

NANOTECHNOLOGY FOR ENERGY APPLICATIONS

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ABSTRACT

With growing needs of human race in present developing world, energy demand is expected to be doubled by year 2050 and the demand of energy will be tripled by the beginning of next century. There is urgent need to develop alternative energy resource(renewable) which are free from conventional fuel fossil or neutral from CO₂. Nanotechnology is creation of useful materials from the existing material by alloying them to make composite material or making them through control manipulation of 1-100 nm length scale which induce novel properties into material in electrical, chemical, mechanical, optical, and magnetic domain. Renewable energy which can be produced by newly introduced properties of materials at Nano scale has advantages of increased efficiency, electrical storage capacity and decreased amount of pollution from the use of energy. Carbon based nanomaterial find most of its applications in the field of energy applications and have been predicted future applications in the fields of hydrogen storage and electrical energy storage. Batteries and capacitors are the most prominent applications in the field of energy storage. Solar cells and fuel cells are some more areas of application of carbon based nanomaterial in the field of energy applications. Thus we can summarize various application domains of newly created energy are Photovoltaic, Thermophotovoltaics, Solid State Lighting, Batteries, Thermo Electricity, Photo catalysis, Thermo insulation, Capacitor, hydrogen etc in conversion, conservation and storage of energy.

Keywords: Renewable ;Photovoltaic; Solid State Lighting; Batterie; composite materia; magnetic domain.

1. INTRODUCTION

Nanostructure science and technology is a wide area of research which involves various disciplines of science and technology. It has greatly contributed to the worldwide growth over the years.

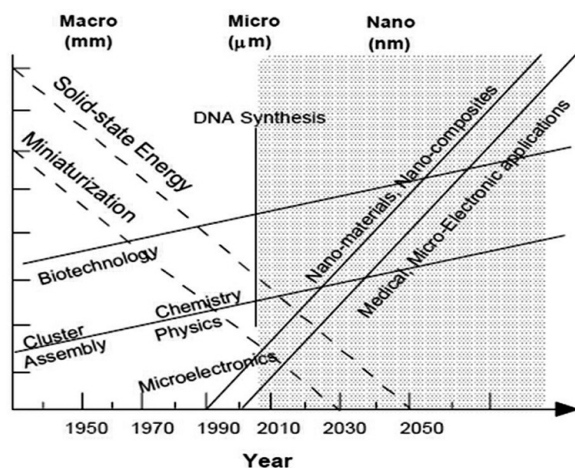


Fig. 1: Evolution of science and technology and future[1]

Nano scale materials are those objects where the dimensions if measured then at least one dimension is less than nearly 100 nanometers. A nanometer is measured as one millionth of a millimeter -Which is almost 100,000 times thicker than the diameter of a human hair. Nanomaterial generate huge interest for researchers as at Nano size of substances distinguished optical, magnetic, electrical, and other properties are surfaced. These newly highlighted properties have the ability for great impacts in electrical, electronics, medicine, and other fields.

In the previous decade, nanostructured materials and nanoparticles have been emerging as the necessary ingredients for electro-optical applications and enhancement of device performance by using of the light management aspects of the nanomaterials. Some application areas which are transformed profoundly by use of nanomaterials includes smart coating devices (e.g., photochromic, electrochromic, and thermochromic devices), solar energy, and sensing[2].

The two main reasons for distinct behavior of materials at the Nanoscale are increased relative surface area and

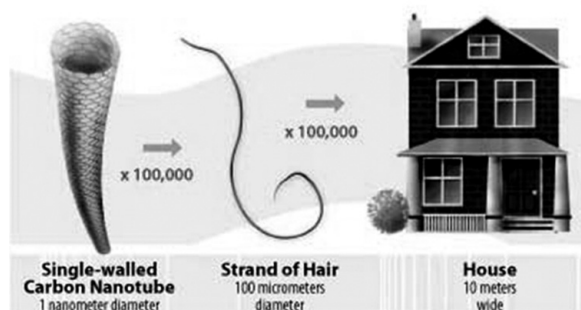


Fig. 2: Nanomaterial for Example (Carbonnanotube)[1]

new development in quantum effects. Nanomaterial has greater chemical reactivity due to much greater surface area to volume ratio as compared to their conventional sized material, hence adversely affects their strength. Quantum effects play an important role at the nano scale in determining the materials properties and characteristics, which results in novel magnetic, electrical and optical behaviors. Nanotechnology provides the greater surface area to volume ratio than their conventional design, the production and application, the Manipulation, the building, the properties-responses and functionality of structures, by controlling the shape and size, and devices and systems of the order or less than 100 nm [18]

