Content Unit

Nano in Energy

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The topic

First introduction

The demand for energy is growing, but so are some of the related issues that it causes, such as climate change. When we say energy, we mean everything from the electricity that we use in our homes, to the way we power our cars, planes and trains. Nanotechnology has the potential to change the way in which we capture, store and use energy and gives us the possibility of making energy cleaner, more efficient and cheaper.

This is a growing field of interest both as a market opportunity, but also to meet the challenges that our reliance on polluting energy sources has caused, namely the impacts of climate change and pollution. As we move society away from its dependency on burning fossil fuels to produce energy, we look towards nanotechnology as one means to solve some of the technical challenges. New nanomaterials can help us better capture energy, such as making more efficient solar cells; store energy, such as making better batteries for electric vehicles; and use energy, such as making better insulation materials for buildings that reduce their energy consumption.

It is important to understand that we there is no one single change that can be made in the energy value chain of capturing, storing and using energy that will by itself, resolve climate change. We need to look at making adjustments and technical improvements across the whole of the energy cycle, so we can produce clean energy that we can store safely and use it efficiently.

Practical relevance – This is what you will need the knowledge and skills for

In this section you will learn about how nanotechnology can be used throughout the energy system, from energy capture, storage and use. Some examples will be shown of applications already in use, as well as some future opportunities that are still being developed.

Overview of learning objectives and competences

In *Nanotechnology in the energy value chain,* you will learn how nanotechnology can be applied across the whole of the energy value chain.

In *Some nanomaterials and nano structures used in the energy value chain*, you will learn about some of the nanomaterials and nanostructures that are proposed for use within the energy sector.

In *Nanotechnology for energy in the automotive sector*, we will go into more around one specific are of energy usage, that of the automotive sector.

Learning objectives	Fine objectives
LO_Nanotechnology in the energy value chain_01	FO_BB01_01 what is the energy value chain? FO_BB01_02 nanotechnologies that can be used across the energy value chain

	FO_BB_01_0 some examples of nanotechnologies used in energy
LO Some nanomaterials and nano structures used in the energy value chain_02	FO_BB02_01 examples of nanomaterials used in energy FO_BB02_02 graphene and how it is used in energy FO_BB_02_03 carbon nanotubes and how they are used in energy FO_BB_02_03 silver nanoparticles and how they are used in energy
LO_Nanotechnology for energy in the automotive sector_03	FO_BB03_01 nanotechnology in car batteries FO_BB03_02 why making cars lighter helps with energy FO_BB_03_03 using nanotechnology to reduce friction and save energy

