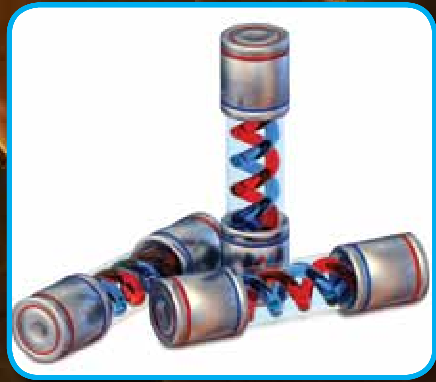

February 2011

Nanotechnology and Energy

NANOTECHNOLOGY
PUBLIC ENGAGEMENT

The Energy Challenge

The link between human activities, increased greenhouse gas (GHG) emissions and climate change was scientifically confirmed and agreed internationally in 2007. Since then, efforts to identify alternative energy sources have been heightened due to dwindling fossil fuels, and an anticipated increase in the demand for energy of more than 50% by 2025.

The Kyoto Protocol – an international, legally binding commitment by countries to lower their GHG emission levels according to agreed goals, is something of an incentive. Developing countries, including South Africa, which is ranked in the top 10 GHG polluters globally, are not legally bound under the Protocol to curb emissions. However, in December 2009 in Copenhagen at the 15th Conference of the Parties (COP 15), South Africa voluntarily committed to reducing emissions by 2020.

It is not the first time that alternatives have been sought: the energy crisis in the 1970s (OPEC oil embargo) forced countries to look elsewhere and develop alternative energy strategies, until the oil price dropped, resulting in global consumption tripling in the years that followed.

As a result, South Africa is exploring other energy options, both to meet the growing energy requirements whilst providing cleaner, cheaper alternatives to fossil fuels. It is intended that by 2018, of the total energy produced nationally, 5% would be from renewables, 20% from nuclear and 70% from coal (of which 30% would be based on clean coal technologies, where the harmful environmental effects can be reduced and the emissions contained).

One of the approaches being explored in many countries, including South Africa, to tackle this energy challenge is nanotechnology.

What is Nanotechnology?

Nanotechnology is the act of manipulating materials at very tiny scales (generally regarded as nanoscale) – essentially at the atomic and molecular size levels. When materials have one or more of their dimensions under 100 nanometres, the normal rules of physics and chemistry often no longer apply. As a result, many materials start to display unique and sometimes, surprising properties. The strength of nanomaterials, their ability to conduct electricity, and rate of reactivity increase dramatically. For example, silver shows increased anti–microbial properties, inert materials like platinum and gold become catalysts, and stable materials like aluminium become combustible. These newly discovered properties of nanoscale materials have opened up exciting fields of study and applications in areas that can improve the quality of human life in the fields of water and health.

NANOSCIENCE is the study and discovery of these properties.

NANOTECHNOLOGY is the use of these properties in special products and applications.

(Source: Manfred Scriba, CSIR)

What Can Nanotechnology Do?

Nanotechnology is often called an 'enabling' or 'refining' technology as it allows the specificity of existing technologies to be improved. A large part of nanotechnology focuses on nanofabrication, which involves manufacturing or engineering materials at the nanoscale, capitalizing on the novel properties seen at this scale. Changing the

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shape, structure and form of materials at this scale greatly impacts the characteristics of the final product, and thus the use. This is enabling materials to be engineered that are lighter, stronger, more durable, heat-, water- or fire-repellent, etc.

> *'It's a tantalizing idea: creating a material with ideal properties by customizing its atomic structure'.*
>
> Jennifer Kahn, 2006, National Geographic

Nanotechnology and the Energy Crisis

Nanotechnology, and in particular, nanofabrication, offers a variety of tools to contribute to solving the energy crisis, since creating materials and devices smaller than 100 nanometers (nm) offers new ways to capture, store, and transfer energy. The level of control that nanofabrication provides could help solve many of the problems that the world is facing related to the current generation of energy technologies, including the array of alternative, renewable energy approaches.

