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Energy Efficiency – Can Nanotechnology Change the Equation?

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ENERGY EFFICIENCY - CAN NANOTECHNOLOGY CHANGE THE EQUATION?

ENERGY EFFICIENT BUILDING, FUTURISTIC CONCEPT

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***Abstract**: This dissertation examines if nanotechnology can be used to achieve greater energy efficiencies in industries as well as in residential housing. Nanotechnologies is an emerging science where several fields converges, and there are great potential to harness the special properties that only reveal itself on the nanoscale. With insulative nanolayers, components in turbines can be used at higher temperatures which raises the thermodynamical efficiency rates. By using nanocomponents, the energy usage of applications can be significantly reduced, while retaining the same characteristics and functionality.*

Keywords: Nanotechnology, Energy Efficiency, Fossil fuels, Global warming

Contents

1. Introduction

1.1 Energy efficiency

In the early twenty-first century; the world economic output reached new heights never seen in history before, and continues to expand at an unprecedented pace. The economic growth have lifted hundreds of millions of people in developing countries out of poverty, joining the middle class, and billions of more people strives for the level of material abundance already reached in the developed world. Furthermore the world population is projected to add at least two billion more individuals in addition to the seven billion people that already occupies the planet. The energy requirement for this population is immense; the present population of world currently consume around 12,000 Million Tons of Oil Equivalents (MTOE) or 750.000.000.000.000.000.000 Joule of energy each year. The consumption is expected to increase by at least 50% by the year 2030 to 18,000 MTOE. The trend have raised concerns about the consequences as well as the sustainability of the economic foundations of the system, namely the burning of fossil fuels as the main provider of energy, which comprises over 80% of our energy requirements.

The problem posed is that more and more evidence stacks up against Carbon-dioxide, which is emitted by all fossil fuels when combusted, as being a leading cause for global warming as well as other environmental drawbacks. It has only caused limited damage yet, but strong scientific evidence suggests that it has potential to do so in the long run; with rising sea levels, desertification of fertile land and acidification of oceans among some of the predictions being made about the consequences. Another issue is that the proven supplies of oil, the leading form of fossil energy is depleting steadily, and there would simply not be enough to go around by margin if all humans on the planet would want to consume it in the quantities that the developed world does today. This fact will put pressure on the price for the commodity to previous unimaginable heights, and by economic necessity it prompts us to think about alternative solutions of how to supply our seemingly insatiable demand of energy. In the long run we need to get us of off the dwindling supplies altogether, and to find new ways of generating energy. However, even if we did this rapidly if would probably take more than a generation to achieve, and currently; we are not doing this rapidly. There are however another partial solution in the short run; if we could somehow convert the stored energy provided by fossil fuels, as well as other sources, with greater efficiency; we could get more energy out of the fuel and hence reduce the amount consumed. If we furthermore build appliances that uses the energy supplied more efficiently with less loss to unwanted forms of energies, the usage of our dwindling fuels could be decreased, and buy us the much needed time to make the transition into a more sustainable energy base for our Civilisation. [1] [2]

To achieve this is not easy however, as for example the energy conversion rate in an modern but ordinary car engine from the potential energy content of gasoline to motion in the engine is about 18% to 20%. Even more energy is lost through the transmission to the wheels with the subsequent even lower efficiency rate from the potential energy that originally was used to motor the vehicle ahead. The present technology have been developed for more than a century to achieve this situation we have today. The same trend is visible in other applications. A 60W incandescent lightbulbs for instance only converts about 2.1% of the energy supplied to it into visible light, and for other household appliances as well as in the industry there are similar inefficiencies. In contrast, the energy conversion in biological system from hydrocarbons into useful energy reaches almost a complete efficiency of just under 100%, implying to us that it should at least in theory be possible to improve the energy efficiency of our technologies considerably. [3] [4] [5]

A promising new field of science that has the potential to help mitigate our energy problems and help us reach greater energy efficiencies is the field of nanoscience. Nanoscience and nanotechnology should not themselves be seen as a specific fields of research or technology, but rather as a new practical dimension of the length scale where many different fields converge. Nano itself means dwarf in ancient Greek and refers to a length scale that is about a billionth of a meter, or 10^{-9}m. At this length scale which itself is in the order of atoms make the sciences of chemistry, electronics and biology become indistinguishable from each other and converges into a single field. Specific physical phenomenas that only reveals itself in this nano-realm can be harnessed to get novel properties out of the old materials, that can yield great benefits in the macro-realm where they are used routinely today. [6] [7]

The nanofield shows great promise, but the question is just how and in what ways it could be used to help us in our slowly escalating energy crises already in the foreseeable future, and more specifically how it in the short run can help us increase our energy efficiency. To present possible nano-solutions to these problems and to discuss these alternatives are the aims of the present theses.

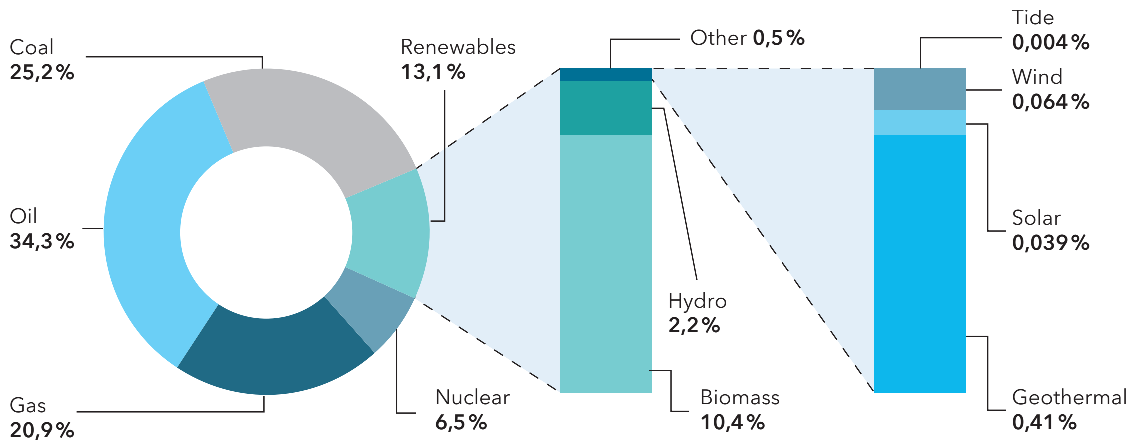


Figure 1.1, Energy sources of global primary energy supply 2006. Source: Hessian Ministry of Economy, Application of Nanotechnologies in the Energy Sector, 2008, p 14.

1.2 Aim and purpose of the study

This dissertation aims to shed light on how nanotechnologies can be used to increase the energy efficiency and how it can help with energy conservation in both industrial processes as well as in residential housing. The base for the study is the energy dilemma the world currently finds itself in, and the need for us to rapidly find new ways to get more value out of less resources with less side-effects. One reason for looking into the field of nanoscience to solve or mitigate the problem is due to the fact that there has been rapid increase in the theoretical and practical knowledge in a rather scientific field. There are strong indications that the new technology can, make an important impact on how we think when designing new products, even though it has not yet been implemented to any significant degree in the areas where it may be needed most in terms of energy efficiency. There are however considerable discoveries in the nanofield already proven in research and development departments and universities, and the purpose of this review is to shed light on these technologies and show in which areas they could best be implemented to serve their purpose.

1.3 Focus

In order to narrow down the scope, the theses will not look deeply into the large amounts of emerging nanotechnologies that could be used to generate electricity on its own, but will rather look into how nanotechnology can help existing power generation facilities and industry to achieve higher energy efficiencies or lower carbon emissions. I will mainly focus on industry but will also look into how residential housing, that might generate its own power, can be helped to become more efficient and reduce energy losses by the use of nanotechnologies.

Figure 1.2, Energy usage is increasing. From left Coal Fired power plant, Large crowd, Shanghai at night needs electricity. Source: nettereklam.com, onepennysheet.com, chinaodysseytours.com

1.4 Research Question

How can nanoscience be used to raise the energy efficiency of established industrial technologies and in residential housing

1.5 Hypothesis

Nanotechnological solutions can greatly increase the energy efficiency of existing technologies through the exploitation of novel phenomenas that only reveals itself on a small length scale. By taking advantage of surface properties, volume to surface ratios and quantum phenomenas, which is what nature does, it should enable existing technologies to come closer to their thermodynamic efficiency limit. The nanotechnologies used should be able to conserve energy, reduce input of energy or increase the output of the applications and at the same time be economically viable alternatives.

2. Method

2.1 Type of study and previous research

This dissertation is foremost a literature study, where it is looked into the literature of energy efficiency to determine what problems that is posed; and into the literature concerning nanoscience to identify possible solutions for the problems. There are also several studies from various sources that look at the whole picture of how nanotechnologies can alleviate and help with the transformation into a more energy-efficient and sustainable society; often in the context of a region and how it can be economically beneficial for it. Studies such as this have been done by the German state of Hessen and from the American state of Pennsylvania among others, and they usually have their focus of how the new technologies can help their region to become more competitive and efficient to compete with other regions in this new industrial landscape. There are also reports like this from the EU, and United States that have a similar focus on the economic and competitive impact. Other reports can be found from companies or science institutions that work with energy efficiency and nanoscience, such as the French LITEN association; where they try to bring nanotechnologies from the science laboratories of universities out to industry where it can be implemented and serve it's purpose. There are also numerous books on the subject, as well as papers from universities.

The literature concerning the need for energy efficiency and areas of possible improvement are very wide, ranging from EU and UN reports- to Greenpeace and Al Gore. There are also some voices that speaks out against some of the reasons for increasing energy efficiency, where some believe that climate change is not a significant issue or that there are much more fossil fuel available in the ground than argued by others, many of these arguments are usually made on political grounds. The latter have in this theses largely been ignored since their arguments not shall be discussed until the technology data have been scrutinised and discussed – to argue for or against political issues are difficult or meaningless until the material ground for the discussion is clarified.

The literature on nanoscience is well established, there are books and papers form university scholars and reports from a multitude of actors such as governmental, science and state entities. The problem in this area, however, is that since it is a rather new area of science, the field is moving rapidly forward in so many directions that it is hard for the literature to keep pace. This means that there is a certain time lag that is not neglectable and can't really be ignored. Another problem is that a lot of the information and relevant knowledge may probably not be found in literature at all, and is only known by the persons doing the front line research themselves.

In order to alleviate this problem, frontline researchers and other relevant people that might have the information and ideas of how to solve some of the problems posed by energy efficiency with nanotechnologies will be interviewed. The interviews will be carried out face to face, which can give new insight into the problems as the discussions moves into direction not originally intended, and will give the dissertation greater significance and depth. The interviews will not be recorded, since it may have the effect on the interviewees as they might not talk as freely and vivid of the subject that they otherwise would. Since the subjects are rather non controversial it should not be hard to get the interviewees to back up the findings at a later stage.

Forest. Source: Apple Template

Wood. Source: Apple Template

Forest. Source: Apple Template

2.2 Data collection

It was foremost tried to get hold of official documents, and also searched for documents and scientific papers in databases that contained relevant information. In the cases when it could not be found found any good documents, it was tried to get in touch with organisations and asked them for internal or other unreleased information that could be of interest. In other cases where informations was more scarce, or informations was to comprehensive, it was tried to get an interview with someone that could have the proper knowledge and could answer the current questions. Lund is home to the Lund Technical College, LTH, as well as the Nanometer consortium and the only Nano-Engineering program in Sweden. This means that there is a rich ground of local science and expertise that could easily be obtained through interviews with key researchers and professors. In Lund there is also a nearby Science park with many locally anchored companies that may use nanotechnologies in their field, and that may also have rich research and development departments that uses nanotechnological instruments and solutions to solve some of their problems. These could perhaps also be interviewed to get a better idea of how they perceive nanotechnologies, if they have an action plan of how to use the new technologies and if they may already be using some of the nanotechnologies that are available today to improve their energy efficiency in some way.

2.3 Data analysis

Much of both the primary and secondary data will be gathered from actors which may have a bias for presenting the information in a way that suits their purpose. This must be taken into account when analysing the data, and critical eyes will be needed especially in relation to companies and state entities that may want to overstate their own importance or perhaps impact of the respective technology in the field. This problem will probably be less evident with literature from university authors and science papers, but even these may have an incentive to present their findings in a investment friendly manner, since the impact of their work may be directly proportional to the funding for it.

A great deal of data will be in a qualitative form, but may be converted when possible to a quantitative form where it is more easily to identify statistics and trends. Data will be visualised whenever it is possible for easier comparison and understanding and nano-scientific concepts will tried to be illustrated graphically to more easily convey the gathered information.