- # Nanotechnology in the energy sector

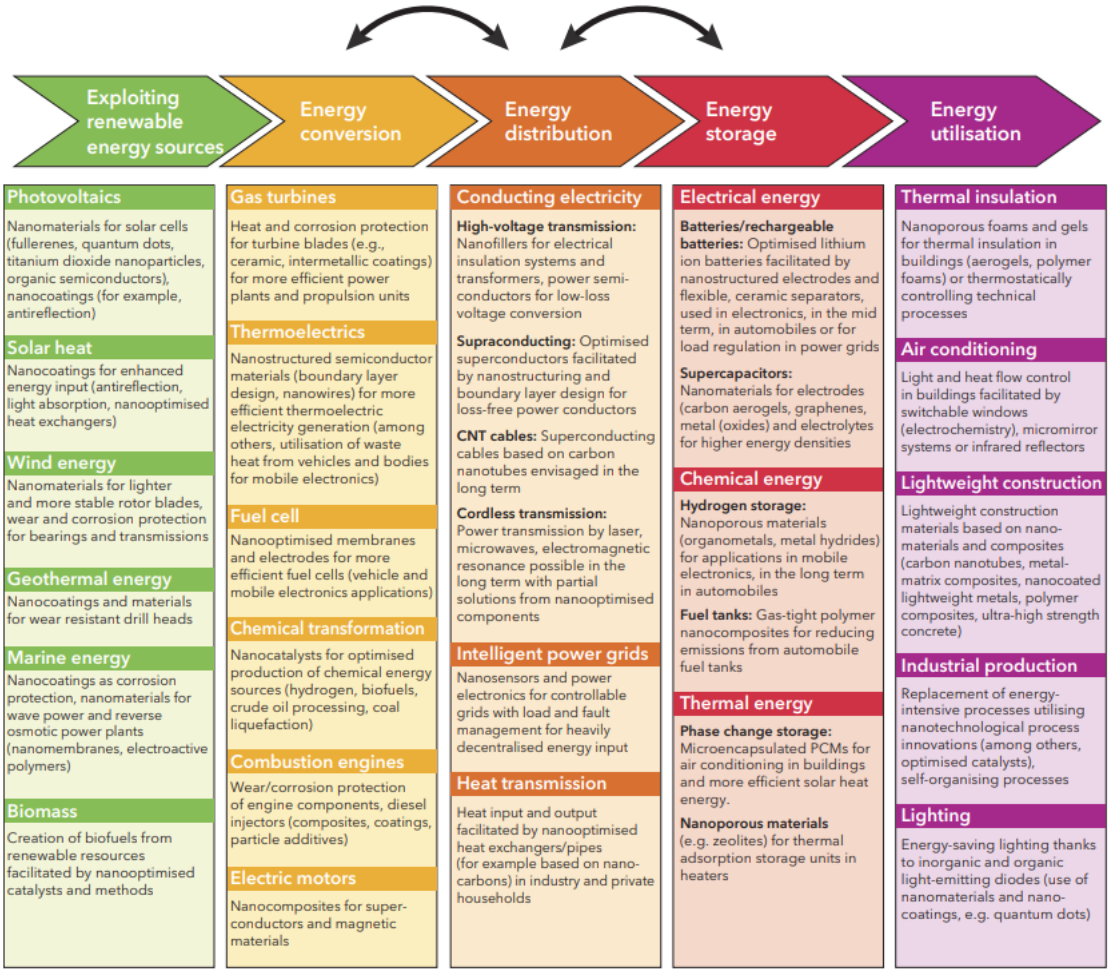
The demand for energy is growing throughout the world as populations and industrial activities grow. We all need to use energy to drive our cars, warm our houses, power our electronics and to produce the food we eat and the goods we buy. The traditional energy sources that we have relied upon of coal, gas and oil still provide the majority of the global energy production. However, there are two main reasons why these sources of energy are not sustainable in the future. Firstly, these fossil fuels are a finite resource and will eventually run out. Secondly, burning fossil fuels leads to climate change and there is a need to reduce the amount of carbon that we release into the atmosphere.

Nanotechnology is already playing a role in all areas of the energy supply chain and there are also hopes that it will help us better harness cleaner energy, store energy more efficiently and to use the energy

we generate more effectively. Nanotechnology is a broad field and so there is not one solution for energy, but rather a range of possibilities of what can be used across the whole of the energy value chain. The energy value chain stretches from:

- Energy capture- or being able to exploit different energy sources;
- Energy conversion- converting energy from one form to another, e.g. from wind (kinetic energy to electricity);
- Energy distribution- moving energy from one place to another such as a country's electricity supply grid;
- Energy storage- being able to keep energy for when it is needed, like a battery;
- Energy utilisation- so how nanotechnology can help us use the energy more efficiently, for example by better insulating our homes or reducing the weight of cars so that they use less fuel.

There are many different nanotechnologies that can be applied across the whole energy value chain as illustrated below.



Source: Ministry of Economics, Energy, Transport and Regional Development – State of Hessen, *Application of Nanotechnologies in the Energy Sector* (2015)[1]

Example

Solar Cells

Solar cells are currently made from semiconductor materials and manage to achieve around 10-15% efficiency, meaning that they do not convert as much as the sun's energy to electricity as is desired. Nanoscale silicon particles have been used to reduce the amount of sunlight that the solar cell will reflect, and the new design allows the light to be guided better and absorbed on the solar cell and

not reflected away and thus improving the efficiency of the panel. Even the most used material for producing solar panels is the crystalline silicon at present, new promising alternatives are emerging like perovskite for example. Nanostructured perovskite solar cells are remarkably more efficient compared to the existing silicon ones, but still some technological issues have to be solved.

Example

Wind Turbines

Wind turbines are used to harness wind and convert it into electricity as a good renewable source of energy. The turbine blades need to be both strong and lightweight so that they can withstand the huge forces that they are exposed to, whilst still being light enough to turn efficiently. The edges of turbine blades can be protected by making them from a graphene composite. This improves the durability of the edges and prevents them from being damaged and thus reducing their aerodynamic efficiency. This helps reduce the chances of damage occurring and thus saves on the cost of maintenance or having to replace the full blade.