Nanotechnology is being used in various forms, including bulk materials with nano-scale characteristics, as well as various types of nanoparticles.

Nanotechnology and Energy Research

The sun is the primary source of energy on earth, and nanotechnology based applications are being developed to better harness this energy in various ways. Nanotechnology can be applied at every stage of the energy value chain, including:

Production and Conversion: The conversion of primary energy sources i.e. the sun into electricity, heat and kinetic energy can be made more efficient and environmentally friendly using nanotechnology. Producing electricity through the conversion of sunlight, known as solar photovoltaics (or solar cells), is a field where nanostructured materials and nanotechnology are contributing greatly. Successful research could result in a significant reduction of the manufacturing cost of these solar cells, and also improve efficiency. Cell types being investigated include thin-layer solar cells, dye solar cells or polymer solar cells. The use of a layer of quantum dots - tiny blobs of one semiconductor grown on the surface of another, added behind the conventional multi-layer compound, is also being investigated. It is anticipated that nanotechnology will help develop the ideal solar cell, incorporating optimum structure and design.

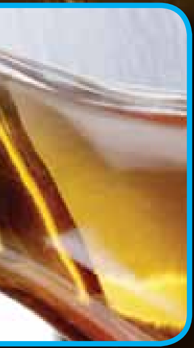
Nanofabrication of materials is also being used in other energy conversion processes where specific, extreme conditions need to be withstood, such as heat resistant turbine materials. Coal fired power stations can also be made more environmentally friendly using nano-optimised membranes, which separate out and store the carbon dioxide. Thermoelectric energy conversion using nanostructured semiconductors promises increases in efficiency that could pave the way for a broad application in the utilisation of waste heat, e.g. from car or human body heat for portable electronics in textiles. Hydrogen fuel cell technology is another area where nanotechnology can be applied to improve efficiency.

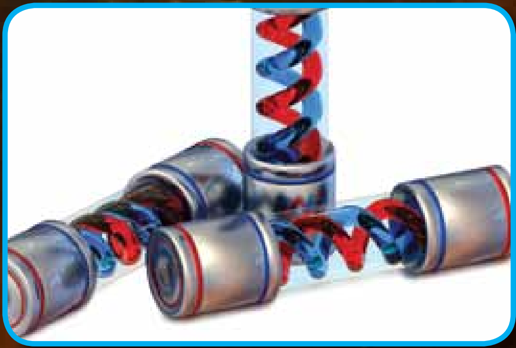
Other renewable energy sources are also being 'improved' using nanotechnology including: wind energy, using lighter, more durable nano-based materials for rotor blades; geothermal, using nano-coatings and composites for wear-resistant drilling equipment; hydro/tidal power, using nano-coatings for corrosion protection, and biomass energy ('biofuels') using nano-based precision farming to optimise yields.

Energy Storage: Energy storage devices can be significantly enhanced by the application of nanotechnology – batteries and super-capacitors in particular. Batteries are needed to supply electrical energy when not connected to the electricity grid, such as is used for mobile phones. Materials can be engineered using nanotechnology to make the relevant components of lithium-ion batteries heat resistant, flexible, and high-performance electrodes. Thermal energy storage could also be better exploited using nano-porous materials like zeolites, which could be used as heat stores in both residential and industry grids.

Energy Distribution: Nanotechnology can help reduce the extreme losses experienced when power is distributed. The extraordinary electric conductivity of nanoparticles, such as carbon nanotubes, can be applied in the manufacture of electricity cables and power lines. Nanotechnology also has application in the development of wireless energy transport (laser or microwaves).

Energy Usage: Increased efficiency in energy usage and reduction in unnecessary consumption could also be enabled by nanotechnology, and contribute to a sustainable energy supply. Nanofabrication can ensure that materials are optimally suited to their task, whether they be wear resistant, lightweight, anti-corrosive, etc, impacting everything from building and construction technology, insulation and lighting to optimised fuel combustion.





Benefits of Nano-energy

Reduced energy consumption – By optimising/increasing efficiency in energy storage, generation and conservation, energy consumption will decrease through nanotechnology applications.