2.4 Disposition

The first section will explain the concept of nanotechnology itself, and what specific properties which it has that is useful. This part will not have as many references as the other ones, since it mostly contains universal knowledge known to all who are active within nanoscience. After this, the main section contains certain nanotechnologies and concept, and also some short examples in which areas in industry the application could be used for. There may be subcategories to a certain nanotechnology or phenomena, and in that case it will be divided down into a few categories with the same setup as in the original case. Secondly, a number of industrial problems and possible specific solutions from the nano-field will be examined and also contain an economic and energy efficiency estimate to get an idea of the potential of the technology in the field.

Thirdly there need to be an analysis of the potential of the nanotechnology regarding its contribution to economic and energy efficiency. The last technology part deals with some of the untraditional applications of nanotechnology, where perhaps most of the potential and hope in the field lies. This is not as comprehensive, but be more visionary than the other sections. This section will also contain the discussion part, and the dissertation will end with a conclusion that will round up the work and summarise the findings.

3. Nanotechnology

3.1 What is nanotechnology

The field of nanoscience is not as entirely new as one might believe. The usage of nanoparticles were utilised even in ancient roman times where they where used for example for dying glass [8], and nanoparticles have in recent times successfully been used in toothpaste for instance for over 70 years. What defines nanotechnology is the scale of the engineering being done, and should perhaps not be seen as a single field but rather as a length scale where many different fields emerge.. In figure 3.1 a visualisation of length-scale is given as a reference to understand how tiny the nano-scale is. A nano-particle is defined as a particle that has a diameter of 100 nm or smaller. [1]

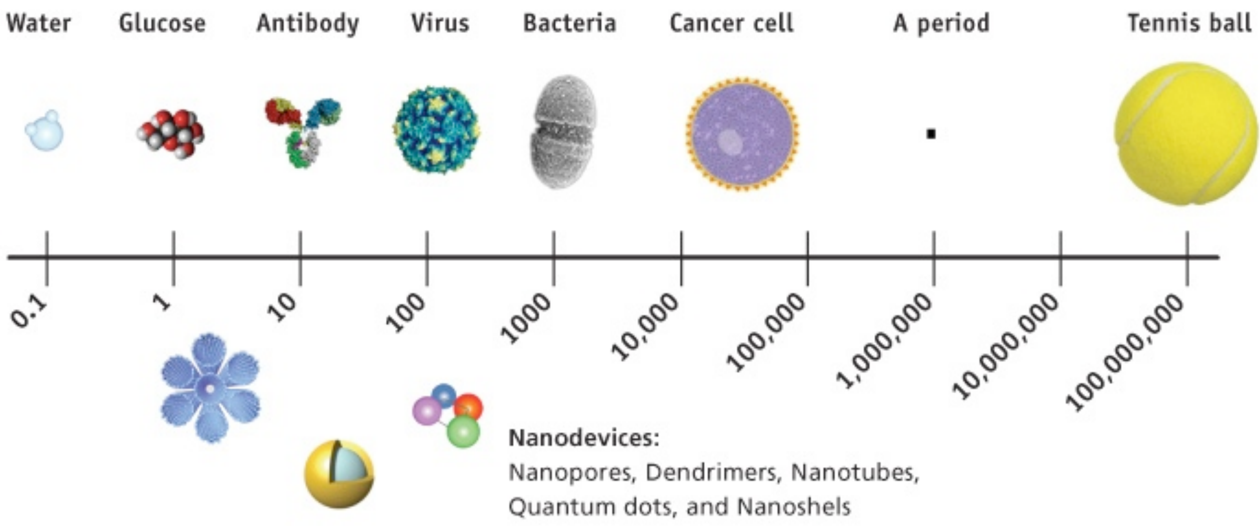


Figure 3.1, The nano length scale in nanometer. Source: www.fda.gov

The difference with the usage of nanoparticles back in the ancient Roman times and now, is that the Romans didn't understand how it worked, or even that they used nanometric properties at all; they just uncovered something that worked and hence decided to use it again. The same can be said for the usage of nanoparticles in toothpaste, and other involuntary usage of nanoparticles before modern day [9]. What defines nanotechnology today however is that we understand what we are doing, we know about the quantum mechanical phenomenas and the physics at work behind them, which make us able to envision a usage for the phenomena and produce the certain product of material taking advantage of it. However, it is only in the last few decades that we have been able to see and probe the nanoscale with some real success, which is partly the reason that the field of nanoscience came into existence.

3.2 What enabled nano?

What has enabled scientists to do this is a multitude of innovations and technologies that has been developed in the last 50 years, and is still far from perfected to their full potential. One such thing is the electron microscope that have enabled researchers to look deeper into the nano-realm than ever before. Before the invention of the electron microscope, the best resolution we had was with advanced optical light microscopes. The limitations of these was that it was impossible to see anything smaller than about the wavelength of the light being used, and if using ordinary light it means that the smallest thing you can resolve will be around 300 nm. This is huge; about 1000 atoms in length, and makes it impossible to see any of the nano structures that builds up the material surface. By using electrons instead of photons as the probing agent, researches found that they could get significantly higher resolution, but brought with itself new problems and challenges where some are still being worked out. [6]

It is possible to envision why smaller wavelength is needed to probe smaller structures by comparing it to bouncing basketballs and small rubber balls at a car, and determining the shape of the car by looking at the balls bounce back trajectory. The basketball will bounce of the windshield at a certain angle, the wheels are at a certain angle, etc. But it will have about the same trajectory wherever on the wheels rim surface it bounces off. The small rubber balls will in contrast bounce back at different trajectories at the smaller structures on the rims such as voids and angles, and it will hence be possible to determine the structure of the rims, unlike the case with the larger basketballs. The same reasoning applies to light (photons) and electrons, where the much smaller wavelength of the electrons around 12 picometer or 12 x 10^-12 m, is smaller than an atom and can be liked to the small rubber balls compared to the large photons which is like the basketballs. There is however other effects of the electrons such as scattering; that limits the resolution to a bit larger than the actual wavelength, but it is still possible to achieve a much higher resolution than it is with ordinary light-sources.

Figure 3.2, Random rims that will produce unsimilar bounce-off patterns from small rubber balls. Source: Google - Rims

To produce and detect the electrons bouncing of the specified sample surface it not as easy however, but there are a number of techniques of achieving this; such as in a SEM (Scanning Electron Microscope) or TEM (Transmission electron microscope). There are currently also other techniques to probe the atom size scale, such as the AFM (Atomic force microscope) where a extremely sharp tip moves across a sample to ”feel” the surface, and build up an image. In the nanobio field it is a common technique to attach small luminous particles to for instance a protein. When excited with light of a specific wavelength the luminous nanoparticles starts to emit light with another wavelength, and by fitting a gaussian curve to a number observations; it is possible to resolve very small distances despite using light as a source. In figure 3.3, schematic pictures of a SEM and a TEM are shown.

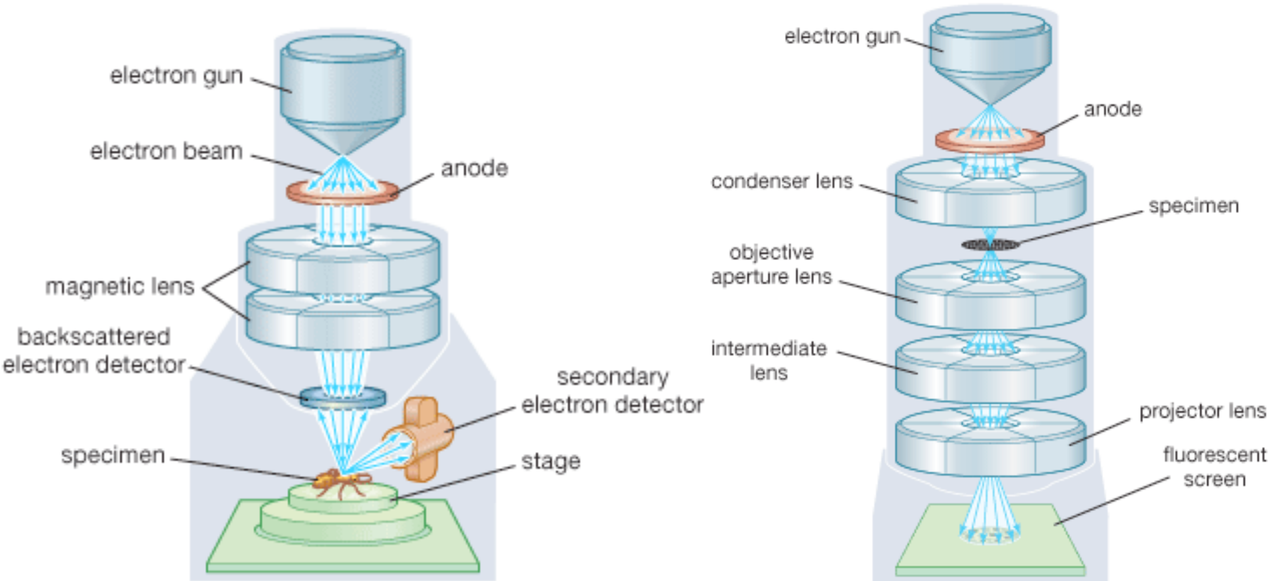
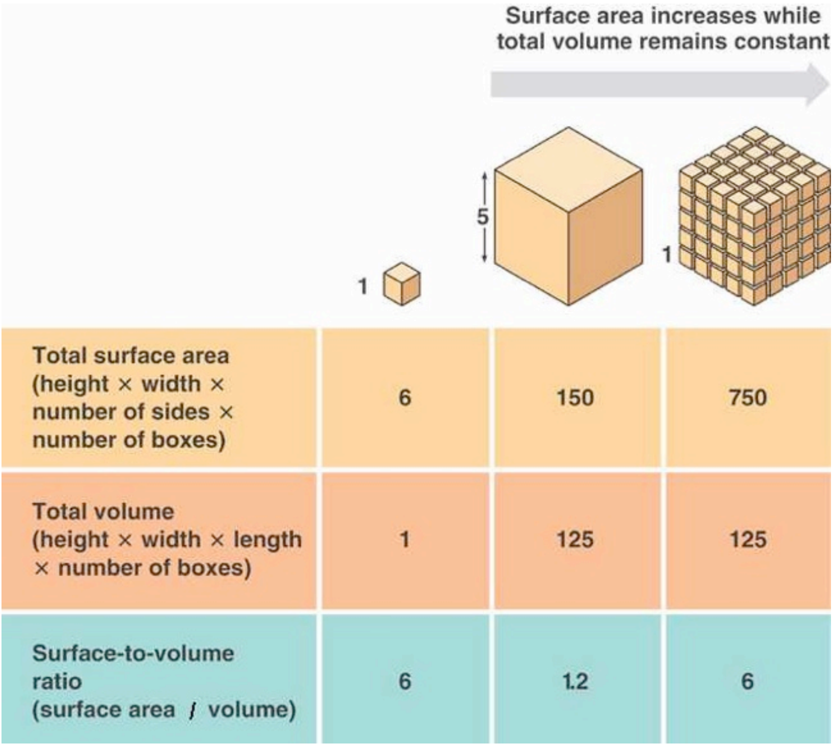


FIgure 3.3, Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM), Source: Encyclopaedia Britannica

These nano-realm probes are complimented with substantially larger and much more expensive equipment such as synchrotron radiation and neutron spallation sources, where the latter can cost more than a billion Euros to build and needs the space of a small industrial complex to encase it. So counter intuitive, it can take extremely large machines to probe the extremely small distances of the nanoscale. The SEM and AFM on the other hand can easily fit onto a desktop in a normal office space. These are some of the most important tools that have enabled the field of nanoscience to come into existence, and are used to explore atomic structures and phenomenas at the smallest of scale at all major universities, that has research in the field around the globe. The new microscopes, or nanoscopes to be more precise, have unlocked the door of understanding everything from how catalytic processes occur in an exact manner, to the determination of the atomic crystal structure of semiconductors and metal alloys. With the new technologies it also became possible to nanoengineer materials, and to evaluate the material properties of certain designs. What is discovered is that by manipulating materials in the nanoscale, some really interesting properties could be obtained and used.

3.3 The power of the small

There are many reasons why the physics of the nano-realm is different, and dependent of what field you work in. But a profound property that all nano-sized structures have in common compared to commonly sized objects, is its extremely high surface to volume ratio. It is rather easy to visualise this, by arranging a constant volume into a number of cubes and calculate the surface area. This important concept is shown in figure 3.4, and a relevant example of nanoscale particles is shown in figure 3.5.