Some Nanotechnologies Used in the Energy Sector

Different nanotechnologies can be used in the energy sector, with different nanomaterials or nanostructures giving variations in functions and providing a wide variety of possible uses.

Definition

Nanomaterial

A nanomaterial can be defined as a material in which one or more of its dimensions is between 1 or 100 nanometres. We are mainly concerned here with engineered nanomaterials, which are materials in the nanoscale that have been purposefully manufactured to have that size with the intention of it having certain properties.

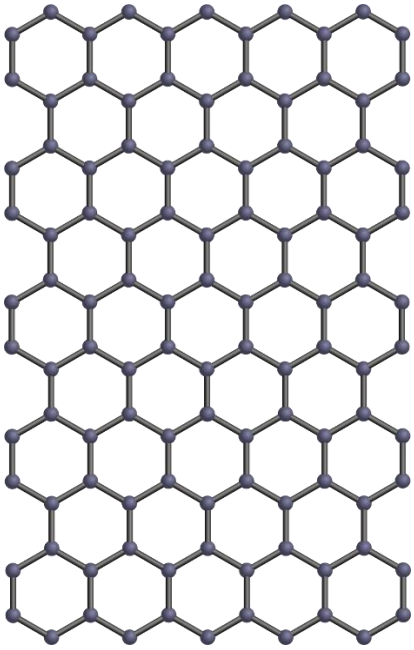
Nanostructure

A nanostructure is a structure with at least one dimension in the range of 1 to 100 nanometres. Examples can include a 1 dimensional nanostructure (such as a nanotextured surface), a 2 dimensional nanostructure where it has two dimensions at the nanoscale (such as a carbon nanotube) or a 3 dimensional structure, with all 3 dimensions at the nanoscale (such as a nanoparticle).

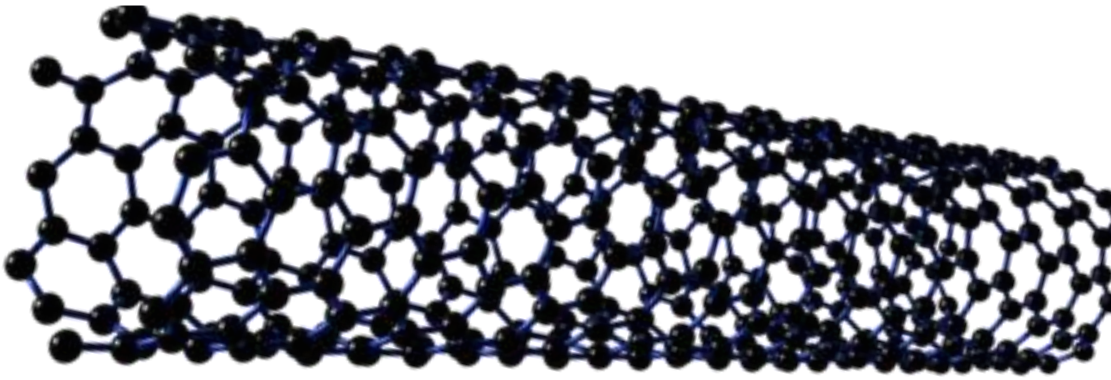
A wide variety of nanomaterials can be used within the energy sector, with their potential uses depending upon the functionality and physical properties of the material. Obviously, some materials can be used as they are electrically conductive, whilst others will be used for their strength or durability. Some materials have multiple properties that can be useful. Nanomaterials are often used in conjunction with other materials, many of which will be non-nano in size, and are used to provide added functionality. Thus, a nanomaterial may be added into a composite material to make it electrically conductive, or because it provides more strength or makes it more insulative. There is such a wide variety of nanomaterials that can be used it is impossible here to list them all, so a few illustrative examples will be given to show how some nanomaterials could be used within the energy sector.

Graphene: A very thin layer of carbon that is described as a 2D material, as it can be a large molecule measured in one direction, whilst still being only one atom thick. Often described as the world's thinnest material, graphene is also one of the world's strongest materials, as well as being electrically conductive.

It is its interesting physical properties that make graphene a candidate for many different applications, including in the energy sector. It has been suggested that batteries made using graphene could be flexible and light, whilst also being able to charge quicker and for them to hold power for longer. As well as being light and strong, graphene has a high surface area which allows it to store more energy, making it an ideal candidate material for use in energy storage.



