potential to be used as a multi-purpose material in several industries. The material strongly absorbs light of all visible wavelengths, reflecting very little of it, accounting for the shiny and black colour of graphite; yet amazingly a single graphene sheet is nearly transparent because of its extreme thinness. The material is about 100 times as strong as would be the strongest steel of the same thickness so it can be used easily and effectively in aerodynamic vehicles and other places where structural strength is an important factor.

2.1.2. Brief History of Graphene

- Scientists had theorized the potential existence and production of graphene for decades. It has likely been unknowingly produced in small quantities for centuries, through the use of pencils and other similar applications of graphite. It was possibly observed in electron microscopes in 1962, but studied only while supported on metal surfaces.
- In 2004, the scientists Andre Geim and Konstantin Novoselov rediscovered, isolated and studied graphene at the University of Manchester in UK. In 2010, they were awarded the Nobel Prize in Physics for their "ground-breaking experiments regarding the two-dimensional material graphene". High-quality graphene proved to be surprisingly easy to isolate in tiny quantities but with no suitable way to produce it at a commercial level.

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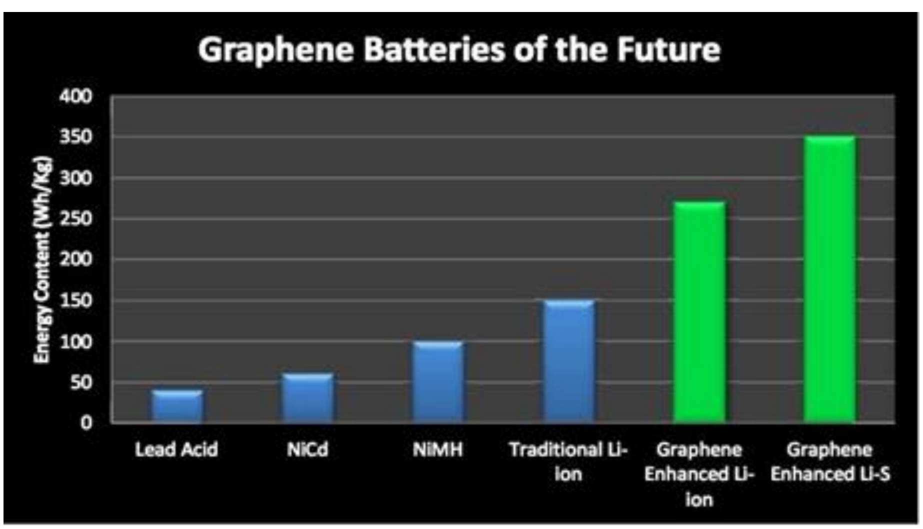
- Graphene has become a valuable and useful nanomaterial due to its exceptionally high tensile strength, electrical conductivity, transparency, and being the thinnest two-dimensional material in the world. The global market for graphene was $9 million in 2012, with most of the demand from research and development in semiconductor, electronics, electric batteries, and composites.
- It has been regarded as one of the most revolutionary substances to be ever discovered by man due to its incredible thermal, electric and tensile properties to name just a few.

2.1.3. Graphene vs Lithium-ion batteries

- Graphene is a much better conductor of electricity than lithium, in batteries, while being of a semiconductor nature thus making it a far more suitable option to be used in batteries. This will make the batteries far more efficient and reliable because they will be able to transfer charge quickly and with more speed thereby resulting in better performance.
- Graphene is exponentially more capable of storing more energy than a lithium-ion battery of the same size. Graphene batteries have been proven to have a much higher capacity on average than lithium-ion batteries, even at a small size. Lithium-ion batteries can store up to 200-300 Wh per kilogram while graphene can store up to 2,000 Wh per kilogram making it a much more space- efficient and economical store of energy. It means that graphene has much higher energy density than lithium, therefore being much more cost-efficient and enduring at the same time, making it far more suitable for energy-intense operations than lithium-ion batteries can ever be.



Energy capacity comparison between different batteries

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- Graphene is a better conductor of heat than lithium therefore keeping the internals comparatively cooler than the inside of a lithium-ion battery. This brings about a considerable change in the life of the battery and makes the graphene battery effectively as well as ecologically better than a lithium-ion battery.
- Compared to the best li-ion battery we use today; graphene battery has five times more energy density. In addition, after 400 charge/discharge cycles, no loss of capacity observed. Lithium-ion batteries may cause problems including explosion. Opposed to this fact, graphene batteries are more reliable in terms of safety. What is more, as graphene is an allotrope of carbon which can be found in nature, using it over lithium is eco-friendly and low-cost.