Total surface area (height × width × number of sides × number of boxes)	6	150	750
Total volume (height × width × length × number of boxes)	1	125	125
Surface-to-volume ratio (surface area / volume)	6	1.2	6

Figure 3.4 , Surface to volume ratio. Source: Kankakee Valley School Corporation Moodle

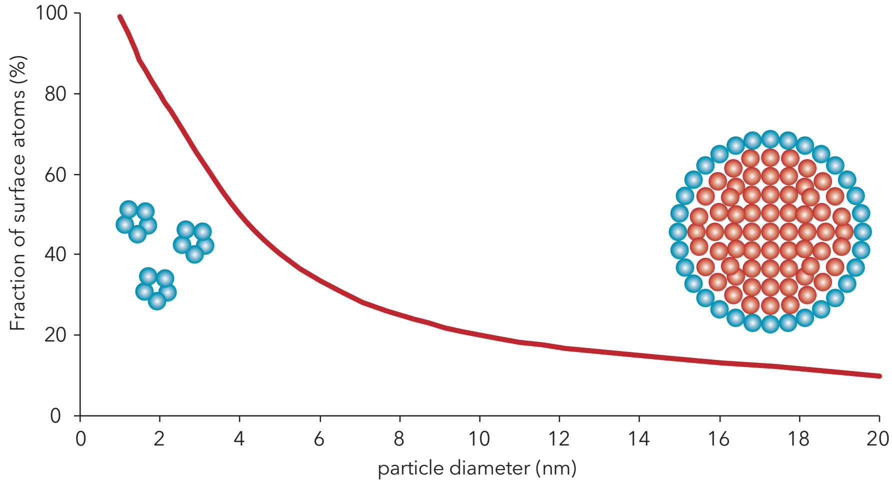


Figure 3.5, Surface Area vs Volume of nanoparticles. Source: Hessian Ministry of Economy, Application of Nanotechnologies in the Energy Sector, 2008, p 10

The high surface to volume ratios is key for many applications, since it is on surfaces on objects that chemical and physical reactions usually take place, and nanoparticles can give thousands of times higher surface-area per gram of particles than in a bulk structure.

Another concept to understand is that the dominant forces that govern interactions of ordinary objects, can be displaced by others when the scale becomes very small. Diffusion is for instance negligible in the world around us, but small organism and cells would not be able to function at all if it were not for diffusion to move around proteins and chemicals in the cells, and it is a major force in the nano-realm. Also the concepts of barriers and conductors in the world of nanoelectronics change, where electrons easily can ”tunnel” beyond boundaries and interact to its surroundings according to probability functions rather than solid physical rules. In contrast fluidic systems on the micro and nanoscale become laminar (streamlined) and very predicable in contrast to the turbulence of large flows. Surface tension becomes an extremely prominent force at the same time as gravity becomes less important. Magnetic poles of magnets can also be isolated if they are not too large, in contrast to the macro-world where the attempted isolation of a magnetic pole always will result in two new magnetic poles.

These are just some out of many interesting properties that change when entering the nanoscale, and it offers many possibilities for engineers to exploit them to their advantage. Some of these can be used to increase the energy efficiency of machinery and products which is what will be explored in the next section. [6]

3.4 The nano age

Nanotechnology will profoundly change the way we do engineering and how we think about materials and products. Ever since the dawning of man we have used what we could find in nature, be it flint stones and wooden sticks in the stone age or coal and iron in the modern age; we have used them as they where for a purpose for which they deemed useful in, which was certainly not their original purpose. Trees for instance makes oxygen, captures CO_2, fixates nitrogen, distills water, converts solar energy into complex sugars and foods, creates microclimates, cleans toxins, changes colours with the seasons and self replicates; and we cut them down to write on them! [10]

In metallurgy we have for centuries learned that by heating and cooling the iron as well as mixing it with a certain amount of carbon, the material becomes stronger. We didn’t know exactly why though, and Japanese katana-sword smiths also included prayers and the burning of scrolls among other rituals alongside the useful ones and treated them with equal importance to the crucial quenching and folding. [11]

Figure 3.6, F.L. Carbon Nanotubes, Conceptual nanorobot delivering medicine to red blood-cells, Molecular buggies, actually made in laboratories and can be driven across a surface. Source: www.tacticalwarfightergear.com, www.piercemattie.com, www.physorg.com

In modern day chemistry, we do know what reactions we want, but we essentially just mix a few billions of one kind of molecules with a few billions of another sort of molecules, heat it up and hope that we get out the product we want. This is an extremely crude method, and nature outsmart us everyday both in terms of efficiency and selectivity for the same processes. We often need extreme heat or cold to perform many of the reactions, acidic environments as well as sterile conditions so that no other reactions take place. Whereas nature can do everything at about for example 37° C, with thousands of other reactions taken place alongside it. Even as the body is filled with toxins or alcohol and run a fever at the same time, flawlessly billion times a second every day.

The same pattern is visible for numerous processes; we want a certain property and search for a material that kind of suits our purpose, but with numerous other unwanted characteristics. In modern nanoscientific engineering, the process is thought of in an unsimilar fashion. We want a certain characteristic such as strength, ductility and electric resistance for a material. We then search the world of physics for wanted atoms and crystal structures that could do this trick, find out in which conformation they should be oriented in space, do computer simulations and if it works, and the wanted structure is engineered by rather precise methods. This is of course the ideal way of doing it and often far the real case. However, this way of thinking about materials and atoms as lego-pieces that can be built up in a way that we want them to, and engineer their exact behaviour is a really big step in human technical evolution. In this light, nanotechnologies should not be seen as a revolution into a new Internet or computer age, but rather be seen as a movement similar to that of moving from the stone age into the bronze age. Which implies a more profound evolution that stretch for hundreds of years into the future, with unimaginable social and economic consequences of which we have almost not yet even seen the beginning of. Because of the enormous demand for energy transformation and efficiency increases, it is probable that the energy sector will be one of the first industries that will be spearheaded by this revolution, and we will now look into some of these technologies that could be used for this purpose in more detail.

In 2006 world wide investments in nanotechnologies amounted to approximately USD 12.4 billion, spread almost evenly between the public and private sectors, where the United States leads the way in private investments, and the European Union outspend the rest of the world in public investments. Nanotechnology is seen by state actors as vital to increasing the competitiveness of their respective economies in everything from car manufacturing and life science to traditional industries such as construction and the textiles. The economic value of nanotechnology is leading the way for evermore investments in the field and much of the applications are not seen as direct technologies, but rather as enabling technologies that may lead to breakthroughs in diverse ranges of industries that is currently hard to predict and that we have yet to see the beginning of.

The market potential of nanotechnological solutions are therefore immense. Most of these early implementations are thought to take place early in the value added chain, with stronger and more durable materials more fit for their purpose. These materials may in turn provide actors further up in the value chain to produce new innovative application previously impossible prior to the introduction of new components and materials. It is estimated that over USD 40 billion can be saved worldwide in the short to medium run in the energy sector by implementing nanotechnologies that already exists today. Nanotechnology is also in the short run considered to have the greatest potential in reducing CO_2 emissions, by avoiding wasteful resource consumption and promote more efficient energy usage. [1] [6] [12]

Nanotechnologies will probably define the coming centuries as leading technological change in society, and could lead the way into a more environmentally sustainable civilisation. The fossil fuel age will probably not end because we run out of oil, just as the stone age did not end because we ran out of stones. But rather it will be a technology such as bonze in ancient times or nanotechnology in current times that will tip the balance into a better way of producing goods and services, and we will in the next section look into some of the currently available nanotechnologies that perhaps will spearhead this development.

4. Nanotechnologies

4.1 Surface layers and coatings

A certain application where nanotechnologies can make a real difference is in the coating of surfaces on ordinary materials in order to improve its properties. The surface of a material is the only place in where the material used for an application meets the outside world, the bulk of a material usually only provides structural support or works as a barrier or conductor for some type of energy. There are several uses for having nanostructures on a surface and some of them will be gone through in turn.

4.1.1 Hydrophobic surfaces

During the last few years a rather new technology have started to become commercialised, and it is the technology of hydrophobic surfaces. It is essentially surfaces that does not allow water to wet the surface or stick to it. If this is done, the surfaces do not have to be cleaned since the dirt are not sticking of the surface either. Plants have used this effect for a long time, and the usual example is that of lotus leaves seen in figure 4.1, which never becomes dirty. With the new microscopes scientist have been able to unlock the secrets of nature and implement the technique on man-made surfaces.

Figure 4.1 Lotus leafs, Source: Wiki/Lotus effect

Source: Smartgarmentpeople.com

Source: hk-phy.org

The key is to not get the water droplets to touch the surface so it can stick through van-der-Waal's forces, and it is possible to achieve this by constructing a rugged surface that consists of peaks and canyons. In between the peaks air will be trapped, and if the canyons are small enough; the surface tension will be to high for the water droplets to enter the valleys at all and will instead be forced to only move on top of the peaks. In essence the droplet rarely touch the surface at all, but rather travels on a cushion of air thereby limiting the interaction with the solid surface to only being a fraction of what it would be on an ordinary flat surface. Dirt particles and other pollutants will also mostly reside on top of the peaks, and since it is more energetically favourable for them to stick to the water droplet when it roles by than it is for it to stay put on the marginal surface of the material; it will cause the surface to be essentially self cleaning if exposed to water. The concept is shown in figure 4.2.

The level of hydrophobicity or wetting, has to do with the configuration of the surface as well as the properties of the layer material itself. Some materials such as teflon is for instance much less sticky than a piece of wood, but the main thing is to get the micro or nanostructure right in order for the material to becomes ultra-hydrophobic. What makes this so practical is that if such a rugged surface would be applied to glass of a building facade for instance, it would not have to be cleaned anytime but rater be taken care of by itself every time it rains. Concrete and other facades with a hydrophobic surface would not be able to be vandalised by spray-cans since the paint would just run off the surface, soot would not stick to facades etc.

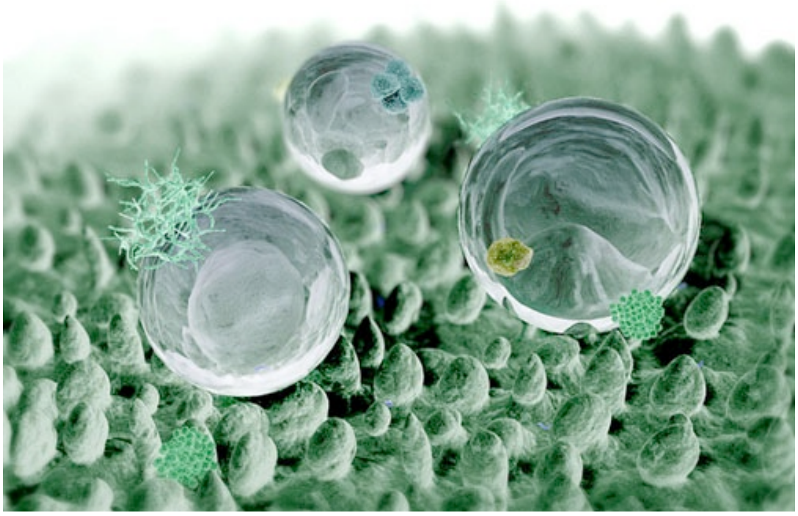


Figure 4.2, Conceptual Hydrophobic surface, where dirt is collected by the droplets rolling by. Source: balconette.co.uk

Another effect is that the resistance from the surface to a flow of a liquid becomes considerably lower than for a flat material, and could possibly be used to reduce the force required to move liquids in channels or tubes. This would have a positive energy efficiency impact on all systems that considers resistance in flows as a problem, the shipping industry would need less energy to propel ships forward through the water if the hull of the ship would be coated with a hydrophobic surface, pipes for pumping around heat would require less energy to move around the fluid etc.

As a mean of energy efficiency it could also applied to all energy producers that do not want high resistance on surfaces of filth on their machinery. In a hydropower plant, hydrophobic surfaces could be coated at surfaces where water is to be transported, reducing the resistance of the flow and thus saving more energy potential for the energy generation step. Other uses could potentially be found in wind energy and rotor blades, where the hydrophobic surfaces could prevent ice and frost to build up on the surfaces and lower the efficiency of the plant.

