Nanotechnology applications

Energy Sector

Fuel cells

Catalysts are used with fuels such as hydrogen or methanol to produce hydrogen ions. Platinum, which is very expensive, is the catalyst typically used in this process. Companies are using nanoparticles of platinum to reduce the amount of platinum needed, or using nanoparticles of other materials to replace platinum entirely and thereby lower costs **hydrogen ions to pass through the cell** but do not allow other atoms or ions, such as oxygen, to pass through. Companies are using nanotechnology to create more efficient membranes; this will allow them to build lighter weight and longer lasting fuel cells.

Fuel Cells: Nanotechnology Applications under Development

Small fuel cells are being developed that can be used to replace batteries in handheld devices such as PDAs or laptop computers. Most companies working on this type of fuel cell are using methanol as a fuel and are calling them DMFC's, which stands for direct methanol fuel cell. DMFC's are designed to last longer than conventional batteries. In addition, rather than plugging your device into an electrical outlet and waiting for the battery to recharge, with a DMFC you simply insert a new cartridge of methanol into the device and you're ready to go.

Fuel cells that can replace batteries in electric cars are also under development. Hydrogen is the fuel most researchers propose for use in fuel cell powered cars. In addition to the improvements to catalysts and membranes discussed above, it is necessary to develop a lightweight and safe hydrogen fuel tank to hold the fuel and build a network of refueling stations. To build these tanks, researchers are trying to develop lightweight nanomaterials that will absorb the hydrogen and only release it when needed. The Department of Energy is estimating that widespread usage of hydrogen powered cars will not occur until approximately 2020.

Solar Cells

How can nanotechnology improve solar cells

Using nanoparticles in the manufacture of solar cells has the following benefits:

- Reduced manufacturing costs as a result of using a low temperature process similar to printing instead of the high temperature vacuum deposition process typically used to produce conventional cells made with crystalline semiconductor material.
- Reduced installation costs achieved by producing flexible rolls instead of rigid crystalline panels. Cells made from semiconductor thin films will also have this characteristic.
- Currently available nanotechnology solar cells are not as efficient as traditional ones, however their lower cost offsets this. In the long term nanotechnology versions should both be lower cost and, using quantum dots, should be able to reach higher efficiency levels than conventional ones.

Solar Cells: Nanotechnology Applications under Development

Researchers at MIT are studying solar cells made from single molecule thick sheets of graphene and materials such as molybdenum diselenide. They are predicting that this type of solar cells could produce up to 1000 times as much more power for a given weigh of material than conventional solar cells. They have completed computer modeling and are working on building the solar cells.

Researchers at MIT have developed a solar cell using graphene coated with zinc oxide nanowires. The researchers believe that this method will allow the production of low cost flexible solar cells at high enough efficiency to be competive. esearchers at Princeton University have developed a solar cell that almost eliminates losses due to reflection of light. They use a 30 nanometer thick gold nanomesh (a layer with a regular pattern of 175 nanometer diameter holes) along with an active layer thinner than the wavelength of light. They found that this combination traps most of the light in the solar cell, increasing the efficiency of the cell.

Researchers at Duke University are developing another method to reduce losses due to the reflection of light. In this method the combination of **silver nanocubes scattered over a thin gold** losses due to reflection.

Batteries

How can nanotechnology improve batteries?

Using nanotechnology in the manufacture of batteries offers the following benefits:

- Reducing the possibility of batteries catching fire by providing less flammable electrode material.
- Increasing the available power from a battery and decreasing the time required to recharge a battery. These benefits are achieved by coating the surface of an electrode with nanoparticles. This increases the surface area of the electrode thereby allowing more current to flow between the electrode and the chemicals inside the battery. This technique could increase the efficiency of hybrid vehicles by significantly reducing the weight of the batteries needed to provide adequate power.
- Increasing the shelf life of a battery by using nanomaterials to separate liquids in the battery from the solid electrodes when there is no draw on the battery. This separation prevents the low level discharge that occurs in a conventional battery, which increases the shelf life of the battery dramatically.

Batteries: Nanotechnology Applications under Development

Researchers at North Carolina State University have demonstrated the use of silicon coated carbon nanotubes for in anodes for Li-ion batteries. They are predicting that the use of silicon can increase the capacity of Li-ion batteries by up to 10 times. However silicon expands during a batteries discharge cycle, which can damage silicon based anodes. By depositing silicon on nanotubes aligned parallel to each other the researchers hope to prevent damage to the anode when the silicon expands.

Researchers at Los Alamos National Laboratory have demonstrated a catalyst made from nitrogen-doped carbon-nanotubes, instead of platinum. The researchers believe this type of catalyst could be used in Lithium-air batteries, which can store up to 10 times as much energy as lithium-ion batteries.

Researchers at USC are developing a lithium ion battery that can recharge within 10 minutesusing silicon nanoparticles in the anode of the battery. The use of silicon nanoparticles, rather than solid silicon, prevents the cracking of the electrode which occurs in solid silicon electrodes.