Comparison of Al-Graphene Battery with Tesla 85 kWh Lithium-Ion Battery			
Property	**Lithium-Ion Battery**	**Al-Graphene Battery**	**Benefit**
Power	85 kWh	**100 kWh**	**15% more power**
Energy Density	265 Wh/kg	**2,000 Wh/kg**	**7.5x stored energy**
Range	426 km	**3,500 km**	**8x range**
Recharge time	4.5 hours	**15 minutes**	**not much longer than refueling with petrol**
Weight	544 Kg	**387 kg**	**30% lighter**
Dimensions (cm)	10.16 x 284.48 x 177.8 for 16 modules	**7 x 200 x 100 for 8 modules**	**54% smaller**
Estimated cost	A$22,200	**A$11,450**	**50% less**
Durability	8 years (est.)	**15 years (est.)**	**Lasts almost 100% longer**
Accumulated battery loss	5% initially, then 1% per 3,000 km	**1% initially, then 1% per 3,000 km**	**Retains peak efficiency longer**
Estimated Manufacturing cost	~A$200/kWh	**A$20/kWh**	**Reduced Manufacturing Cost**

Cross-data analysis between graphene and other batteries

- Graphene batteries are also far more enduring than the lithium-ion batteries, which are prone to exploding and overheating problems, thereby increasing the applications in which there are extreme conditions or very heavy energy demand.
- From an economical viewpoint, graphene batteries will also get cheaper over time since graphene is a form of carbon, one of the most abundant elements on the planet and even the universe, while lithium is not present in required quantities and the lithium-ion batteries continue to depletion of lithium at an unprecedented rate paired with the

increasing demand

- Due to the high capacity, low endurance and large serial-parallel numbers, lithium-ion batteries can cause problems concerning safety, durability, uniformity and cost. Moreover, it can be over- charged or over-discharged affecting the performance by the time. And transportation is another issue, since li-ion batteries represent shipping hazards. But graphene batteries would be relativelyeasy and manufacture to transport.
- All of the above reasons prove that graphene batteries are much more viable than lithium-ion batteries and if, utilised to their full extent, would bring about a revolution in major industries and fields of science.

2.1.4. Why Graphene batteries are not in global use today?

The main reasons why graphene batteries are not mass produced and in global today are:

- Extremely pure graphene is required for batteries and currently there are no easy and cost-efficient ways to mass produce graphene and create batteries since pure graphene is notoriously hard to manufacture.
- Graphene when produced without proper molecular arrangement loses some of its properties but such highly precise processes that are also cost-efficient to perform are yet to be implemented on a commercial level.
- All the ways that currently exist to manufacture graphene batteries are not very cost-effective and time consuming therefore graphene cannot be mass produced currently and used in batteries since that would not be in way economically and commercially suitable to human beings.

2.2. 3-D Printing to mass produce graphene use it in batteries

Commercial and high precision 3-D printing: 3-D printing has proven to be a coming-of-the-age, extremely precise and potentially very advanced and life changing field. But it still remains largely non-commercial and very expensive because the printers are very expensive and take a lot of time to manufacture even small things therefore being inadequate to be used for this purpose at the current time. But when 3-D printers are commercialised and made fast and cheap enough it would prove to be a really suitable option to be used for making graphene batteries at an affordable price and within short amounts of time. That would then go on to revolutionise several major industries including all kinds of portable electronic devices including mobile phones and electric vehicles. This would also prove to be good for the space industry since graphene batteries could be used as viable sources of power instead of using dangerous radioactive substances therefore making space travel safer and easier. It would also help fulfil the ever-increasing demand for batteries since they are required in almost everything mechanical or

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electrical that is in a portable form factor mainly including mobile phones and many other similar devices. Therefore 3-D printing needs to be developed and commercialised as soon as possible in order to fulfil the energy storage needs of humans in the future.

Results

The paper was written to provide a brief summarisation about the basic nature of lithium-ion batteries and state their various shortcomings and disadvantages. It then discussed the basic properties of graphene – a material made of carbon atoms structured together, that has amazing properties and would be a viable replacement for lithium as the basic material used in battery building because of the innumerable advantages it has when used over lithium-ion batteries. It also stated the potentially most suitable way to manufacture graphene – 3-D printing and talked about benefits of development and commercialization of 3-D printing to mass produce affordable graphene batteries in a time-efficient manner to make energy-storing much more viable than it and increase the capabilities of batteries that will have a very big impact on the human lives by improving several sectors of technology.

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