CONTEMPORARY RESEARCH IN INDIA
ISSN 2231 - 2137

NANOTECHNOLOGY IN ENERGY STORAGE

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Received: 24/02/2018	Edited: 02/03/2018	Accepted: 08/03/2018

Abstract: *The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled "There's Plenty of Room at the Bottom" by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology on 29 December 1959 (Fenyman 1960), long before the term nanotechnology was used. Nanotechnology is a multidisciplinary as well as an interdisciplinary area of inquiry and application.The development of nanotechnology in India has been mainly conceived and continued on the premise that this new and emerging technology has huge potential to help the country address societal challenges.*

This paper is an attempts to capture the use of nanotechnology in energy storage by highlighting the various initiatives undertaken by the government to promote basic R&D in it, the major actors involved and the state of regulatory framework existing in the country. It also looks into these aspects vis-à-vis certain global initiatives/trends.

Keywords: *Nanotechnology, energy storage, Global trends, low cost.*

"We missed the semiconductor revolution in the early 1950s. We had just gained independence. But with nanoscience and technology, we can certainly be on an equal footing with the rest of the world"

- ***Prof CNR Rao, 2006***

Introduction:

Nanotechnology represents the study of the control of matter on an atomic and molecular scale. Nanotechnologies describe the creation, analysis and application of structures, molecular materials, inner interfaces and surfaces with at least one critical dimension or with manufacturing tolerances (typically) below 100 nanometers. The decisive factor is that new functionalities and properties resulting from the nanoscalability of system components are used for the improvement of existing products or the development of new products and application options. Such new effects and possibilities are predominantly based on the ratio of surface-to-volume atoms and on the quantum-mechanical behavior of the elements of the material. Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology involves imaging, measuring, modelling, and manipulating matter at this length scale. US: National Nanotechnology Initiative (2001) Nanotechnology is an interdisciplinary S&T that encompasses IT technology, the environmental sciences, life sciences, material sciences, etc. It is for controlling and handling atoms and molecules in the order of nano (1/1 000 000 000) meter, enabling discovery of new fuctions by taking advantage of its material characteristics unique to nano size, so that it can bring technological innovation in various fields. Japan: Second Science and Technology Basic Plan (2001-2005)

Nanotechnology Global Trends:

Nanotechnologies provide the potential to enhance energy efficiency across all branches of industry and to economically leverage renewable energy production through new technological solutions and optimized production technologies. The National Nanotechnology Initiative launched by US Government in 2001 as a mission mode multi-agency programme was a very well articulated programme providing a roadmap/vision for development of this area in different sectors with an underlying belief that this technology will create US leadership in different industries. Strongly influenced by the US model, different countries started dedicated programs with liberal public funding support. Some visible outcomes of global investment in nanotechnology can be seen. Huge investment provided the impetus to create advanced instruments for engineering nano-materials. The below provides an overview of the nanotechnology initiatives by some developed and emerging economies

Country	Key coordinating Body	Nanotechnology Initiative (Yearof Commencement)	Funding	Key Areas
US	Multiagency Governance at Various Levels. Command and Control Mode. Nanoscale Science Engineering and Technology Subcommittee	National Nanotechnology Initiative (2000)	USD 1.5 billion in 2009	All aspects of nanotechnology
Japan	No Specific Coordinating Body	The Atom Technology Program (1992) Nanotechnology and Materials Program (2001)	USD 250 million	Nano-electronics, nanomaterials
South Korea	Ministry of Education, Science and Technology, Ministry of Knowledge Economy	Korean National Nanotechnology Initiative (KNNI), 2001-05 (Phase I), 2006-10 9Phase II	2001- 10 USD 2 billion	ICT applications, e.g. high density memory, displays
Taiwan	National Science Council, Department of Industrial Technology	Taiwanese National Nanotechnology Program 2003 (Phase I), 2009-14 (Phase II)	USD 550 million USD 685 million.	ICT applications primarily opto-electronics
China	National Steering Committee for Nanoscience and Nanotechnology	National Steering Committee for Nanoscience and Nanotechnology (2000)	2001-05 USD 250-300 million. 2006-10 USD 760 million.	Nanomaterials, and ICT applications
India	Multi-agency DST (Initiation & implementation of NSTI & Nano Mission) DIT, DBT, CSIR, DRDO, ICMR, ISRO, DAE	Nano Science and Technology Initiative (2001-06) Nano Mission (2007-12) DIT Nanoelectronics initiative 2004 onwards	USD 16 million (NSTI) USD 250 million (Nano Mission)*	Nanomaterials, biomedical, electronics, energy (solar), water