Nanotechnology is an emerging technology as researchers have seen great prospect into advancement of already established products by applying nanotechnology principles and developing wide range of new applications. Application areas of Nano sciences and Nano engineering lie in the fields of pharmaceuticals, advanced materials, electronics, cosmetics, packed food, chemical engineering, precision mechanics, optics, energy production and storage, and environmental sciences.

Nanotechnology is a dynamic and emerging field where more than 50,000 nanotechnology articles have been published annually worldwide in recent years. European Patent Office has got more than 2,500 patents filed [18].

Nanotechnology can be instrumental in solving serious humanity problems such as energy Sufficiency, climate change or dreaded diseases:

The world's desire for energy is rapidly growing while at the same time problem of critical environmental issues as well as dwindling resources is emergent. To manage this situation new means to produce, transport, store and consume energy in more efficient ways are required to be developed.

The amount of the current installed solar PV capacity, the continuous reduction in cost of installed PV systems,

and the continuous reduction in cost of PV generated electricity are the three factors that have established fact that PV technology is no longer a pure research area, PV technology is a very important method to generate green electricity for meeting the requirements of rich and poor all over the world [3].

Nanotechnology promises to be the handy tool which will solve our problem and provide necessary assistance. Designing and developing new innovative material properties on the Nano scale have enabled new applications and solutions. Energy-efficient LED lights, low friction nano lubricants, new nanomaterial for thermal insulation, and lightweight Nano composites on the market. This is just the beginning [15].

Nanotechnologies will be able to revolutionize the entire field of energy from usage to supply, conversion and storage. Improvement in energy efficiency is the need of hour.

2. METHODS AND PRINCIPLES OF NANOTECHNOLOGY

Unique Nanostructures

Nanostructured material which is the main building block of unique nanostructures was first used by Romans in fourth century AD to decorate royal cups and glasses. They have made glass using bulk gold metal film and gold colloidal film. Most of the visible part of the electromagnetic spectrum and very strongly in the IR and at all longer wavelengths are absorbed by the thin, bulk gold metal film. It dips slightly near 400–500nm, it appears blue due to the weak transmission of light in this wavelength when held up to the light [18].

Noble metals resonate in the visible or infrared area of the electromagnetic spectrum. Decoration of the glass is guided by visible properties of the spectrum. Glass matrix has metallic particles whose electrons are excited due to light effect, blue and green light are absorbed and scattered by the cup which is relatively shorter wavelength of electromagnetic spectrum. In reflected light effect greenish appearance is given by cup where as if white light source is placed, long wavelength phenomena scatters red color as it absorbs the shorter wavelength only.

Size Dependence

Noble metals and other such as Gold can behave uniquely at nanostructured stage only because their optical and electronic properties are governed by quantum confinement in nanoparticles. Electrons can move freely in bulk size semiconductor within the range of few hundred nanometres as defined by Bohr radius. There is separation between the conduction and valence band by energy gap for

bulk semiconductors. But when size is reduced to quantum dot stage (Nano scale), excitations cannot move freely discrete atomic states that are determined by quantum dot radius appear. Semiconducting Quantum Dots have many similar characteristics to bulk semiconductors and because of their small size their Exciting Bohr radius is confined [4]. When size of bulk material is reduced to nanometer size quantum mechanical characteristics of the electron contribute to its behavior such that it dominates physical properties. Electrons are confined in all the three dimensions.