Carbon nanotubes: A rolled up cylindrical sheet of carbon atoms which are either single walled (one rolled sheet) or multi-walled (cylinders of carbon within other cylinders of carbon), carbon nanotubes (CNTs) have unique and interesting properties. The functional properties of different CNTs depend upon their different physical properties, such as diameter, length, or chirality (twist). They are one of the stiffest and strongest materials that can be made, far stronger than steel for example, but are also light in weight. These properties make them ideal for use in strengthening composite materials, such as those used in the blades of wind turbines, where they can add strength. CNTs are also a great potential material for use in energy storage, where they can be used to replace the graphite electrodes in rechargeable lithium-ion batteries. As they can be made thinner and lighter and are also highly conductive, CNTs could allow batteries to be made much lighter, which is useful in areas such as vehicle batteries.



Silver nanoparticles Silver does not seem an obvious material to use in energy generation or storage due to the high cost of the material. However, at the nanoscale a small amount of material can go a long way! Silver nanoparticles, also known as AgNPs, have very high electrical conductivity. The electrical conductivity of silver is $6.30x10^7$m/ohm, in comparison with copper at $5.96x10^7$ m/ohm, making silver a better conductor. This makes it ideal for use in printed electronics, where it can be added to inks to create conductive inks. Inks with AgNPs in their mix have been considered for use in solar panels, where being able to print panels rather than manufacture them using the traditional photolithography, would speed up the rate and reduce the cost of manufacture.

Nanotechnologies in the Automotive Sector

Energy for certain uses, such as transportation, requires the energy to be stored to be used when required. In cars, this has been done using petrol or diesel fuel, which are then burned to release the energy they contain to power our cars and trucks. Automotive energy storage is one area where nanotechnology has been highlighted as being a breakthrough technology that will provide substantial benefits for all of us. But as well as storing energy more efficiently, it also helps if the energy is used more efficiently, and energy loss is reduced. This is another area where nanotechnology can have a significant impact.

Nanotechnology in Batteries for Electric Cars

We are all used to seeing batteries in many of the products that we use daily, from our mobile phones to our cars, there is a reliance on batteries of different sorts to provide electrical power. Batteries are one of the main things people think about when you talk about energy storage, and they come in all different shapes and sizes and are used for different purposes.

Cars are responsible for around 12% of the total EU emissions of carbon dioxide and there will be an effective ban on new fossil fuel powered cars from 2035. The aim is to encourage the switch to zero emission engines, which means that there will be a need to have a rapid transition to alternative power sources for transport, which will mean invariably more cars being powered by electrical batteries. Car batteries need to be both powerful and light and nanotechnology can provide materials that are both able to store energy well and are lightweight.

There are different ways of utilising nanotechnology into a battery. Improving the amount of power that a battery can provide and decreasing the recharge time can be accomplished by coating the surface of the electrodes with nanoparticles, which increases the surface area of the electrode and allows more current to flow between the electrode and the chemicals inside a battery. Alternatively, the current graphite electrodes in lithium-ion batteries can be replaced with CNTs, which can double the storage capacity.

New battery technologies are the focus of many ongoing research projects both in academia and industry. One barrier that is preventing their mass uptake into our cars is the cost of manufacturing nanomaterials at scale. Solving this challenge will help unlock these technologies for use in the next generation of electric cars.