The technique has its limitations though, for water in gaseous form such as in a gas-turbine engine or boilers, hydrophobic surfaces would probably not yield a reduced pressure drop and resistance since the whole principle builds on the surface tension of liquids, that would be reduced to almost nothing when the water or other fluids are present in their gaseous form. Another problem is the degradation of the surfaces from wear and tear. Pollutants such as fats and other water insolvent fluids can also stick to the structure and make non-hydrophobic unless cleaned, and sufficient mechanical or chemical forces could possibly over time grind down the surface to the point that it acts no better towards fluids than a normal uncoated surface. There is not really an easy solution for this problem, besides using extremely tough nanomaterials such as reenforced or carbon nanotubes based materials that would potentially be unaffected by the shear-forces. Another solution is to shrink the hydrophobic pattern even further in the nanoscale, since smaller peaks would be both sturdier and less affected by drag forces. There are hydrophobic materials where the peaks are around 2 nm apart, and these are termed ultra-hydrophobic due to their almost non-existent wetting. Materials such as these are however yet seldom used for hydrophobic surfaces commercially, and since the materials used today are mostly silicon and micrometer sized patterns, one must be aware of the limitation and carefully calculate the durability based on the environmental stresses the material will be subjected to, before applying it to a certain technology. [6] [40] Figure 4.3 shows a man made hydrophobic material.

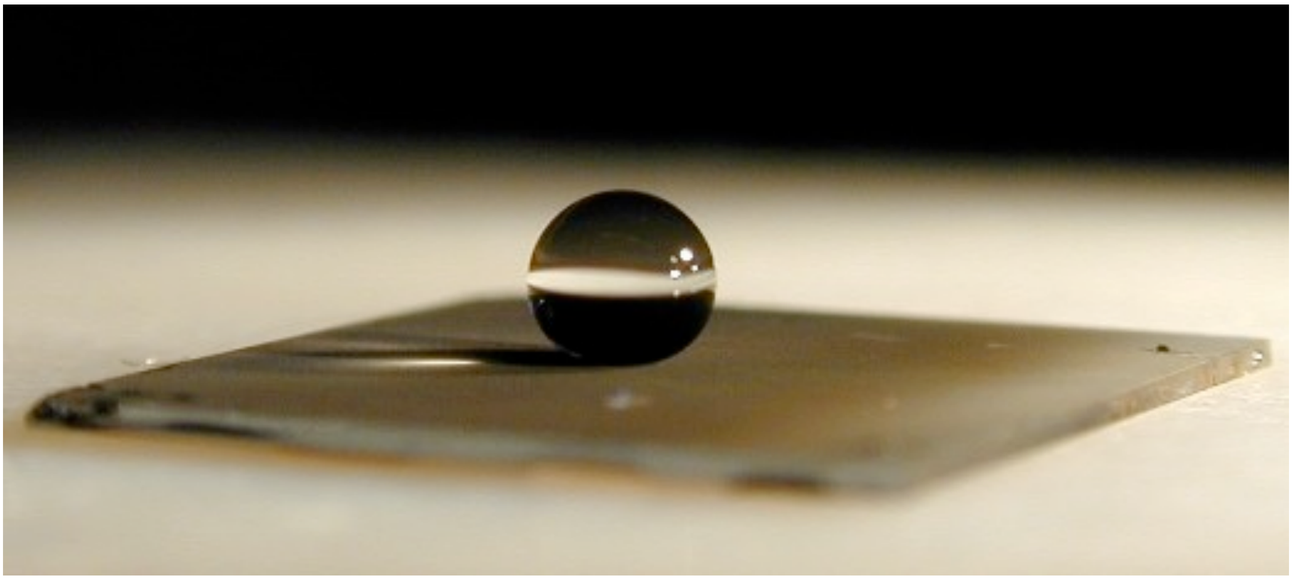


Figure 4.3 Man made hydrophobic surface, where the droplet almost not touching the surface of the material at all. Source: pmmh.espci.fr

4.1.2 Barrier coatings

Another application of nanomechanical coatings is that of using it as a barrier for physical of chemical purposes. Ordinary barrier materials can have some other property beside being a good barrier for a certain chemical or physical phenomena, it can for instance be very heavy or be brittle and weak or in other cases expensive. Physical and chemical phenomenas only react however with the surface of the material, and physical phenomenas such as electrical currents, heat or light usually experience their largest interaction at boundaries as well. By not using the bulk material as a barrier, but instead coat the surface with a a few nanometer thick layer, it is possible to obtain the barrier properties but use another material that have different properties in the bulk more fit to its purpose. An advantage of using nanometer thick surfaces is that the materials does not behave as when in a bulk form, a brittle material can for instance become very flexible, and light-blocking materials can become transparent. Another advantage is of course that very little materials have to be used, which is key for expensive substances. A quick calculation shows that the amount of material that have to be used for a 5 mm thick one square meter palladium barrier is around 60 kilo for a bulk material. In contrast a nano-layer palladium coating of 10 nm on a bulk material of different sort, will only use 0.2 grams while possibly retaining the same barrier characteristics, thus having a substantial impact on the materials that can economically be used for certain applications.

This reduction of used material to a millionth of the amount materials used for a slab, enables engineers to use more exotic and expensive materials such as palladium or gold if it would better suits their purpose without having to cope with the extreme costs, but still retain the same well suited physical properties of the material. The effect this might have on energy efficiency may not be obvious, but it will enable the usage of better materials that may yield better results than previously possible, which can reduce the amount of energy needed for certain applications. It may also provide longer life-spans for certain components, meaning less maintenance and inefficient shut down and power ups of machinery, as well as a reduced usage of expensive or limiting resources.

Some barriers could be used for simply blocking chemicals that have corrosive or etching properties, this could elongate the lifespan of components significantly depending on the application. Another very interesting usage is that of thermal barriers that insulate materials. This is currently used in industry today in for instance the turbine industry, but they have not used nano-coatings but rather coatings that is almost a millimetre thick or more. However, there is a possibility to use nanosized layers instead to achieve the same results but with better properties.

Another usage could be to block radiation or to provide electrical insulation. An interesting usage is that of thin fils that can be applied to glass surfaces such as windows to block out parts of the electromagnetic radiation that is not wanted, but let through other wave lengths. This is especially useful for blocking infrared or heat radiation, and letting through the visible light that illuminates the spaces. For industry and offices that needs to cool their buildings with air-condition or by active air circulation, nano-coated windows can significantly lower the energy usage of the facility by not letting the heat inside. [6] [13]

4.2 Crystalline structures and grains

Many materials order themselves on the atomic level into a crystalline form if given the opportunity since it yields the most stable thermodynamic structure. The definition of a crystal is that of a material that has a repetitive long range pattern, and will in a diffraction experiment give an ordered diffraction pattern. The atoms or molecules in a structure can order themselves into various crystalline forms, depending on the material and growth conditions. In the semiconductor industry it is essential to use crystals for building everything from memory chips to processors, since it gives a certainty and process-ability that would be impossible for amorphous materials. A few examples of crystalline structures is visualised in figure 4.4.

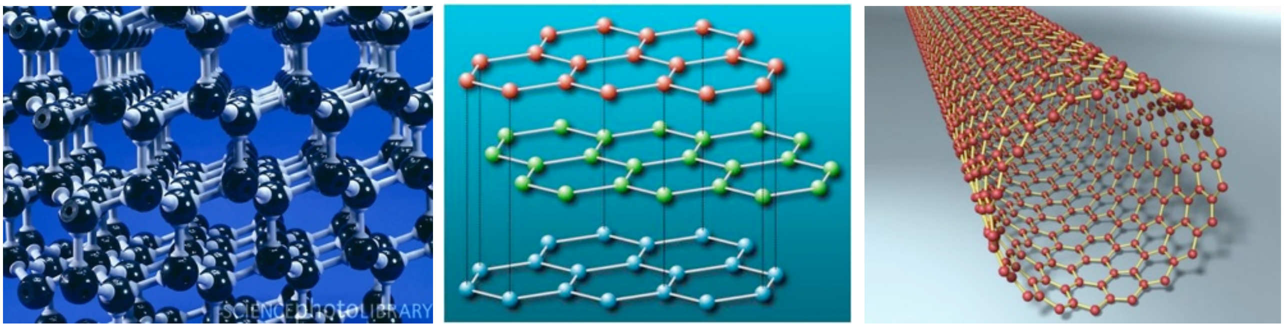


Figure 4.4 Diamond structure Source: Sciencephoto.com, Graphite structure, Source: Waikato University, Carbon nanotubes, Source: Tech-faq.com

The importance of crystals goes way beyond semiconductors though. The only difference between a piece of graphite that we use everyday for writing in pencils and a gem diamond is essentially only the crystal structure, but it makes a world of difference in electric, thermal and structural properties of the material. Both diamond and graphite comprises of carbon atoms, but graphite is a soft and black material while diamond is transparent and one of the strongest materials ever known to man. By using different crystalline structures for specific applications, it is possible to radically change the properties of the material and even the amount of energy that it takes to produce it. A common example is carbon nanotubes, which are essentially a sheet of graphite rolled up into a tubular structure. This material has a weight that is about a third of steel, but is around 200 times stronger. The reason for this lies in the difference in the nanostructure in the materials. A metal such as steel is not actually a single slab of material, but rather comprises of millions of small grains that are held together by van-der-Waals forces. The energy required to deform such a material is equivalent of moving the grains in relation to each other, and the amount of grain-boundaries will thus be the limiting factor of the materials strength. This has been taken note of, but it is now possible for metallurgists to produce a special kind of steel with a structure called bainite, which is about 4 times as strong as ordinary steel. The only difference between this material and ordinary steel is the way it is cooled, and the resulting sizes of the grains that is formed from it. Smaller grains amounts to more grain-boundaries, and a stronger material. In the case of a carbon nanotube however there are no grains and grain-boundaries since the structure is in the form of long pillars of carbon atoms. The only way to deform the structure besides bending it, is to break one of the carbon-carbon bonds that holds it together, which is a much harder and requires a lot more energy to achieve. In figure 4.5 the microstructure and grain boundaries of steel is shown, taken from a scanning electron microscope, as well as a conceptual picture of a carbon nanotube. Another interesting point about the rolled up structure of carbon nanotubes is that the depending on which way it is rolled up, it can either be an insulator or an conductor. The crystal direction also becomes important at surfaces, where some surfaces can be corroded away easily, while others may be much more resistant. [13] [6]

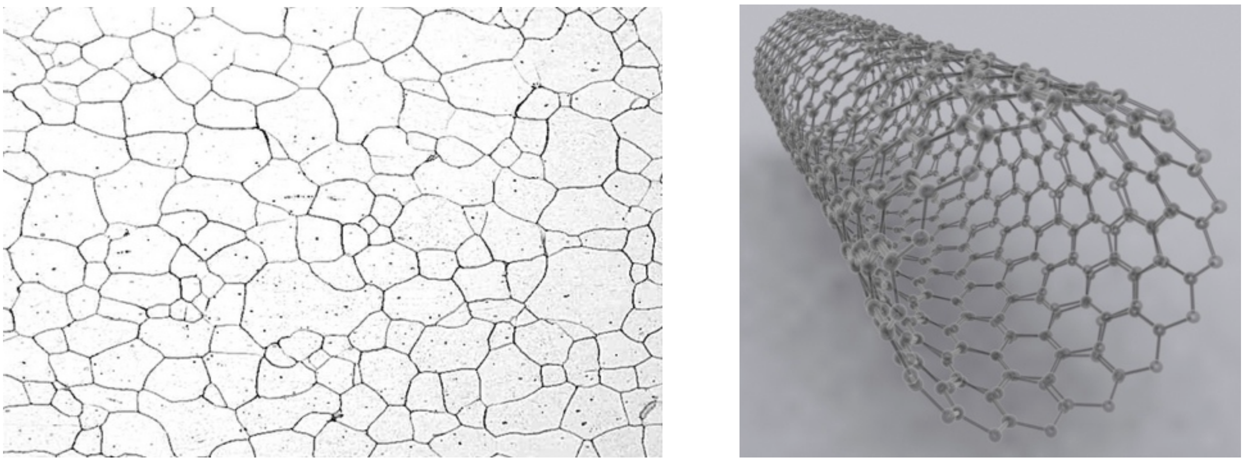


Figure 4.5. The Microstructure of steel with clearly visible grain-boundaries, and a conceptual picture of a carbon nanotube. Be aware that the cross section of the carbon nanotube is less than a thousand of the cross section of a normal grain boundery. Sources: Arcelormittal.com, Archimorph.wordpress.com

The usage of materials while taking into account their crystal structure is very important, and is already taken into account in today's engeneering. When building turbine blades for instance the crystal should be aligned in the direction of the centrifugal force, in order to get maximum performance out of the material. In the making of concrete which is responsible for around 10% of global CO_2 emissions, scientists at Massachusetts Institute of Technology, MIT, recently discovered a method that could drastically reduce the amount of energy required to make it while also increasing the toughness of the material, thus needing less of it. This was achieved by looking into the crystal structure of concrete in an electron microscope and by doing computer simulations to determine the exact structure that would yield the highest performance, which enabled the scientists to create a concrete from almost the same material components as in normal concrete but with a much higher energy efficiency with a much higher durability and with halved CO_2 emissions. [14]

By incorporating these kinds of materials in the construction of new housing and industry, the amount of energy input would be reduced at the same time as the lifespan of the construction would be increased and possibly yield a higher return on investment in the long run. Other components such as machinery and plumbing should also be looked at to possibility increase the strength and durability, while reducing the mass of the component. Less mass means less need for support and construction material. Less mass also means less energy to move around the components, with subsequently higher energy efficiency for all machinery and constructions using them. More durable materials also means a lot less replacements is needed, which yields an additional energy efficiency and economic incentive to the technologies. [6] [7]

4.3 Catalysts

A related technology to barrier coatings, is catalytic coatings. Just as with surface barriers catalytic interactions only takes place on the surface of materials, hence the catalytic component do not necessarily have to be very thick. If a certain mass is converted into a nano structural form instead of a bulk piece, the reactive surface can become several magnitudes larger. An example of this is the large surface area of zeolites or nonporous materials, where the surface area because of the internal cavities can be as large as 200 square meters per gram of material. A gram grain of the same material would only have a surface area smaller than a square millimetre or so. This have large implications for all industries that are involved in catalytic processes, such as in the refining industry where cracking is essential to make better use of crude oil. And since the surface area becomes so large at the same time as the amount of the material is substantially reduced, it is possible to use exotic, expensive materials with high catalytic efficiencies, that would otherwise be ruled out due to the large costs. Palladium can be one such example.