Nanotechnology: System Overview

The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled "There's Plenty of Room at the Bottom" by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology on 29 December 1959 (Fenyman 1960), long before the term nanotechnology was used. In his talk, Feynman described a process in which scientists would be able to manipulate and control individual atoms and molecules. Over a decade later, in his explorations of ultra precision machining, Prof. Norio Taniguchi coined the term nanotechnology (Taniguchi 1974). It wasn't until 1981, with the development of the scanning tunneling microscope that could aid in viewing individual atoms that modern nanotechnology began. Eric Drexler expanded Taniguchi's definition and popularised nanotechnology in his book Engines of Creation: The Coming Era of Nanotechnology (Drexler 1986). Nanotechnology offers, for the first time, tools to develop new industries based on cost-effective and cost-efficient economies, thus seriously contributing to a sustainable economic growth. Nanotechnology is a broad term tipically used to describe materials and phenomena at nanoscale, i.e., on the scale of 1 billionth to several tens of billionths of a meter.

Nontechnology

Evolution of Nanotechnology in India

The development of nanotechnology in India has been mainly conceived and continued on the premise that this new and emerging technology has huge potential to help the country address societal challenges such as provision of drinking water, healthcare, etc., and simultaneously achieve economic gains through growth in the nanotech-based industrial sector. The 9th Five-Year Plan (1998-2002) had mentioned for the first time that national facilities and core groups were set up to promote research in frontier areas of S&T which included superconductivity, robotics, neurosciences and carbon and nano materials. In 2001-2002, the DST set up an Expert Group on "Nanomaterials: Science and Devices". The Government identified the need to initiate a Nanomaterials Science and Technology Mission (NSTM) in the 10th Five Year Plan (2002-07) after taking into consideration the developments in nanotechnology. A strategy paper was evolved for supporting on a long-term basis both basic research and application oriented programmes in nanomaterials (DST 2001).The Tenth Five Year Plan (2002-2007) document identified various areas for mission mode programmes.

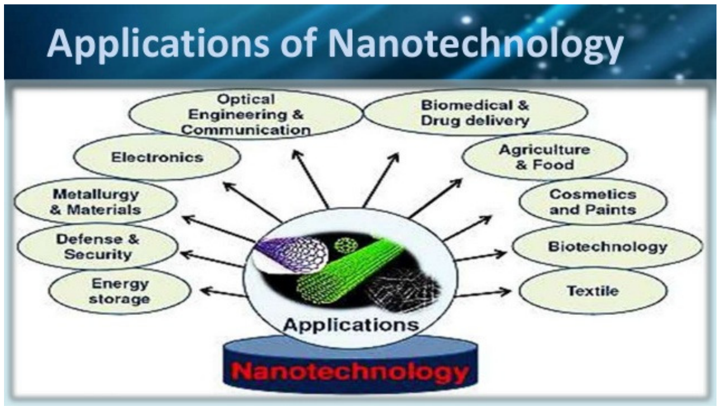
The Eleventh Five-Year Plan (2007-2012) categorically mentioned projects to create high value and large impact on socio-economic delivery involving nano material and nano devices in health and disease. The generous Eleventh Five Year Plan Budget allocation of Rs. 1000 crore was earmarked for the Nano Mission when it was launched in 2007 (GOI, 2007).In the Twelfth Five Year Plan (2012-2017) too, the government gave its approval for continuation of the Mission on Nano Science and Technology (Nano Mission) in its Phase-II at a total cost of Rs. 650 crore. The Nano Mission, in this new phase, would make greater effort to promote application-oriented R&D so that some useful products, processes and technologies also emerge. It will continue to be anchored in the Department of Science and Technology and steered by a Nano Mission Council chaired by an eminent scientist (PIB 2014).Expenditure on Nanotechnology R&D by Various Stakeholders (2001-2012) is given below

Stakeholders	R&D Expenditure in Nanoscience and Technology (in Rupees Crores)
Department of Science and Technology	567.55 (NSTI 60; Nano Mission 507.55)
Department of Information Technology	326.63
Central Manufacturing Technology Institute	67.23
Indian Council of Agricultural Research	10.18
Council of Scientific and Industrial Research	0.78

Note:: 100 crore ≈ 27 million USD; The total reported expenditure is 973.37 crores. Besides this other agencies including industries have also made expenditure for which figures are not available at this stage.