Making Cars Lighter with Nanotechnology

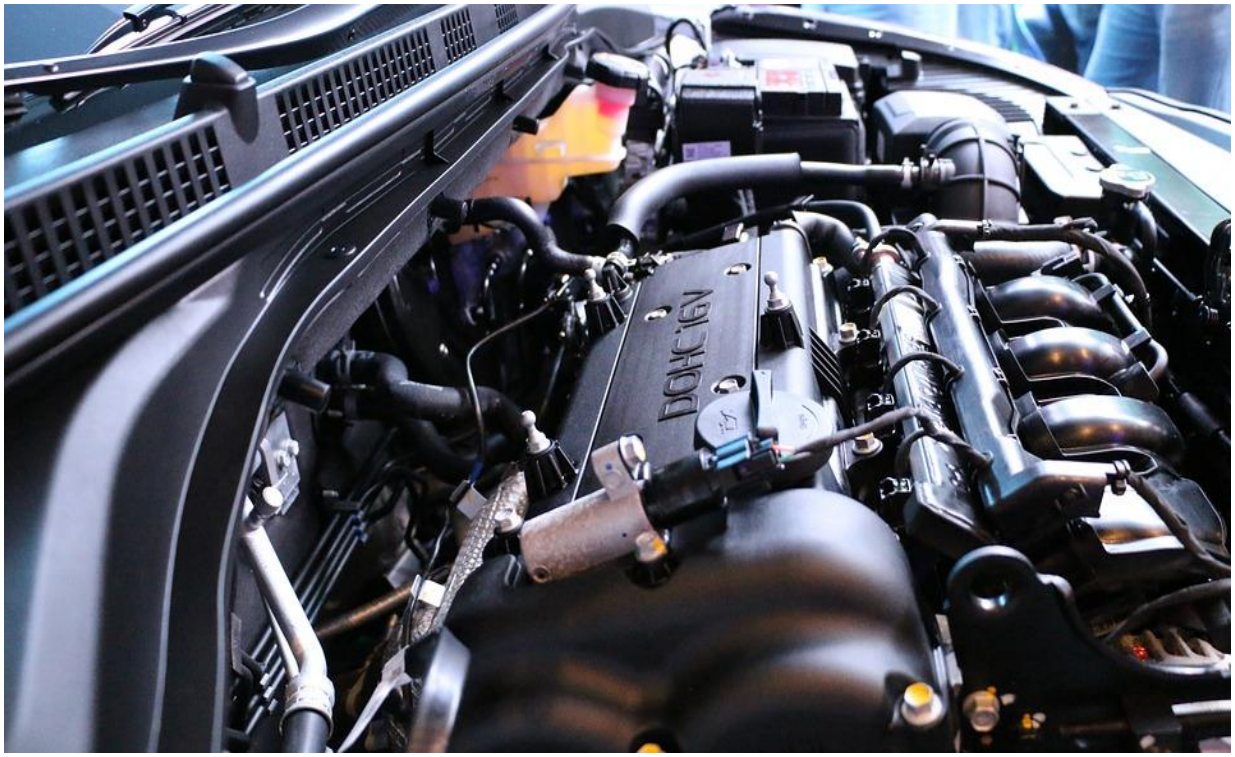
Making cars lighter does not at first seem to be related to energy. However, making cars lighter helps to reduce the amount of energy required to power our cars. Making fossil fuelled cars lighter helps to reduce the amount of fuel that they burn and reduces the amount of CO_2 they release. Making electric cars lighter helps reduce the size of the batteries needed to power them, which makes the cars cheaper to produce and sell. However, making cars lighter does not mean just using the lightest material available, or else we would all be driving around in cars made of paper! We need to also consider safety, which means using a material that is both light and strong.

Nanomaterials offer several options for weight saving in car bodies. Nanocomposites provide weight savings and offer very favourable weight to strength ratios. Polymer nanocomposites can be manufactured that use nano sized filers such as in nanoclays or CNTs within a polymer matrix. The addition of the nanomaterials adds strength into the polymer, whilst not adding as much weight as traditional polymer fillers. It may also be possible to use nanomaterials that provide additional functionality, such as electrical conductivity and allow future cars to replace electrical wiring as well. Using nanomaterials could allow a weight saving of 20% and in some cases, even more, all of which will help reduce the amount of energy needed to power the car.

Definition
Nanocomposite A material that incorporates nanomaterials into a matrix of standard materials. Examples in nature include bones in the human body. Manufactured examples include polymer nanocomposites, which are plastics with nanomaterials added for functional effects, such as increasing the strength of the material matrix that it is being added into.