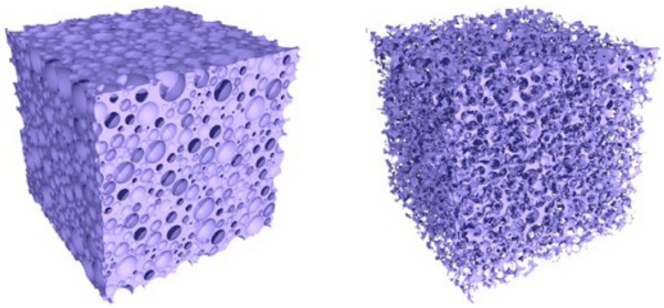


Figure 4.6, Nanoporous material with huge surface area. Source: http://www.ifw-dresden.de

By using an efficient catalyst, the energy efficiency of processes can be raised substantially. Nature itself use nanosized catalysts in the form of enzymes that are made of organic substances to perform almost all reactions being done in the cells. And since nature has an energy efficiency approaching 100% for its reactions, it may be a good idea to somehow try to replicate these techniques with nano-particles. This is currently being done, with nanometer thick films on combustion components as well as the usage of zeolites in catalytic processes in industry. However, there is plenty left to be done in this area, and the usage of nano catalysts have great potential of raising the energy efficiency of all processes in industry in the both the medium and the long run. Figure 4.6 shows two nano-porous materials, with a large surface areas. [6] [16] [17] [18]

5. Applications

5.1.1 Gas turbines and Coal fired Power plants

The conversion of fossil fuel into useful energy such as electricity, heat or kinetic energy by combustion is today the main source of energy for the world's economies. The efficiency of converting the stored chemical energy into electricity is much varying though. Coal-fired power plants around the globe have an average efficiency of round 30%, whereas the best modern plants today can boast efficiencies of over 45%. Gas-turbine power plants that uses oil or natural gas as feedstock can reach an even higher conversion ratio of over 60%. This is a enormous difference, and has had a profound impact of the economics as well as on the subsequential CO_2 emissions that are produced in the process. Estimates yields that a replacement of all the old inefficient coal-fired power plants into new ones, would reduce the world wide emissions of CO_2 with over 35%, as well as allow slower depletion of the dwindling resources with less harm to the environment from extraction as a bonus.

Further optimisation of this process would yield even higher returns, and since nature has set the standard approaching the thermodynamic limit for similar processes of reacting hydrocarbons with oxygen to create useful energy, this is really the limit we "should" aim for. In order to do this in today's power-plant designs there is a need to, in contrast to nature, raise the temperature of the operations in plants even more. There are already plans trying to raise the temperature in gas turbines to over 1600°C within 10 years to increase the efficiency to well over 60%. This would however mean extreme conditions for the materials that would be in contact with the gas, (aluminium melts already at 660°C as a reference) and would require new materials that are extremely heat resistant in conjunction with other wanted properties such as being light and strong. One way to do this is to use nano-inter-metallic compounds like aluminium-titanium alloys, coated with nanostructured thermal barrier layers for the gas turbine blades. Besides being very strong, they would be able to withstand extreme temperatures of operations without having a too low durability in order for them not to be economical. The formulas for stress-durability in metals are pretty straight forward, and a lowering of the temperature of 5 degrees may entail as much as a 15% increase in the lifetime for the component before it succumb to the forces and environment it's exposed to. [1]

To use nano thermal barriers on the surface of the turbine blades would provide a big leap forward for the industry. Thicker more crude versions of these have been used for a while and are indispensable in modern plants, since the metals of most turbine blades would melt already at 1500° C without them. To make the nano thermal barriers is however not straight forward; they need to have as low heat conductivity as possible, as well as having a thermal expansion coefficient close to that of the substrates in order to minimise tensions that could otherwise cause the layer to crack and eventually even fall of. Layers such as these can be applied to the surfaces by a multi-source plasma coating process or trough solid vapour deposition, and could contain both active and adhesive as well as barrier layers that is applied with nanometer precision to build up an optimal material combination for the wanted properties. Today a similar process is used on many turbine blades, but with the layer usually being of a single type of material, applied onto the surface that may contain an enriched alloy in the outermost layer. [41] This technique is for example used for aircraft engines, with ceramic layers of zirconium oxide, that together with efficient cooling systems for the blades allows for a lot higher temperatures and efficiencies than for what unprotected blades would have, which enables longer lifetimes for the components.

With nanometer sized coated layers that are applied with various material combinations. It would be feasible however to achieve a lot higher thermal efficiencies than with the current state of the art techniques. The durability of the components could be increased considerably, thus giving an added economic incentive for the process, as well as allowing for even higher temperatures than currently possible, which would enable higher energy efficiencies and the subsequently lower CO_2 emissions from the plants that are using them. Calculations approximates that around one million euros could be saved each year from an efficiency increase of one percent in a 400 MW gas and steam turbine power-plant, and since estimations yields that the efficiencies could be raised much more than that with the nano thermal barriers, an extrapolation for the industry as a whole would amounts to several billions euros in savings each year worldwide.

Thermal barriers systems such as these is built up of a base material that should consist of a lightweight alloy that have as high melting point as possible and it must also have high heat conductivity along its axial directions so it can release the heat that are unavoidably transferred to it, in aircraft engines titanium aluminides are used for this purpose. Applied on the base material is usually an adhesive layer, that besides making the thermal barrier stick, must be able to balance difference in thermal expansion coefficients of the base and the coating materials. The adhesive layer can also serve as an oxidation protective layer that prevents damage to the base material, with todays techniques it is usually achieved through the application of a Al_2O_3 layer, which serves as a reservoir of aluminium for possible oxidation and thus keeps the bulk aluminium of the base material matrix in place. On the top of this layer is the thermal barrier or barriers themselves that keeps the heat out. On top the outermost thermal layer it would also be possible to apply a layer a few nanometer thick for chemical protection as well as anti oxidative purposes, depending on the environment the turbine blades are supposed to work in. Another factor that needs to be taken into consideration is the thermomechanical gradient stresses that the materials are subjected to, due to shut-down and initiation processes, which can create cracks and failure of the layers if they are not taken into account. Besides these demands, the base material must also be able to handle the mechanical stresses that the shear pressure drop will cause in the turbine. A lot of research in this field is currently being conducted, and a hot topic is the search for test methods to determine the influence of the adhesion layer have on the life time of the components as a whole, which is key to develop more efficient material combinations. The purpose of the layers in not to keep the heat out indefinitely, since in a closed system it is just a matter of time before the core temperature of the blades will reach the same temperature as the outside environment. Because of this there needs to be efficient cooling along the axial direction of the blades in order to reduce the temperature of the components. The purpose of the thermal barriers layers is to reduce the heat-flux into the blade core, so that less heat needs to be transported away from the inside of the components. [1] [6]

5.1.2 Boilers

Another problem for the day to day operation in coal fired or incineration power plants of any sort face, is that residues from the combustion process is deposited on the inner walls of boilers or in heat exchangers; building up thick unwanted cakings on the walls which requires very costly and time consuming maintenance. It also reduces the efficiency of the plant, where the need for powering up and shutting down cause considerable losses in both energy and economic efficiencies. The solutions for this could be to coat the inside of the boilers with antiadhesive layers that is based on nano structured materials and principles that makes the soot unable to stick to the wall. Or even better, to act as a catalyst that break down and combust the soot whenever it comes in contact with the surface. This could significantly reduce the amount of cakings and the subsequent maintenance it requires, and should thus be able to increase the efficiency of the plants operation as a whole. Potentials for this kind of technology go well beyond boilers of power generations purposes though, and could have wider applications in many other industrial processes such as in heat exchangers, where encrustation can cause considerably lower thermal efficiency over time, among others. [1]

5.1.3 Carbon capture

Not directly energy efficiency but a related technology that could alleviate some of the environmental impact that most of our energy production has, is the capturing of greenhouse gases such as carbon dioxide. Carbon dioxide is largely recognised as the biggest contributor to the global warming, as well as a direct cause for other problems such as acidification of oceans and the potential devastation it could cause in many ecosystems. If the CO_2 could be separated from the exhaust gas of fossil fuel powered plants, it could be prevented to escape into the air and perhaps be pumped down underground in sealed sediment layers. The problem is however that the burning of fossil fuels usually produces almost equal amounts of CO_2 and water, and is mixed into ordinary air with oxygen, nitrogen and other gases. The separation of CO_2 from this mix is possible today, and there are a number of coal-fired pilot plants scattered around the globe that does so. But it entails energy efficiency losses for the plants of around 10% or more, which have very negative consequences for the economical viability of the plants. It also increases the amount of coal that needs to be extracted from the earth to produce the same amount of electricity as an ordinary plant, often leaving ugly scars in the landscape.

By using nano optimised membranes that can separate the CO_2 from the surrounding air, the inefficiency of this process could be reduced substantially. A method in trial is to use nanostructured polymer membranes with catalyst coatings on the surfaces, that can convert the CO_2 into hydrogen-carbonate if water is present on the surface. Hydrogen carbonate is a solid which takes up a lot less volume than the gas, and easily separates from the air for further storage. If this or other similar approaches is used, it would not increase the efficiency of plants per se, but would decrease the inefficiency from the carbon sequestering process. This could reduce the global warming and acidifying impacts of the fossil fuels powered plants to negligible levels in comparison with un-treated exhausts from plants. [1]

Working in tandem the nanotechnologies that would improve the energy efficiency and decrease the environmental impact of fossil fuel powered power plants as well as industry, could provide the lion's share of our efforts to build a more sustainable economic energy foundation. It would not be enough though, and there will eventually be a need for replacing them with other sources of energy in the long run. But in the meantime they could by rough estimations reduce our emission of CO_2 by at least half, which would have a huge impact on the energy equation and environmental impact on earths ecosystems. One thing that has to be remembered however when talking about more efficient plants, increasing the temperature in turbines or using thermoelectrics, is that nature has an energy efficiency in cells of converting hydrocarbons into useful energy just under a 100%. So harnessing the stored fossil energy in a similar fashion that we have been doing in more or less the same way for 200 years may not be the best way to go forward at all, and it is very likely the case to be that nanotechnology will open up new avenues of research that render these whole lines combustion technology completely obsolete and unnecessary in the long run. [6]

5.2.1 Heat flux and general energy consumption in buildings

The heating of buildings is one of the mayor areas of energy consumption in the world. In Britain around 60% of the electricity consumption per household is contributed to space heating, and with water heating included it amounts to over 82%. [19] The energy produced for this consumption can come from multiple sources with different environmental impact, but in either way; decreasing this large portion of energy intensive activity would have a drastic impact on the energy production requirements regardless of the origin.