Areas where nanotechnology is used

Today, a life without nanotechnology is hard to imagine. Nanotechnologies to be more specific: nanomaterials are already used in numerous products and industrial applications. Our Nanotechnology Products and Applications database already provides an overview of how nanomaterials and nanostructuring applications are used today in industrial and commercial appplications across industries



Energy sources:

Nanotechnologies provide essential improvement potentials for the development of both conventional energy sources (fossil and nuclear fuels) and renewable energy sources like geothermal energy, sun, wind, water, tides or biomass. Nano-coated, wear resistant drill probes, for example, allow the optimization of lifespan and efficiency of systems for the development of oil and natural gas deposits or geothermal energy and thus the saving of costs. Further examples are high-duty nanomaterials for lighter and more rugged rotor blades of wind and tidepower plants as well as wear and corrosion protection layers for mechanically stressed components (bearings, gear boxes, etc.). Nanotechnologies will play a decisive role in particular in the intensified use of solar energy through photovoltaic systems. In case of conventional crystalline silicon solar cells, for instance, increases in efficiency are achievable by antireflection layers for higher light yield.

Nanotechnology: Energy Storage:

Nanotechnology is the science of microengineering. Microengineering is the science of engineering that deals with particle manipulation if those particles are smaller than 100 nanometers. Atomic and molecular manipulation is the essential core of nanotechnology. This science is used to create applicable particles. Any introduction to nanotechnology is likely to be a bit hard to grasp on a rational level for those who like to deal in the concrete. However, it should be stated that one can visualize the concrete from the results of the particle manipulation. It is often the basics of our everyday materials. Nanotechnology not only helps make the application process faster and cleaner, but it also provides for smaller particles that coat the skin better which provides much better sunscreen protection.

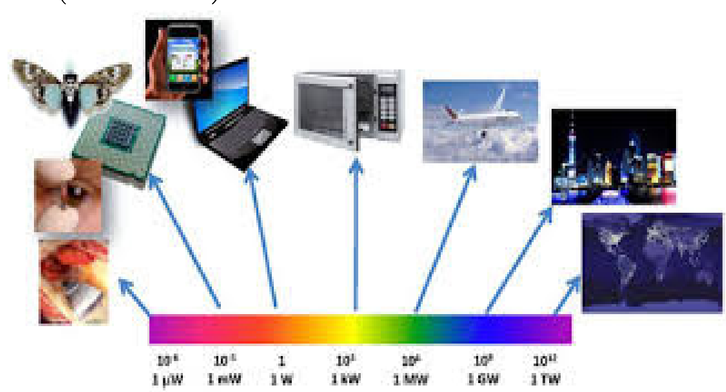
The worldwide energy demand is continuously growing and, according to the forecasts of the International Energy Agency, it is expected to rise by approx. 50 percent until 2030. Currently, over 80 percent of the primary energy demand is covered by fossil fuels. Although their reserves will last for the next decades, they will not be able to cover the worldwide energy consumption in the long run. Nanotechnology is generating a lot of attention these days and therefore building great expectations not only in the academic community but also among investors, the governments, and industry. Economists predict a $1 trillion global market for nanoproducts over the next 10 to 15 years.

In order to guarantee a consistent supply of electrical energy, there are a number of flexibility options available to help balance out the difference between energy supply and demand. Energy storage comprises a wide range of technologies and applications and is classified according to the way in which the energy is stored.The storage of electricity is relatively complex. It must first be converted into another form of energy, which is associated with loss. Depending on the storage method, even more energy can be lost while the energy is being stored and when it is reconverted into electricity.

The ability to store energy locally can reduce the amount of electricity that needs to be transmitted over power lines to meet peak demands. Energy storage could allow downsizing of baseload capacity and is a prerequisite for increasing the penetration of renewable and distributed generation technologies such as wind turbines at reasonable economic and environmental costs. Suitable energy storage is critical to the increased use of renewable energies, particularly solar and wind, because these are inconsistent resources. Nanotechnology may play a role in distributed generation through the development of cost-effective energy storage in batteries, capacitors, and fuel cells. The next generation of storage devices may be optimized by nanoengineered advances and the use of nanoscale catalyst particles (Foster 2006).