Researchers at Stanford University have grown silicon nanowires on a stainless steel substrate and demonstrated that batteries using these anodes could have up to 10 times the power density of conventional lithium ion batteries. Using silicon nanowires, instead of bulk silicon fixes a problem of the silicon cracking, that has been seen on electrodes using bulk silicon. The cracking is caused because the silicon swells it absorbs lithium ions while being recharged, and contracts as the battery is discharged and the lithium ions leave the silicon. However the researchers found that while the silicon nanowires swell as lithium ions are absorbed during discharge of the battery and contract as the lithium ions leave during recharge of the battery the nanowires do not crack, unlike anodes that used bulk silicon.

Researchers at MIT have developed a technique to deposit aligned carbon nanotubes on a substrate for use as the anode, and possibly the cathode, in a lithium ion battery. The carbon nanotubes have organic molecules attached that help the nanotubes align on the substrate, as well as provide many oxygen atoms that provide points for lithium ions to attach to. This could increase the power density of lithium ion batteries significantly, perhaps by as much as 10 times. A battery manufacturer called Contour Systems has licensed this technology and are planning to use it in their next generation Li-ion batteries.

Electric or Hybrid Cars

Electric and hybrid cars are becoming more popular given the cost of a tank of gas. Work by nanotech companies such as Altair Nanotechnologies and A123Systems to improve the performance of lithium ion batteries may make electric cars even more appealing. Lithium ion batteries have a higher power density than the nickel metal hydride batteries currently used in electric and hybrid cars. Using lithium ion batteries you can store the same amount of power in a lighter weight, smaller, package. Also lithium ion manufacturers project that their batteries will last about ten years, about four years longer than nickel metal hydride batteries.

However previous generations of lithium ion batteries were slower to charge and had safety issues, much publicized when batteries in laptop computers caught fire. Nanotechnology companies have changed the material used in the lithium ion battery electrodes. Each has used its own proprietary material composition both to reduce the risk of the battery catching fire and to incorporate the ability of a nanostructured surface to provide faster charge transfer between the chemicals in the battery and the electrodes.

It appears that the efforts of these companies will result in improved hybrid and electric cars. Once nano-enhanced lithium ion batteries pass evaluations by GM and other car manufacturers, electric or hybrid cars can be produced that will have higher performance than cars using nickel metal hydride batteries or the same performance while using smaller/lighter batteries.

Of course for hybrid or electric cars that use nano-enhanced lithium ion batteries to gain a foothold the batteries will also have to come down in price and be manufactured in large numbers. It will be interesting to see how battery manufacturers manage the manufacturing ramp up if the demand for these batteries increases both for electronic devices, such as laptop computers, and cars.

Fuel

How can nanotechnology improve fuel availability?

Nanotechnology can address the shortage of fossil fuels such as diesel and gasoline by:

- Making the production of fuels from low grade raw materials economical
- Increasing the mileage of engines
- Making the production of fuels from normal raw materials more efficient

Nanotechnology can do all this by increasing the effectiveness of catalysts. Catalysts can reduce the temperature required to convert raw materials into fuel or increase the percentage of fuel burned at a given temperature. Catalysts made from nanoparticles have a greater surface area to interact with the reacting chemicals than catalysts made from larger particles. The larger surface area allows more chemicals to interact with the catalyst simultaneously, which makes the catalyst more effective. This increased effectiveness can make a process such as the production of diesel fuel from coal more economical, and enable the production of fuel from currently unusable raw materials such as low grade crude oil.

Nanotechnology, in the form of genetic engineering, can also improve the performance of enzymes used in the conversion of cellulose into ethanol. Currently ethanol added to gasoline in the United States is made from corn, which is driving up the price of corn. The plan is to use engineered enzymes to break down cellulose into sugar, is fermented to turn the sugar into ethanol. This will allow material that often goes to waste, such as wood chips and grass to be turned into ethanol.

Fuel: Nanotechnology Applications under Development

- Increasing mileage of diesel engines
- Nanosphere based catalyst that reduces the cost of producing biodiesel
- Modifying crops to allow cellulous material, such as corn stalks to produce enzymes that are triggered at elevated temperatures to convert the cellulous to sugar, simplify the production of ethanol.

- Modifying bacteria to cause the production of enzymes that will convert cellulous material to ethanol in one step, rather than converting cellulous to sugar which is than fermented into ethanol.

Fuel: Nanotechnology Company Directory

Company	Product	Advantages
Headwaters	Nanocatalysts used in the conversion of coal to liquid fuels and in the upgrading of low grade crude, such as crude from shale oil	Additional raw material, coal, for producing gasoline, diesel and other liquid fuels
Refinery Science	Nanocatalyst used in upgrading low grade crude	Making low grade crude oil, such as from oil sands, usable for producing gasoline or diesel
Oxonica	Nanoparticle cerium oxide catalyst for diesel fuel	Increased mileage and reduced air pollution
H2OIL	Nanoclusters which helps gasoline and diesel fuels burn more completely by breaking the fuel into smaller droplets	Increased mileage and reduced air pollution
Catlin	Nanosphere based catalyst that reduces cost of producing biodiesel	Producing diesel from vegetable oil
Agrivida	Bioengineered plants that produce enzymes to simplify the conversion of cellulous to ethanol	Ethanol production using corn stalks

Nanotechnology offers Alternatives to Fossil Fuels

With the uncertainty about supply of crude oil, as well as high prices, other sources of fuel are now a hot topic. An interesting option is ethanol, currently made from plants such as corn and sugar cane. Companies and universities are working to develop a process for producing ethanol from many other types of plant material; which may significantly increase the amount of ethanol available as fuel. Nanotechnology may be of help in this effort.