Surface effect also dominates at Nano crystal size. When size of a crystal is reduced from 30 to 3 nm, the number of atoms on its surface increases from 5% to 50%, it will begin to perturb the periodicity of the “infinite” lattice hence fewer direct neighbors than atoms in the bulk atoms at the surface will result in less stabilized than bulk atoms [18].

Metal NPs

Thermal and electrical conductivity of metal is determined by electron mean free path (MFP) which also determines color of the metal. General value of MFP is between 5-50 nm. Any reduction in the MFP value allows electrons to scatter of the crystal surface which results in increase of resistivity of metal particles. Change in state of conduction and valance band will occur for small particles at discrete level. For example gold particles such change results in change of gold color from red to orange at size around 1.5 nm.

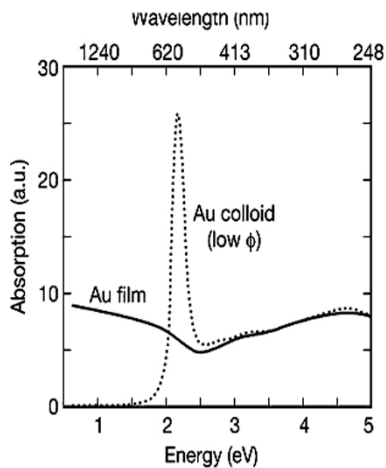


Fig 3: Absorption spectra of a gold Nano crystal film which absorbs only above 1.8 eV like a Semiconducting material due to the quantum confinement effect and a thin, bulk gold metal film of equivalent thickness which absorbs like a typical metal in the infrared energy region. ϕ is the volume fraction of gold in the sample [18]

3. FROM MICROELECTRONICS TO NANO ELECTRONICS

Gordon Moore has predicted in 1965 that no. of transistors to be fabricated over an IC is expected to be doubled in every two years, this prediction is well known as Moore's law in microelectronics. Development in microelectronics has reached to state that in 2010 Intel's processor exceeded 2,000,000,000 transistors [18]. The development is now approaching a dead end where the smaller and compact is no longer any faster. The main reason for this restriction in growth is amount of power dissipated is beyond limit and the heat generated in the process could not be handled at such microelectronic scale of semiconductor fabrication.

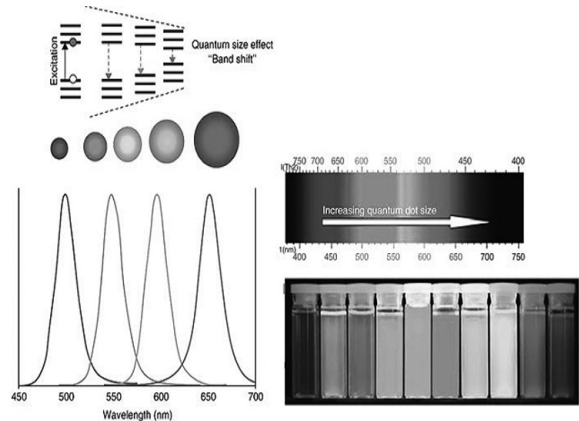


Fig. 4: Schematic drawing representing the changes on optical behavior of nanoparticles associated with their size. Top: Electronic structure of QDs with “blue shift” due to quantum confinement [18]

MOSFET which is preferred as transistor where we think of compact active device element is desired. Miniaturization is achieved by reducing channel length between source and drain for example the channel length which was made of silicon which was doped with n or p type of material was of 50 nm in 2003 and has been reduced to 10 nm today. Critical size limit usually called the lithographic limit does not allow feature size to be reduced below a physical limit in top down development model of MOS fabrication followed in microelectronics. Reduction of channel length is very critical as it results in more no. of transistors over and IC or more no. of logic gates i.e. increased processing power hence decrease in the response time for logic operations.

Nanoelectronic research has opened new dimensions where quantum-mechanical laws are more dominant such that Nano electronics will operate on quantum-principles [18]. Thus nanoelectronics and microelectronics both provide different device and system level solutions. Three dimensional topology of nanostructured objects

which are synthesized using bottom-up fabrication which demonstrate quantum concept and electromechanical principles.

