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Applications of Nanomaterials to Improve Hydrogen Fuel Fell Efficiency

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Humanity faces an imminent energy crisis in the near future. With the abundance of non-renewable energy sources like coal, fossil fuels and oil rapidly decreasing, the world needs a new source of energy to support society. These current sources of fuel are unsustainable and are responsible for the vast quantities of greenhouse gases that are produced annually (Guo, 2012). Amidst this approaching catastrophe, hydrogen has emerged and presented itself as a viable alternative to the fossil fuels that are quickly running out (Pereira & Coelho, 2015).

Hydrogen can be harnessed and used as a fuel in a hydrogen fuel cell to be oxidized by oxygen, producing energy and water as a by-product (Guo, 2012). While fuel cells may be the ideal pursuit for the automotive industry, they are hampered by several limitations, the largest of which is hydrogen storage (Li, *et al.*, 2012). A more efficient means of storing hydrogen must be found if fuel cells are to be usable in the future. Amidst the urgency of solving this problem, nanomaterials have emerged as the most effective means of absorbing and storing hydrogen.

There are several promising methods through which hydrogen efficiency can be improved; the first is through the use of metal hydrides (Pereira & Coelho, 2015). Metal hydrides are appealing as a potential means of absorbing and retaining hydrogen because they can bond with hydrogen and store it densely (Guo, 2012). Among the metal hydrides, magnesium hydride shows the most potential, being able to absorb up to 7.6% of its weight in hydrogen (Lim, *et al.*, 2010). While this is a promising amount, magnesium hydride has a very slow rate of hydrogenation as well as dehydrogenation, which is not suitable for the requirements of a vehicle where fuel may be greatly needed in a very short period of time (Pereira & Coelho, 2015). Improving such slow hydrogen exchange requires extremely high temperatures, oftentimes upwards of approximately 340 degrees Celsius, which comes at a high risk of harm to the operators of these vehicles (Niemann, *et al.*, 2008). Thus, magnesium hydride must be improved to make it more effective at storing hydrogen fuel.

Fortunately, several means exist to improve the hydrogen yield of the magnesium hydride. The first method is milling, or grinding the magnesium hydride into nanocrystalline phases, which has resulted in a lower activation energy of hydrogen desorption (Niemann, *et al.*, 2008). Another possible solution is to mechanically mix the hydride with elements like vanadium, niobium and titanium (Pereira & Coelho, 2015). This technique has shown that more efficient gas exchange

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can occur at temperatures approximately 40°C to 50°C lower than normal (Pereira & Coelho, 2015). Thus, through the use of nanoscale interactions, the efficiency of magnesium hydride can be greatly improved.

Carbon nanotubes may serve as another potential candidate for storing hydrogen within fuel cells. Carbon is well known for its ability to absorb gases, and any macropores that may be present have no significant effect on its ability to do so (Lim, *et al.*, 2010). However, even at high temperatures and pressures, carbon is not well suited for hydrogen absorption because the molecular interactions are still too weak (Lim, *et al.*, 2010). Where carbon may be more useful is in the form of single walled carbon nanotubes (SWCNTs) as experiments have revealed that gases can be further condensed when confined within the narrow walls of a SWCNT (Dillon, *et al.*, 1997). A vehicle that will operate on hydrogen must be able to store it efficiently and what is promising about SWCNTs is that they will condense hydrogen efficiently in scenarios that do not promote its absorption (Dillon, *et al.*1997). The significance of this is that it means that a lot of hydrogen can be stored within the cell without reacting or chemically binding to the components of the cell, greatly improving efficiency. SWCNTs and are so efficient at retaining hydrogen that they are capable of absorbing up to 10% of their own weight in hydrogen, which is a significant improvement over the metal hydrides (Niemann, *et al.,* 2008). Therefore, the key to improving fuel cells may be in the carbon nanotubes.

Another key prospect in improving hydrogen storage are fullerenes. Fullerenes are spherical arrangements of atoms bonded to one another, forming a closed-cage arrangement (Niemann, *et al.*, 2008). One particularly suitable candidate is the B_{80} fullerene constructed with magnesium (Li, *et al.*, 2012). The fullerene has a shape similar to that of a soccer ball with pentagonal and hexagonal atomic arrangements. The magnesium has an optimal position at the centre of the pentagonal faces (Li, *et al.*, 2012). In an experiment with this magnesium located at the centre of the pentagonal faces, the combination proved extremely efficient at absorbing and retaining hydrogen gas, the cause of which may lie in the van der Waals forces (Li, *et al.*, 2012) between the nanotubes and hydrogen. A charge imbalance between B_{80} and magnesium results in the polarization of both of these elements which acts to attract hydrogen that has been introduced (Li, *et al.*, 2012). The negative nature of the boron atoms attract the positively charged hydrogen atoms which results in improved retention of hydrogen within the cell (Li, *et al.*, 2012).

The B_{80} and magnesium fullerene has great potential but one that may offer a simpler solution is one composed completely of carbon, C_{60} (Niemann, *et al.*, 2008). Due to the remarkable absorption abilities of carbon, it should be extremely efficient at storing hydrogen in fuel cells (Lim, *et al.*, 2010). Hydrogen is believed to be able to bind to the C_{60} fullerene on both the inside and the outside of the structure, which can result in a $C_{60}H_{60}$ complex (Niemann, *et al.*, 2008). This structure can bind approximately 7.7% of its own weight in hydrogen (Niemann, *et al.*, 2008). While this is very impressive, the reverse reaction, the release of hydrogen as fuel, is more problematic (Niemann, *et al.*, 2008). The reverse reaction requires temperatures

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upwards of 873 K, which is far too high for a commercial vehicle as it places the operators in harm's way (Niemann, *et al.*, 2008). Fullerenes offer a promising future for improving fuel cell efficiency but they are still beset with several drawbacks that must be overcome.

In conclusion, nanomaterials have immense potential for improving the hydrogen- absorbing efficiency of fuel cells. Despite considerable limitations today, the obstacles that fuel cells face can be overcome through the use of nano-scale materials such as metal hydrides, carbon nanotubes and fullerenes (Lim, *et al.*, 2010). Fuel cells are the next step in energy generation for society as they offer clean energy without any harmful waste products. While far from perfect, fuel cells are on the right track to being improved due to advances in the understanding of nano-scale materials such as SWCNTs, fullerenes and metal hydrides. Nanomaterials offer a means of storing hydrogen more efficiently but also more safely and at lower costs, both of which are crucial if fuel cell technology is become more prominent in the future (National Nanotechnology Initiative, 2015). The world is in need of a new source of reliable energy and nano-materials are the most promising means of improving the fuel cells that will offer society the energy it needs.

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