Currently ethanol used in gasoline in the US (about 5 billion gallons a year) is produced from corn. The starch in the corn kernels is converted to sugar using enzymes. This starch is then fermented to make ethanol. However in order to make a useful reduction in the US consummation of crude oil, we need to up that production significantly. The goal set recently by the US government is to produce 35 billion gallons of ethanol a year within the next ten years.

The corn stalk is composed of a material called cellulous which is not converted to sugar by the enzymes used in the current ethanol producing process. To increase production of ethanol several companies and universities are trying to use the cellulous portions of the corn plant, such as the stalk, along with other plants that are currently thrown away. Nanotechnology is helping this effort by allowing researchers to study the molecular structure and function of bacteria and enzymes. This enables them to either select enzymes capable of converting cellulous to sugar or to modify enzymes to make them useful in the conversion process. Being able to use cellulous material such as wood chips, grasses, and corn stalks (in fact, most plant material) would increase the amount of feedstock available for ethanol production.

In another proposed method cellulous is heated and converted into carbon monoxide and hydrogen gas. A bacteria is then used as a catalyst in the conversion of the gas to ethanol. Nanotechnology may help this process both through genetic engineering of the bacteria to improve its performance as a catalyst and by providing alternative catalysts. For example, researchers have found that carbon nanotubes containing rhodium (Rh) nanoparticles act as very effective catalysts for the conversion of the gas to ethanol.

The US Department of Energy is a believer in cellulous feedstock for ethanol production. It has provided grants to six companies to help fund pilot production plants for the conversion of cellulous feedstock to ethanol using both the methods described here.

Researchers at Michigan State University are trying a neat trick. They are genetically engineering corn to include the needed enzyme. The plan is to make the enzyme inactive until triggered by high temperatures. When the cellulous part of the corn, such as the stalk, is processed, the high processing temperatures would activate the enzyme and convert the cellulous to starch. This would avoid the added cost of producing the enzyme separately.

Researchers at the University of Rochester are studying how bacteria chooses a particular enzyme, or enzymes, to break down at particular type of plant or other bio mass. They hope to generate enzymes that can convert cellulous to ethanol in one step, rather than the two steps used by the existing processes.

There are obvious cost savings of using yard waste to fuel our cars, and ethanol has a head start as an alternative fuel in that over 5 million cars in the US have already been equipped by the vehicle manufacturer to run either on regular gasoline or an 85% ethanol/15% gas mixture. These so-called Flex Fuel vehicles represent a portion of cars manufactured over the last several years. Manufacturers have done this in exchange for being allowed to produce other vehicles with low gas mileage. If cellulous-based ethanol production is shown to be economical, there are already cars on the road that could use the fuel.

The advantage of cars that can be filled up with either gasoline or ethanol has been demonstrated in Brazil which uses much of its sugar cane crop to produce ethanol. Drivers with Flex Fuel cars are able to chose their fuel depending upon which is less expensive at the time, and most cars sold in Brazil are capable of using either fuel.

Using nanotechnology/genetic engineering to produce ethanol from cellulous has the potential to make a serious dent in our consumption of crude oil. However we do need to keep an eye on some safety issues. For example precautions must be taken to insure that a built-in enzyme is only activated in the processing plant, not while the crop is in the field, and that corn with the special enzyme is not mixed with crops grown for human consumption. We can hope that corporations and universities will make public the steps they take to insure that the methods they use to simplify the conversion of cellulous to ethanol do not endanger food crops or forests.

Hydrogen Fuel Cells

You may have heard talk about hydrogen fuel cells powered cars replacing gasoline powered cars, but don’t hold your breath. The major obstacles to widespread use of hydrogen fuel cell powered cars in the next few years are the lack of a network of hydrogen fuel stations and the need for lightweight, safe hydrogen fuel tanks.

Researchers are developing hydrogen fuel tanks based upon absorption of hydrogen in solid materials (such as the metal hydride powder that a company named EDC Ovonics is using), carbon or other materials, that are sufficiently safe, lightweight, fast to refuel, and inexpensive to meet the requirements of mass market cars.

Widespread usage of cars powered by hydrogen fuel cells won’t happen until refueling stations become as plentiful as your neighborhood gas station. Currently there are only a few hundred hydrogen fueling stations around the world. One of the basic challenges in establishing these stations is deciding how to refill the hydrogen tank in a car. A 6000 psi hydrogen supply is used to fill the high pressure gas cylinders used on many demonstration vehicles. On the other hand, a 1500 psi hydrogen supply is used to fill the cylinders made by EDC Ovonics; that store hydrogen in a solid. The design of hydrogen tanks needs to be far enough along to standardize the refueling conditions before a network of fueling stations can be built.