Environmentally friendly – Nanotechnology can contribute to 'cleaning' up and reducing the environmental impact throughout the value chain of the energy sector.

Cheaper – The use of nanotechnology can reduce the cost of energy production, distribution and storage, since it has the advantage of reducing the amount of materials used without compromising the expected power outputs. Through miniaturisation, nanotechnology also provides an opportunity to tailor-make solutions.

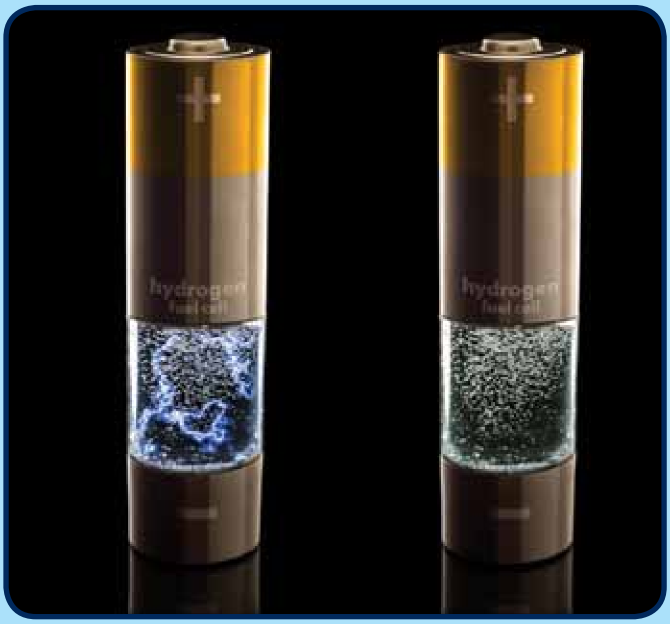
Independent power sources – The application of nanotechnology in the energy sector could contribute to providing alternative sources of energy to the national grid.

Facilitate transition to renewables – The application of nanotechnology in the energy sector could facilitate the transition from fossil fuels to renewable energy.

South Africa and Nanotechnology

Nanotechnology has been embedded in South African strategy and policy since the publication of the White Paper on Science and Technology in 1996, culminating in the National Nanotechnology Strategy (NNS) launched in 2007. This was followed by a Ten–Year Research Plan on Nanoscience and Nanotechnology published in 2010 as a road map to support successful implementation of the NNS. In addition to the commitment to long term nanoscience research, the strategy focuses significantly on developing the human capacity and infrastructure required to develop the sector and stimulate links between research and industry.

Energy is one of six focus areas highlighted in the NNS where nanotechnology can offer the most significant benefits for South Africa. To date, through the Department of Science and Technology (DST), the government has invested over R170 million in different aspects of nanotechnology research and development (R&D). Two Nanotechnology Innovation Centres, at the Council for Scientific and Industrial Research (CSIR) and at Mintek, have been commissioned and have formed collaborative partnerships with industry, universities and other bodies to conduct cutting-edge research.



Hydrogen and Fuel Cell Technologies

The hydrogen economy is undergoing serious consideration in South Africa, in an effort to develop safe, clean and reliable alternative energy sources to fossil fuels. Hydrogen is an energy carrier and is used to store and distribute energy and can be combined with the use of fuel cell technologies to produce electricity.

Invented about 150 years ago, fuel cells directly convert chemical energy into electrical energy in a clean, environmentally friendly way, with no harmful carbon dioxide (CO_2) emissions at the point of use. Converting hydrogen gas to electricity in fuel cells does not destroy the hydrogen, but reacts with oxygen to give water. Hydrogen can be produced from any hydrocarbon compounds, including fossil fuels, but the emphasis in South Africa is upon developing hydrogen from renewable energy sources in the long term. Fuel cell technology is more efficient, reliable, quieter and compact, and if the hydrogen used is from a renewable source, this technology is also cleaner and better for the environment.