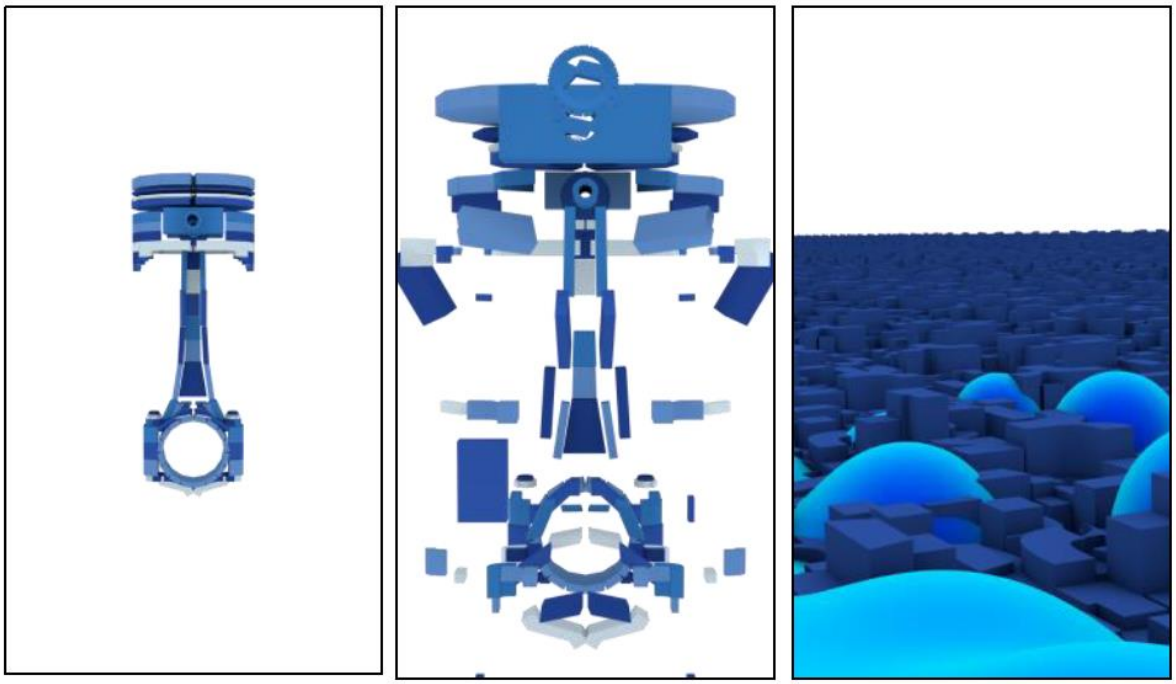
Making Engines Work Better

In engines around 10-15% of fuel consumption is lost due to friction, where parts are moving against each other. This occurs in current fossil fuel car engines, such as the piston rubbing against the cylinder wall, but will also remain a problem in electric cars with the drive shaft. Energy loss due to friction can be reduced by using nanotechnology that helps reduce the effect of friction and makes cars more energy efficient.



Nano coatings can be used on the piston and the cylinder walls that allow the piston to move with less friction. Nanocrystalline coatings using iron carbide and boride nanomaterials with a size of between 60-130nm provide a surface that is extremely hard, but with low friction properties. These tribological coatings are being looked at by many automotive manufacturers to help improve fuel efficiency.

Definition
Tribology Tribology is the science of surface to surface contact or the study of interacting surfaces that are in motion. It looks at the effects that friction, lubrication and wear have on surfaces. It is important to understand tribology when looking at a lot of mechanical systems where you have two components that will rub together.



Nanostructured coatings on a piston showing how the surface interacts with lubrication (taken from SeeingNano project animation https://www.youtube.com/watch?v=9uwGSv7oN8w shared under Creative Commons License)

1.Save knowledge

Summary

This has been a brief examination of the many ways in which nanotechnology can be used in energy. We have learned that nanotechnology can be applied across the whole value energy chain, from the harnessing of energy, through energy storage and onto energy efficiency. The move away from fossil fuels is necessary to help reduce the impact of climate change and as these are finite sources of energy. Moving towards renewable energy means that as a society we will need new technologies to help us exploit these energy sources more efficiently. Wind and solar power, for example, are not constant sources of energy and are weather dependant. We will need to find new ways of storing energy for us to use, both in our houses, but also for our transportation as well.

There are many different nanomaterials that can be used in energy. We have learned about three of them graphene, carbon nanotubes and silver nanoparticles. Nanomaterials can be harnessed for their functional properties, such as strength, electrical conductivity or for being lightweight. Looking at transport, we have learned that again nanotechnologies can be used in different ways. They can be used to help store energy in cars using batteries. They can also be used to make cars lighter so that they use less energy. Lastly, they can also be used to make cars more efficient through reducing the effect of friction on moving parts in car engines

Not all the uses of nanotechnology have been covered and not all the examples given here are currently freely available in the market. There is still much to learn about how we can harness nanotechnology in the energy sector. Nanotechnology is unlikely to be the only way in which technology can be used to combat climate change and help in the transition from fossil fuels to renewable energy sources. But the scope of nanotechnology is very broad, and it has a role to play across the whole of the energy value chain.