Batteries. CNTs have extraordinarily high surface areas and good electrical conductivity,and their linear geometry makes their surface areas highly accessible to a battery's electrolyte.These properties could enable CNT-based electrodes in batteries to generate increased electricity output as compared to traditional electrodes. This ability to increase the energy output from a given amount of material means not only that batteries could become more powerful, but also that smaller and lighter batteries could be developed for a wider range of applications.

Capacitors. While batteries, which derive electrical energy from chemical reactions, are effective in storing large amounts of energy, they must be discarded after many charges and discharges. Capacitors, however, store electricity between a pair of metal electrodes. They charge faster and longer than normal batteries, but because their storage capacity is proportional to the surface area of their electrodes, even today's most powerful capacitors hold 25 times less energy than similarly sized chemical batteries. The below table reveals the same



Atom-thick grapheme: When we talk about nanotechnology and energy storage, we are usually, although not exclusively, talking about graphene, a substance so new the Energy Storage Report spellchecker doesn't even recognise it. This two-dimensional lattice of carbon atoms arranged in hexagons resembles flattened-out chicken wire, but is 100 times stronger than steel, with a very high conductivity of both electricity and heat. Once we have a graphene sheet, we can turn it into a variety of different shapes and forms, including cylindrical nanotubes, a type of foam, and even onion rings. Combining forms, such as sheets and tubes of graphene is also possible. Different shapes have different properties. For example, the diameter of a nanotube decides whether it will behave like a metal or a semi-conductor.

Graphene in batteries and more: It is said that whatever exotic shape we chose, from microscopic bristles of nanotubes to flakes of sheet graphene, the overall result is to dramatically increase the surface area of whatever we attach the graphene to, up to 2,000m2 per gram. When we substrate is a lithium-ion battery electrode, the charge density can be vastly increased, leading to enormous opportunities to increase the efficiency of your energy storage device, which equals smaller, lighter cells that pack a bigger punch. Energy storage applications for graphene don't start and end with batteries, however. Supercapacitors can be made small and cheap by combining flakes of graphene with carbon nanotubes.Another proposed supercapacitor material consists of nanoballs and, again, the incredible surface area graphene provides is key

The (inevitable) drawbacks of grapheme: Despite their relative strength, structures with a thickness of as little as one carbon atom are obviously extremely delicate, which brings us to the first big problem with nanotechnology in energy storage. Pulverisation is the term for the degradation experienced by these flimsy structures during recharging cycles in batteries. It's a problem that needs to be resolved, and at least one lab (at the University of Science and Technology of China, Hefei) thinks it has the answer. Another issue is effective production. We can produce variable-quality graphene in a blender or even with Scotch tape, but the biggest problem with the substance is still cheap mass-production of high-quality single-layer graphene and attaching it to a substrate for practical use.

Graphene in microelectronics: This is not just a problem for the energy storage sector.Thanks to having 100 times greater electron mobility than silicon and incredible thinness, graphene is an ideal material for microchips, plus touch screens, cooling systems and much more.That is why there is considerable corporate muscle behind new production techniques, such as that proposed by Samsung.Since most work on graphene is still very much a lab-based endeavour, it's not surprising that its benefits are not yet being felt in the energy storage sector.

The utilization of nanotechnologies for the enhancement of electrical energy stores like batteries and super-capacitors turns out to be downright promising.Nanotechnologies can improve capacity and safety of lithium-ion batteries decisively, as for example through new ceramic, heat-resistant and still flexible separators and high-performance electrode materials. The company Evonik pushes the commercialization of such systems for the application in hybrid and electric vehicles as well as for stationary energy storage.

Another important field is thermal energy storage. The energy demand in buildings, for example, may be significantly reduced by using phase change materials such as latent heat stores. Interesting, from an economic point of view, are also adsorption stores based on nanoporous materials like zeolites, which could be applied as heat stores in district heating grids or in industry. The adsorption of water in zeolite allows the reversible storage and release of heat.

Conclusion:

The nanotechnology may play a vital role in offering nanoscale materials to renewal energy resources.Nanotechnology could be both relevant and appropriate to sustainable development practices in India. The development of Nano science and technology in India has huge potential to help the country address societal challenges such as provision of drinking water, healthcare, etc., and simultaneously achieve economic gains through growth in the nanotech-based industrial sector. The utilization of nanotechnologies for the enhancement of electrical energy stores like batteries and super-capacitors turns out to be downright promising. Due to the high cell voltage and the outstanding energy and power density, the lithium-ion technology is regarded as the most promising variant of electrical energy storage.

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