The nanotechnology component of fuel cells is contained within the membranes which allow hydrogen ions to pass through the cell whilst blocking the flow of other atoms or ions, such as oxygen. The nanofabrication of these membranes is enabling more efficient membranes to be manufactured, making them lighter and longer lasting. This, in turn, makes the resulting fuel cell smaller, lighter, more durable and less expensive to produce.

Another driving force behind this technology is the prevalence of platinum reserves found in South Africa. Platinum group metals (PGMs) are the key catalytic materials used in most fuel cells, and with more than 75% of the world's known platinum reserves found within South African borders, there is great potential for socio-economic benefits to be obtained from these natural resources.

In South Africa, the interest in hydrogen fuel cells falls within the DST's grand challenge on energy security, under the National Hydrogen and Fuel Cell Technologies Research, Development and Innovation strategy, branded as Hydrogen South Africa (HySA) in 2008. HySA aims to position the country to drive and optimise local benefits from supplying high value-added products (i.e. PGMs) to the potentially increasing international markets. Three Centres of Competence (CoCs) have been established by DST to implement the HySA strategy. Potential products being championed by the CoCs include a portable power source for use as a back-up power source as a quieter and cleaner alternative to generators; a combined heat and power (CHP) source based on fuel cells, to supply decentralised power and heating for buildings and industries; and a fuel cell powered vehicles that could provide another alternative to hybrid and pure electric vehicles.

Risks of Nanotechnology

Nanotechnology risk assessment research for establishing the potential impacts of nanoparticles on human health and the environment is crucial to aid in balancing the technology's benefits and potential unintended consequences. Scientific authorities acknowledge this as a massive challenge, since monitoring the huge volume of diverse nanoparticles being produced and used and their consequent impact is very difficult to track.

In South Africa, a research platform is currently being established by DST to investigate the environmental, safety and health related aspects of nanotechnology. Other initiatives include the establishment of the Ethics Committee constituted by the government, made up of representative stakeholders to ensure that the technology adheres to the ethical issues.

Regulation of Nanotechnology

Although nanotechnology must adhere to general standards such as those set out by the South African Bureau of Standards (SABS) for materials and the Medicines Control Council (MCC) for medicines, nanotechnology regulations in South Africa are currently still being developed. This delay is mainly due to the relative infancy of this emerging technology, and the lack of evidence and scientific data to demonstrate the impact of products already in use. This also accounts for the relatively 'loose' regulations that have been developed around the world (Canada, the USA, Japan and the European Union). It is likely that these regulations will be modified and 'tightened' accordingly as new data becomes available.

It is important that nanotechnology is developed in a safe, responsible, acceptable, and sustainable manner. For this to happen, the entire life cycle of nanoparticles needs to be carefully considered from production to disposal, to allow an informed assessment of the potential human heath and environmental impacts. Risk assessment of nanotechnology is currently starting at several universities and science councils in South Africa – and is expected to become an integral part of the nanotech-nology research in this country.

Key Issues

Other issues to be considered include:

Net energy gains: The manufacturing of nanomaterials is energy intensive with environmental impacts. Are the energy savings through the increased efficiency, etc enough to result in a net energy gain or cost? Will it save energy or not?

Timing: How far along is the research and how long will it take to integrate all the various nano-enabled enhancements?

Who benefits? Will the benefits of applying nanotechnology along the energy value chain i.e. reduced cost and increased efficiency be seen/felt by the consumer or will these be off-set by the high R&D costs associated with the technology?

Promise versus reality: How much of what is being promised to the energy sector will be delivered? What role does political will play in the ultimate contribution nanotechnology can make to sustainable energy supply?

Health and environmental risks: Much is still unknown about the effects of nanoparticles, which are non-biodegradable, on human and health and the environment.

The Nanotechnology Public Engagement Programme (NPEP) is an initiative funded by the Department of Science and Technology (DST) and implemented by the South African Agency for Science and Technology Advancement (SAASTA), a business unit of the National Research Foundation (NRF). Launched in early 2008, the NPEP aims to promote credible, fact-based understanding of nanotechnology through awareness, dialogue and education to enable informed decision making on nanotechnology innovations to improve the quality of life.

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