To heat the air itself is never a problem, since you can quite easily get an 98% energy efficiency of that just by turning on your nearest incandescent light-bulb, the problem is rather to keep the heat inside the house and reduce the losses to the outside world. By using nano-porous materials as an insulate, it is possible to reduce these losses significantly. The idea behind insulation is to reduce the heat conductivity of a material, usually by trapping low conductive gases within a solid material such as a foam or fibrous matrix. By using an aerogel substance that consists of almost 99% pore-volume within a network of nanoparticles, almost the whole solid volume can be considered a gas, but with the added advantage that the gas cannot move around inside the matrix very easily because the pore chambers themselves are smaller than the mean free path of a gas particle, which means that the gas is not able to move and not to even out the heat difference through convection. And since the volume of the solid conductive, usually materials such as silicon dioxide, is almost negligible, the heat transfer through the material becomes similar to that of vacuum panels, with the advantage that there is no need to contain a fragile vacuum that can easily be disturbed by outside stresses. By using insulation such as this not much of the heat is able to get through, and the energy requirements for keeping buildings at a certain temperature can be reduced significantly. In Germany alone, almost 80% of all buildings do not reach up to the allowed anergy standards for new buildings, and requires as much as twice the amount of energy for heating. With the use of nano-porous materials or aerogels technology it would certainly be possible to reduce the energy requirement even more than to required standard, thus saving large additional amounts of energy. An added economical advantage is that since the insulative properties of the material is as good as it is, less than 50% of the volume of insulative material would have to be used while still maintaining the lower heat-fluxes. This means that the living space of an average house can be increased by several square meters, an extra area that otherwise can be very expensive and limited in certain regions, giving an extra incentive to the cost projection of the endeavour. The use of aerogels such as these is not only be limited to low temperature insulation, but carbon aerogels have also shown to allow stable insulation up to 3000°C. [1] [20]

5.2.2 Cooling

Another nano-technology that has great potential, addresses the other side of the temperature equation, namely; how to keep buildings cool in warmer climates. In the Middle east around 60-70% of the total energy usage goes towards cooling inside living areas[21], and even in the more economically evolved Singapore the amount of electricity in an average household that is used for cooling is still around 47% of the total usage [22]. Nanotechnologies can certainly help refrigeration and airconditioners to become more effective, but only up to a certain thermodynamic limit. An alternative however is to, just as in cold climates, insulate the building well to keep the heat out through the walls, but even more important is not to allow the intense heat-radiation to go into the buildings. Just as in greenhouses, glass windows are great at allowing the radiation in but not allowing the heat radiation to escape out. But since the sunlight is part a spectra of different electromagnetic wavelength, it is possible to create materials that only allow the visible wanted light in, while keeping other wavelengths that are only responsible for heating out. This is already being done with nano coatings applied on windows that only lets certain wavelengths to pass, and keeping out others. It is not possible however to keep all the heat out by this technique but it is totally passive, requiring no input of energy while used and would certainly reduce the amount of energy that is used for cooling the inside air. Another option is to use switchable glasses that turn opaque when switching on an voltage across it, which will prevent all wavelength from getting through properly. One of the methods for achieving this is made by using nanoparticles in the material such as Titanium dioxide that can react to an electric voltage, connected to chromgens that changes colour by reduction or oxidation. [23] The disadvantage is that this is an active solution, but may still be energetically favourable compared to to cooling the room by air conditioning and using transparent windows, or maintaining motorised light screens or curtains. And it offers the advantage of choosing between on and off depending on light conditions. [1] [24] Switchable glasses are shown in figure 5.2.

Figure 5.1, Switchable glasses, where the voltage is turned on in the second picture, rendering the glass opaque. Source: easybizchina.com

Several pilot studies of these technologies have been made but is not yet used commercially on a large scale, where economic viability is a main factor for it not having a large impact yet. There is however reason to believe that when the technologies mature, and the production volumes increases technologies such as these should be affordable and viable alternatives in a not to far out future. According to Frost & Sullivan, a market analysis's company, the share of insulative materials market that consists of private consumption is estimated to around 80% of the total market, suggesting that when the technologies has proven significant economic benefits, it may be the end consumers that leads the way in making the necessary retooling to decrease the energy consumption in this part of the economy. [1]

5.2.3 Lighting

Other technologies that shows real promise in decreasing the energy requirements for housing is in the use of more efficient lighting, and where Light Emitting Diodes (LEDs) based on nanotechnologies may very well lead the way. An ordinary LED lamp that is available today has an conversion efficiency of around ten times as much as an normal incandescent lightbulb, with an overall theoretical limit of many times more than that. The LED lamp also has the additional advantage of a much longer lifetime per component as well as being more robust, allowing for more uses and applications than other solutions. Since around 25% of all worldwide electricity usage is diverted to lighting and most lighting comes from either incandescent or fluorescence lighting, which are both much less efficient than LEDs, the amount of energy savings in the world for just replacing these technologies with nanotechnology already available today would yield a significant leap forward. LED lamps are unfortunately harder to make, and costs many times more in initial purchase price of conventional lamps, a cost that is however returned in a few years time in cheaper electricity bills, and is in fact a much cheaper option in the long run. [6] [16] [25]

5.3 Energy transfer and transmission

The problems with electricity as a medium for energy conversion is that when transferred over long distances, there can be substantial losses due to heat during the way. Another challenge is that the conversion at transformation stations from high voltage to a lower voltage, where there also can be some losses in energy. Investments in this area can yield quick payoffs to high end nano material solutions, and will probably be one of the first areas in the power industry where nanotechnology will be widely used. Other problems are that the power grids of today are not designed to the large amount of small energy suppliers of renewable energy that are already coming online, and is expected to increase as we move forward into the 21th century. To alleviate these problems, there are some interesting properties from the nano-realm that can be used. One of these is the technology of super conduction.

Superconductors have been known for quite a while, and can be described as when an electrical current experiences zero resistance in a cable. The first superconductors where made by cooling down different materials close to the absolute zero, or -260° C by liquid helium. This is however a rather expensive process and unpractical for large scale usage, but it still found its niche uses in superconductive magnets used in particle accelerate for instance. It was first thought that it would be impossible to have superconductors operating at higher temperatures according to theoretical models, but in the 70s some materials showed superconductive properties at temperatures almost a hundred degrees higher that the previously thought maximal. There is currently still no widely accepted model today that can explain how and why superconductor works. There are however theories backed up by experiments that have shown that the nanometer crystal structure of the materials is key for obtaining the superconductive properties. Cables made of yttrium-barium copper oxide that are superconductive have already been produced 600 meters long, but are a long way from being a viable economic and practical option for large scale application. They may however become increasingly useful in industry and power generation where high currents and voltages needs to be managed at shorter distances. The traditional problems for these kind of cables are that the production and deposition of all the layers is complicated and thus costly, and this has hampered the prospects for the technology. Nanotechnologies provide an interesting solution to these problems which allows for the control of the microstructure in a way that was previously impossible, and may provide the needed catalyst for supraconductive power transfer that can have a wider usage than today. Supraconductive magnets also have a great potential to be used for electric engines which are widely used in all sorts of industrial applications, and would yield an even higher efficiency rate than traditional electric motors that are still very high compared to competing technologies.

An alternative route to supraconductive energy transfer is to have a more manageable low loss energy transfer that do not need to be cooled at all, but has significantly lower losses than for traditional cables. The possibility to use carbon nanotubes infused in cables which have an extremely high conductivity would be a very attractive option, and could reduce losses for long haul power transfers significantly. The cost of bulk carbon nanotubes must however be lowered substantially in order for this to be an attractive economic option, with better production techniques than today.

Another usage for nanotechnologies in power transmission, is to insulate high voltage power lines. In Europe the voltage in power lines are usually below 400 kV, but in countries such as India and China with large populations centres and increasing industrial bases, operators would like to build high-voltage grids of up to 1500 kV. This creates a need for better insulation of the cables with the higher electrical and mechanical strains. By controlling the material design on the nanoscale enables the optimisation of the insulative properties by applying thin layers that block the electric voltage such as metal oxide powders that can prevent over voltages. The materials can also be constructed to adapt their properties in response to a certain condition such as temperature or mechanical stress, and adjust itself optimally to meet the demands. Materials such as these would also be of special interest when using high voltage underwater cables that are becoming evermore common in response to off-shore wind farms, where there is a need for a resilient highly insulated cable that beside having to deal with the harsh underwater conditions also needs to be economical in order to compete with traditional power generation facilities.

Other trends in the field is the increasing move towards smart grids; electrical power grids that adapt themselves to the consumption and production of electricity that is becoming evermore unpredictive with the introduction of more and more small scale production of renewable energy. To cope with the sporadic supply and demand situation, there are plans to make the grids themselves more responsive and include selfadjusting components that can respond to the fluctuations. To do this however smart components within the electric grid is needed and nanotechnology is keenly looked at as providing possible imbedded technologies within the grid itself, by providing nano sensors that can monitor and control the extremely complex system. Miniaturised magnetoresistive sensors created by magnetic nano layers, could for instance enable online metering of parameters in the grid, and give an input to operators unmatched by today's technologies. The liberalisation of the electricity market all over the world is also a driver of this trend, where transeuropean trade for instance places new demands on the grid in comparison to the old state run systems. The creation of the smart grids would also create stability and resistance against mass power outages, that can stall whole regions for days with enormous costs for the subjected economies. [25]

The increased use of renewables and a grid responsive to the fluctuation in consumption and production from sources could increase the energy efficiency of the system as a whole quite a lot, with lower uses of traditional sources when solar wind and other renewables are producing high outputs and increased uses of traditional sources at peak demand and when the wind is not blowing or the sun is not shining. The energy efficiency of the grid should be increased or at least become more environmentally friendly with less CO_2 emissions, if produced energy from renewables could be stored as well. The potential of nanotechnological solutions in these fields looks very bright. Lithium-ion-batteries are already providing energy storage to portable electronics and electric vehicles, and scientists are working hard to use nanotechnology to provide even better storage capacities with lower prices and with less scarce materials. The prospect for using them for storing the vast volumes of electrical energy that stationary power plants produce is however limited and it may be more economical and practical to convert the electricity into potential energy in the form of hydrogen in electrolysis, or simply just to pump water back up in water reservoirs used in hydro dams. [42]

The market for nano-optimised energy storage is estimated to grow from being worth around one billion USD 2007, to almost USD 5 Billion 2014, and will probably continue to experience fast growth in the years beyond that. If the technology becomes more economical electric storage could be applied to smart grids as well and would decrease the use of expensive and polluting sources at peak demand, thus making the system increasingly energy efficient and more environmentally benign. It may at least be used for remote regions and individual housing projects that produce its own electricity, and would make renewable energy more reliable and practical for those who produce it. [1] [16]

5.4 Catalysts

A catalyst is a material that can reduce the energy barrier in a reaction and therefore reduce the amount of heat needed for the reaction to take place. Catalysts also cause reactions to proceed at a faster pace. Nature is the expert on catalytic processes and their organic catalysts called enzymes can speed up reactions billions of times. It also makes reactions that we need several hundred degrees Celsius high to achieve what happens at room temperature next to thousands of other processes taking place at the same time without influencing it. The way nature does this is to use small nano particles with huge surface to volume area and which are specialised to catalyse a specific reaction. This has enabled nature to achieve an efficiency rate of almost a 100% in many of its reactions and if we could reach towards this target in our own Industrial processes, we would save quite a lot of energy. In basic metal and chemical production there are potential for huge savings in energy requirements by using nano catalysts to substitute or optimise energy intensive reaction steps. Over 80% of the products in the chemical industry are made with catalytic processes and by using of nano particles or nano-porous materials with increased surface areas that would allow for both higher reaction process yields and higher speeds, as well as a lot lower volumes of the catalyst that sometimes can be made out of quite costly materials such as palladium. An example of this is to use a special nano particle called a fullerene which is essentially a really short carbon nanotube. This particle have shown to be able to catalyse the production of styrene, which is a major chemical industrial component that is used in polymer synthesis, and have shown to increase the reaction yields significantly as well as decrease the temperature needed in the process thus lowering the energy demands. There have also been interests to manufacture ceramics with the help of nano scaled powders that would enable lower temperatures in the sintering process and save large amounts of energy. [1] [6] [16] [17]

Another method that can be used to decrease the energy-intensity of processes is to perform the reactions in miniaturised microreactors, where the large surface area of the small chambers enables efficient heating as well as large catalytic surfaces. By parallelisation of the process steps, it would be possible to achieve the large volumes needed in industry as well as lowering the input of energy in chemical production plants significantly. In the case of the petrochemical industry there is also an extensive need to crack hydrocarbon chains in the refining process to get more high value fuel out of the process and there is an interest from the industry to use nano porous catalyst with very high surface areas. The combustion of the fossil fuel itself in power plants is another area where nano catalysts could be used for a more clean burn with less improperly combusted fuels such as soot or carbon monoxide. In the automotive industry the use of exhaust gas catalyst, usually by using precious metals have been in use for quite a while, and it have lowered both energy consumption as well as releasing less harmful gases or particles into the environment. A further step would be to instead of burning the fuels in a reaction chamber, combining the reactants controlled in a nano membrane fuel cell. This would yield an even more efficient reaction of the fuels and without the toxic gases such as nitrogen oxides or carbon monoxide. The technique has been proven to work in cars but should also be applied at electrical power plants, that would increase the energy efficiency as well as lowering the environmental impact with less harmful emissions. To get this technology energy efficient it is imperative to use nano catalysts based on precious metals in the fuel cell. Since nano catalysts is used, the volume of precious metal becomes very small and does not become such as high cost factor as it otherwise would. [1] [18]

5.5 Light weight production materials

In general in all areas of industry, power production and residential housing; using materials that weighs less but still retain the same strength is always favourable from an energy efficiency standpoint. The less materials used, the less materials need to be extracted from the earth and refined at high temperatures. The less a material weighs, the less force and power is needed to lift or move it around and as a building material it will in turn need less support from other materials and can therefore reduce the amount of construction materials even more.

This is an area where nanotechnologies have a huge potential. Carbon nanotubes are 200 times as strong as steel, but weighs only a third of it. It might not be used as a bulk material for some time due to the high price, but it could definitely be used as an reenforcing agent in other bulk materials to increase their strength and thus reduce needed volumes for certain applications. Other lightweight construction materials that are made by controlling the nano structure can be found in metal matrixes or polymer-nano composites, where there are examples of fibre reinforced titanium and aluminium alloys with increased strength. [1] [7] [16]

6. The future of Nanotechnology and Energy Efficiency

6.1 Nanotechnology and the long term impacts for energy efficiency

The applications for nanoscience discussed in previous sections focused on technologies that are more or less already available on the market for implementation, but even greater promise for nanotechnology in terms of energy efficiency definitely lies in future developments.

6.2 Photovoltaics energy

The solar panels that we see today for most applications to produce electricity from the sun's radiation are based on silicon that are produced with similar manufacturing techniques to that of microchips, which makes them rather expensive. The energy efficiency of these silicon panels usually lies around 10%, meaning that 10% of the suns light energy that hits the panel is converted into useful electricity while the rest is reflected, transmitted or absorbed as heat. In nature plants with leafs only converts about 1% of the light energy into energy that the plant can use, so at a first glance it seems as if the 10% efficiency is rather high. It turns out though that the relatively low efficiency in plant is due to that the energy conversion molecule is not present at every single point on the surface, since there are other functions that plants needs to account for in the living system that it encompasses. At the energy conversion centre in the chlorophyl molecule however, the energy efficiency is as in most other cases in nature pretty close to a 100%. So once again nature has set the bar for what can be done, and there has recently been quite some progress in the field in teaching these levels. Satellites that orbit earth have solar panels with conversion efficiencies of around 40-50%, with multiple layer designs that can absorb broad spectra of wave-lengths. The problem with these is that they use extremely rare and exotic materials which makes them extremely expensive, and economically impossible to use for commercial purposes on earth.

Advances in nanotechnology may however make these expensive panels obsolete by replacing the rare materials used, with common materials using advanced nano structures instead. Proven concepts includes the use of multiple nano layers on top of each other of different materials with different band gaps that can absorb different wavelengths of light. These already have a conversion efficiency of over 19%, which is almost double the amount of current silicon wafers and should not be much more expensive to manufacture. There are however some issues concerning the lifetime of these that needs to be addressed. Other areas of research is the use of 3-5-material nano wires, which is 3-D structure where materials of different band gaps are incorporated in the axial direction of the wire. With the incorporation of quantum wells on the side of these structures, the efficacy rate could come close to that of satellite panels without using expensive or rare materials. [25]

Another line of research is the incorporation of nano structures into flexible and cheap materials such as polymers (plastics). OLED (Organic Light Emitting Diodes) as the technique is called when used as light sources, can be used inversely as solar panels when absorbing light and generate electricity instead as the other way around. The efficiency of these may not be much higher than that of ordinary silicon solar panels, but the inexpensiveness and the subsequent versatility of the material may give them an advantage over other techniques as they can be applied on almost all unused surfaces without having to worrying to much about the cost. It will also be possible to use these in a more design aware manner, where the polymers can have different colours, shape and finishes. [6] [26] [45]

The solar radiation on the earth surface is estimated to be on average around 1400-1750 kilowatt hour/m^2 each year on ground level at North european latitudes, with substantial differences during the course of the day as well as along the seasons. [27] The average German person consume just under 52 megawatt hours each year, measured as the total energy use of the country divided by the population and thus includes industry and all other commercial infrastructure and industry. [28] With an conversion efficiency of 20%, it would mean less than 170m^2 solar panels for every person in the country to cover the entire energy need of the nation. This may sound as quite a lot but is actually only a 13x13 meter of area, and considering all the rooftops of commercial buildings, residential housing, government buildings and industry; it would probably be able to supply quite a large part of the entire energy need for a rather large country.

Considering that the solar panels may be supplemented by wind, wave and biopower, it will not need to supply the whole energy need by itself and in conjunction with rising energy efficient appliances and housing, the average kilowatt hours needed for each person should be going down as the new energy infrastructure in being developed.

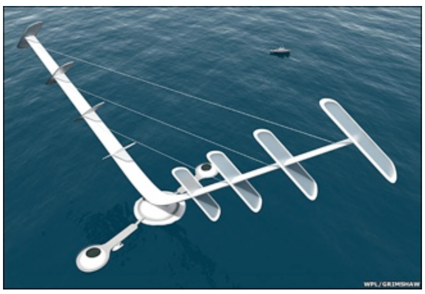
The energy conversion efficiency of the solar-panels using, multi-band gaps nanostructured materials with incorporated quantum dots, should also be able to raise the conversion efficiency to above 40-50% in the medium term and in the long run only nature should be seen as the upper limit. With these rates and if the panels can be produced with economical methods, the area of solar panel demand for each person should go down to half of the estimated or even lower and be able to supply a substantial part of the global energy demand, and would reduce the carbon footprint to next to nothing compared to the burning of fossil fuels. [45]

6.3 Wind power

Wind turbines is another energy harvesting technology that could greatly benefit from the usage of nano structures incorporated into different components of the plant. Wind power currently supplies less than a percent of the global energy demand, but in certain regions and countries the share of is much higher. In Denmark for instance wind power currently supplies over 20% of the electricity demand, and it is projected to rise as new undergoing investments and are coming online. In Germany wind energy already supplies 7% of the total electricity demand, and is estimated to rise substantially in the coming decades. The United Kingdom has long developed plans to build sea based wind power that should be able to supply 25% of the total energy needs within a decade or two. What makes wind power especially interesting is that it is environmentally benign compared to many other sources, and is a technology that has the potential to to supply a substantial part of the energy need of many countries.

The trend in the industry is to increase the size of the turbines to increase the efficiency, which places new demands on the materials used for the construction, and the lighter material that can be used; the better. If the maintenance can be reduced and the lifetime of each turbine can be increased, the competitiveness of the turbines can be raised ever further. The wind parks with most potential is the ones placed at sea, where wind usually is plentiful and there are less disturbance to the environment and the surrounding community. The stresses on the structure are however even greater than they are on land, and nano coated surfaces could provide a key advantage to make the technology even more attractive. A specific problem that needs to be addressed is the buildup of ice on the turbine blades at northern longitudes, which lowers the efficiency of the plants substantially. The application of nano structured hydrophobic materials that could repel the buildup of water droplets on the surface could be one way of dealing with it. Harnessing the wind as a power source should be able to greatly benefit of new advances in nanotechnology and will make them even more competitive in the future while lowering the environmental stresses on the planet with a much smaller carbon footprint. In the long run however it is hard to tell if the current system of harnessing the winds energy by building large rotor blades will be the most efficient one. Perhaps a nano structured net with micrometer size holes that harvests the energy like large sails will become much more efficient, with an enormous surface area and much more efficient energy conversion. Enabling nanotechnologies may prompt actors to move forward into whole new direction in an industry such as wind energy, and is it therefore hard to predict the long term effects it will have. At first it will probably be used to increase the efficiency of current structures, but in the long run it may be used replace them all together. [1] [29]

Traditional Wind-farm Source tonybaldry.co.uk,



Future Wind-farm Source: Windpowerninja.com

Nano Wind-farm. Source: archicentral.com

6.4 Thermoelectricity

REMOVED SETION

Thermoelectrics is a line technologies that converts the heat energy into electric energy by using the Seebeck effect, which can be described as when an electric voltage occurs naturally in a conducting material between two points with different temperatures. The effects is caused because the material wants to increase the entropy of the system by even out the thermodynamical differences between the two points.This is partially done by transferring heat from one point to the other, but can also be achieved by running a current between the two points in the material. This current can be harnessed and used to power other equipment in the form of electrical energy. The bigger the temperature difference, the larger is the energy that can be extracted from the system. There is however a substantial difference between the ratio of heat conducted versus the amount of voltage produced between different materials, and the problem is that most materials that are good at conducting electricity is also good at conducting heat, like metals for example. In order to produce electricity from the voltage, as small as possible heat conductivity is sought after, as well as a high as possible electricity conductor which in most cases may be looked at as a contradiction. The materials often used to achieve this are usually semiconducting compounds such as silicon or germanium alloys, which can yield and energy conversion ratio of up to 5-10% at temperature gradients of 700° and is today in use for niche applications. By using nano sized structures this rather low efficiency could possibly be increased considerably further, and thus allow for a far wider usage provided it may become economically competitive.

New thermoelectric designs based on nano structures can take advantage of the special properties that small sizes can provide. Of special interest is the use of materials that can operate at higher temperatures up to 1000°C such as coboltates. The heat in such a material is transferred by a energy form called phonons, which are scattered at surfaces and grain boundaries in materials. If the structure used to conduct the heat is smaller than the mean free path of the phonons, it will take a lot longer time for the phonons to reach across the whole length of the material without significantly effecting the electrical conductivity, thus allowing for higher efficiencies. One type of structure of interests is called nanowires showed in figure 5.1, which are small pillar-like structures with a diameter of around 70 nm or even smaller, which can be ”grown” on surfaces under special conditions. These are often made from 3-5 semiconductor materials such as gallium-arsenide, or indium-phosphide that resembles the characteristics of silicon, and can have such a low diameter to length ratios that they can be considered 1-dimensional structures. The efficiencies currently reached for these in the laboratory is not much higher than for traditional approaches, and the research is currently on the stage where they try to figure out what parameters that are important to make them work. Research suggests however that the efficiency of these wires in terms of thermoelectricity could reach at least 30% for each wire. This would provide a substantial increase over traditional thermoelectric devices, and could change the economics of the thermoelectrics quite a bit.[43] A similar line of research is being conducted into super-lattice structures of BiTe quantum dots, or even into the production of nanosized powers that will provide a huge increase of grain boundaries in the materials and therefore causes an increased phonon scattering that could yield the same results of heat conduction as in nanowires but perhaps with easier large scale production and with subsequently lower costs. [1]

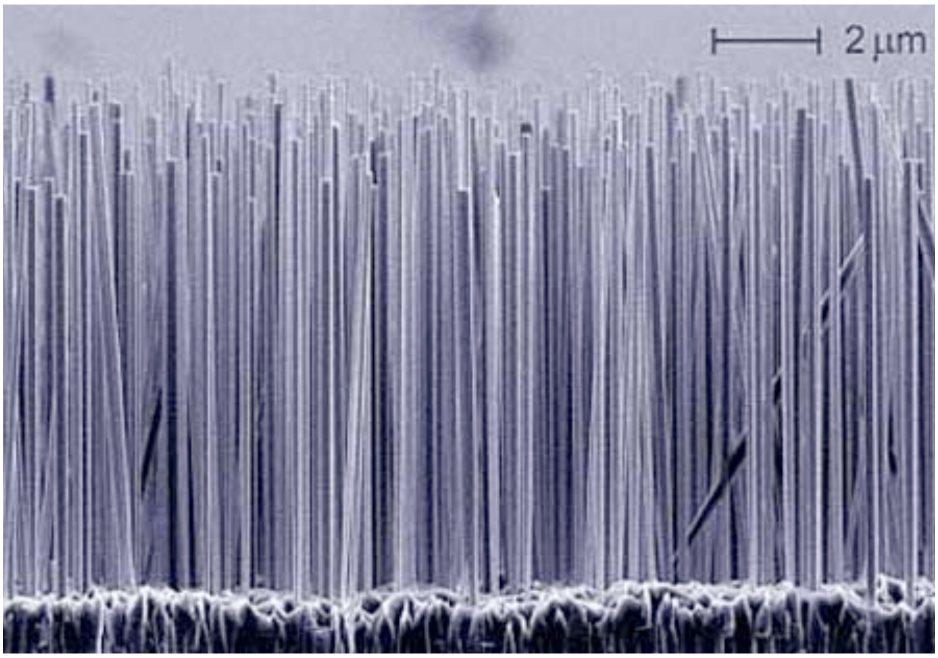


Figure 6.1, Quantum Nanowires, Source: www.scienceprog.com

Provided economical in nature, further increases in conversion efficiency of the thermoelectric materials would allow for a much broader use in industrial processes and applications where heat is generated as a byproduct. There are also other applications for the technology, such as reusing waste heat produced in cars, or even to harness heat from humans to power cell phones or other portable gadgets. The world market for thermoelectric energy today is estimated at almost USD 1 billion, and there is no reason why this should not increase substantially by the usage of nano solutions with increased efficiencies. Since about two thirds of the energy input in a combustion engine are lost to heat, the theoretical electricity generation in Germanys auto market alone could be as much as 10 Terrawatt hours each year, if all cars had generators that would harness 1kW of the heat energy. Which is a lot less than the potential output of several times that number. [1]

6.5 Energy storage

In order to implement the new nano enabled power generating plants into our current power supply there needs to be a way of storing the energy somehow, since we do not necessarily need the harvested energy at the exact same time as the wind blows or the sun shines. One way of doing this is to shut down traditional powerplants whenever renewables are plentiful and only use them at peak demand. Currently this setup works well, but if solar and wind would constitute a substantially larger part of the energy supply this would become a lot harder to compensate for. Another solution would be to store the electrical energy locally by converting the electricity into another energy form and use it whenever needed. One such energy form could be hydrogen split from oxygen in water at a inverted fuel cell.

Fuel cells are one of the most promising long term solutions for reducing the carbon footprint of the transport sector by producing electricity locally in the vehicle by controlled recombining of hydrogen and oxygen, producing no more waste than water and heat as a side-product. The problem with fuels cells is that in order to function, they need to have an effective membrane that separates the oxygen from the hydrogen while allowing ions to get through. This is not possible without using nanotechnology, since the size and charge distinction can only be made by considering the nanometer properties of the solutions. The problem of the application is also that the membrane which is extremely delicate must be able to work in harsh environments with temperatures ranging from -30°C to 100°C. It also has to be durable enough to last the lifetime of the vehicle, while being efficient enough to be environmentally friendly and economical in order to make it competitive. This means that not too exotic materials can be used, and if used should only be used as surface layers imbedded in nano structures that can enhance the ability of the bulk materials. A lot of research resources have already been allocated into this field, and there are already nanotechnology imbedded in the fuel cells used today. In the long run fuel cells should be able to become even more competitive with the use of enabling nanotechnologies, and it could become a real challenger to ordinary combustion of fossil fuel for usage in transport sector. Just as the fuel cells themselves become more efficient with nanotechnology, so will the reversed fuel cell processes of splitting water into hydrogen and oxygen. This could turn it a real alternative for stationary renewable power sources to use as a medium for energy storage and as a buffer for the power grid to deal with key demand. It would thus make renewable such as solar cells and wind power even more competitive and attractive, where locally produced power may be able to generate not only electricity and heat for the home but also fuel for the car and other appliances. Currently the energy efficiency of a fuel cell outcompete their combustion engine counterparts with at least twice the efficiency rates of 40-50%. There is also the added advantage that in the energy extracted is in the form of electricity which implies a lot less energy losses on the way to the point of usage. A drawback is however that there are losses in the water splitting process as well, so the energy efficiency of the system as a whole will be a lot lower, probably around 20-25% with current techniques. If this rate could be raised substantially by using nanotechnology the process could prove to become a vital part of the energy distribution system, serving as a buffer storage that can be used whenever the renewables do not provide the needed amounts of energy. This type of energy generation would also make it much more robust from external shocks, and would make nations much less dependent of dwindling foreign oil supplies or environmentally devastating coal power. [7] [26] [44]

6.6 The sky is the limit

The most important and fastest way that nanotechnology can help us to reduce or our energy hunger is however to help us make more efficiently use with what we already have. Be it to produce lighting with a 50% efficiency instead of 1-2% or desalinate water with reversed osmosis instead of evaporation, it could enable us to reduce our energy need drastically without reducing our quality of living. In the long run nanotechnology will also enable us to do things in ways that are currently unimaginable. There are however glimpses of this future already with futuristic concepts being churned out at research centres all across the globe. An example of this is a concept called Nano Vent-skin, where the exterior of a building is coated with a material that does not just collect the sun's energy to make electricity, but also have small pores that collects the winds energy while at the same time soaking up CO_2 from the air. Since the material would be quite delicate and subjected to rather harsh environments, it would of course be selfregenerating and heal any eventual damage it may be subjected to. The concept may sound like science fiction, but it could well be reality in a few decades, the technology is shown in figure 6.1.[30] Another concept that is similar is the use of a technology called proto cells, where manufactured DNA-less cells would form a structure and selfregenerate in order to keep its form. This technology could be used to build a house, and the material itself would keep it in working condition indefinitely with a premanufactured structure that would repair any damage that it is subjected to. This idea has been considered a serious alternative to be able to save the sinking city of Venice, where the proto cells would build up the deteriorating pillars that keeps the city from sinking into the mud floor. [15]

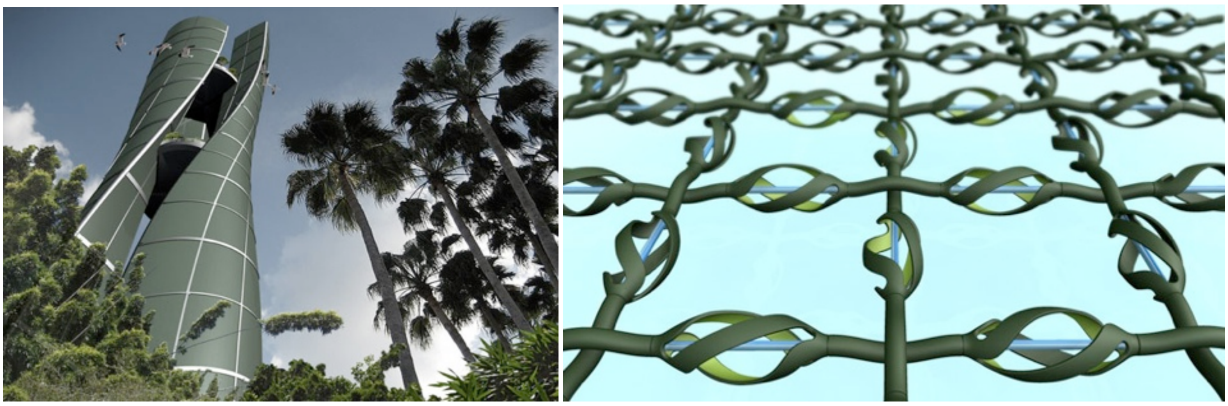


Figure 6.2, Nano vent-skin concept, where the buildings exterior is covered in a self-generating energy fabric that harvest sunlight and the wind. Source: inhabitat.com

Some of these ideas outrageous as they may seem, will probably be possible to implement within a few decades if nano technology continues to develop at the pace as it currently does. Moreover, there will probably be even more concepts that will be as commonplace as the internet today, but as impossible to envision beforehand as today's Google or Wikipedia was a few decades ago. Since there is a growing demand for new energy sources as well as higher energy efficiency, many of the areas where nanotechnology will be implemented will probably be in the energy sector.

6.7 Energy efficiency in the shorter term

As seen in the previous sections, there seems to be many areas where nanotechnology could be implemented already today to increase the energy efficiency of different applications and processes. Just raising the energy efficiency in traditional energy production facilities could possibly decrease the use of fossil fuels quite a lot, with the subsequent lower CO_2 emissions emitted into the atmosphere. One thing that we should have in mind however is that just because implementation of a certain nanotechnology or other technology for that matter would lower the CO_2 emissions and raise the energy efficiency, it doesn't necessarily implies that it would be wise to do so. In the long run; energy production forms that are based on the burning of fossil fuel will not have a legitimate place in the global energy system. There are numerous reasons for this, one being that the rising CO_2 levels seem to change the climate for the worse and destroys marine habitats by acidifying oceans. Another reason is simply the fact that it is an non renewable fuel, meaning simply that there is not an infinite amount of it and that it will slowly but steadily run out. Considering this, it may not actually be wise to spend resources to upgrade old and decrepit plants to better efficiency standards. It may instead be the case that investing these money into renewable power sources would prove a much more efficient investments in the medium and long run.

If however new plants are being built that use fossil fuels as their main source of energy, it is important that these are built with as high standard and energy efficiency as possible and in these areas nanotechnology should be able to help substantially. There are also other forms of combustion plants that work in much the same principle as coal or oil fired plants, but instead burns biomass or garbage in the case of incineration plants. These do not have the same environmental impact and does not use a non renewable resource, which means that they will be with us for some time and may actually prove to be a rather large part of the solution in the future of energy security. It is therefore important that these plants are made as efficiently as possible and the use of nanotechnological applications such as those presented in this theses could be a big part of it.

Commercial building and residential housing is an area where nanotechnology seems to be able to help out a lot. These are nothing that are optional and will be replaced by something else soon, but rather more or less permanent structures that once built, can be remained occupied in one form or another for hundreds of years. Since they consume such a substantial part of our energy demand, it is vital that they are build or upgraded to as high energy efficiency standard as possible. Another point with these kind of insulative technologies is that once implemented, they are more or less permanent features of the buildings and should not demand any high amounts of maintenance and does not consume any energy in themselves. This makes them really cost-efficient in the long run, but could be very expensive to implement for individuals in the short run. Since this may be the case and short term incentives could hamper the implementation of the technology, economic structures should be put in place by states that wish to promote their own long term development. In warmer climates; efficient and especially passive cooling systems should be put in place of the similar reasons and it could be beneficial for states to put up economic structures that promotes the implementation of these in order to promote long term prosperity and smooth out inefficient short term incentives.

The area where most of the short term promise for nanotechnology lies is however to make appliances such as lighting and combustion processes more efficient. The best kilowatt hour sold should be the negative kilowatt hour, which means selling solutions that reduce the wattage needed for achieving the same applications, as in previous examples economic structures should be set up by states to promote this. LED lamps for instance have life expectancies of around 100 000 hours but the initial purchasing price may be up to ten times the cost of other alternatives, which may call for states to intervene to ensure long term energy gains. There are already examples of governments taking charge and putting in place structures that addresses issues such as this, to achieve a more long term agenda. In the EU there is for instance an initiative to phase out incandescent lightbulbs altogether to make room for more energy efficient light sources, and similar initiatives could be put in place in order to force both consumers and producers to make more long term choices. The market of innovations and science should be given as much free room as possible to come up with the solutions to the problems, and governments should set up standards in energy efficiency and regulations to phase out unwanted technologies that harms the long term prosperity of the region involved.

7. Conclusion

7.1 How can nanoscience be used to raise the energy efficiency of established industrial technologies and in residential housing

By reviewing the literature concerning nanotechnology and the impact it may have on energy efficiency, it becomes quite clear that it will have a mayor impact in the future. Much of the impact will probably come in the form of enabling technologies that could be used to improve existing technologies that are already present today, such as heat-coatings for turbine blades or non sticking surfaces for boilers. Nanotechnology will not change the energy equation, but it will definitely make an impact on the economic and environmental nature of both renewable and non renewables energy sources. It will also be used to reduce their energy requirement for different applications, without suffering any loss of quality. This also applies for the use in residential housing, where passive isolation and smart windows could reduce the demand for energy substantially in many regions of the world.

I believe that the future of energy efficiency and nanotechnology will go hand in hand, where nanotechnology will be driven by the demand from the energy efficiency sector. It will become a technology that reduces the electricity need for consumers, and yields more kilowatt hours per input to the producer. Energy efficiency by using nanotechnology will definitely define that the coming decades on the technological frontier, and will help us to make the transfer into a more long term sustainable energy economy without global warming or excessive harm to the environment as a subsequent side effect.

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