Nano electronics thus provide path for absolute miniaturization also the bottom up solution approach of fabrication is more efficient than the conventional top down approach with given technical advancements.

4. NANO IN ENERGY AND CLEAN ENERGY

1. Aspirations of energy sector

Demand of energy is growing at fast rate with the developing world in every second passed. The energy demand growth rate is as high as that it will be doubled by mid of century and tripled by the end of 21st century. Energy sources widely available are dependent on fossil-fuel which are not sufficient to fulfill the need of growing world. Advancement in technology is desired to develop sustainable or renewable energy resources which are CO₂ neutral although these are not cost effective in present world. International Energy Agency (IEA) has predicted that world's primary energy demand between 2008 and 2035 is going to increase by 36%. Electricity demand is expected to grow by 2.2% per year between 2008 and 2035. When CO₂ emissions and the global climate change impact on life and the health of the planet is taken in account then renewable energy sources will play a central role in moving the world onto a more reliable, secure, and sustainable energy path [18].

2. Nanotechnology to fulfill the demand

Most popular and widely available inexhaustible and cleanest of all the renewable sources of energy is solar energy. Earth is intercepting the power from sun, which is estimated to be much larger than energy used by all the resources aspiring for energy. Solar power as alternative energy resources can be used through Photovoltaic technology. Photovoltaic technology has ability to create high-efficiency solar cells which is going to become a key strategy to meeting growing world energy needs. High-efficiency organic photovoltaic (OPVs) is produced currently using nanotechnology to meet this challenge [5]. Nanostructured thin films composed of layers of semi-conducting organic materials (polymers or oligomers) are used in organic photovoltaic that absorb photons from the solar spectrum [5]. These devices can be manufactured via solution-based methods, like as screen printing or ink-jet, enabling rapid mass-production and driving down cost will revolutionize solar energy harvesting [5]. Solar cells being made use of nanomaterial i.e. with combination of III-V material is proved to be highly efficient exceeding by 40% from conventional technology [18]. Application of such solar cells are limited to space applications due to

high cost of manufacturing. Although inorganic materials used for semiconductors like silicon, gallium arsenide have been working well in photosensitive and photovoltaic applications, yet organic materials have advantage of less cost and easily available for manufacturing process also they provide technological advantage of renewable alternative resource. Plastic electronics technologies provide significant improvements in device efficiency-to-cost ratios [18].

3. Characteristics of nanotechnology favoring it as viable alternative source for energy sector.

Unique Properties of Nano scale Nanomaterial

1. Quantum size effects result in unique electronic, mechanical, photonic, and magnetic properties of Nano scale materials [14].
2. Chemical reactivity of nano scale materials significantly different from their macroscopic form, e.g., gold [14].
3. Surface area per unit mass is vastly increased for nano scale materials, e.g., upwards of 1000 m² per gram [14].
4. New chemical formation is obtained, e.g., fullerenes, nanotubes of carbon, titanium oxide, zinc oxide, other layered compounds [14].

ZnS is a very attractive candidate for applications in novel photonic crystal devices operating in the region from visible to near-IR due to its excellent transmission property and its high index of refraction (2.27 at 1 μ m) [7].

They exhibit outstanding properties when compared with other materials: A) Thermal conductivity – comparable to diamond along the tube axis. B) Electrical conductivity – probably the best conductor of electricity on a Nano scale level that can ever be possible C) Mechanical – the toughest, strongest, and stiffest fiber can be made. D) Chemistry of carbon – they can be reacted and manipulated with the richness and flexibility of other carbon molecules. E) Molecular perfection – it will be essentially free of defects. F) Self-assembly – it will have strong van der Waals attraction which will lead to spontaneous roping of many nanotubes [8].

Environment Friendly Clean Energy-

Properties of material modified at the Nano scale, make it stronger, lighter, have improved viscosity, enhanced stability or improved thermal and electrical properties.

Photovoltaic and photosensitive alternative for energy given by nanotechnology is environment friendly and clean energy as nanomaterial used are of low friction Nano lubrications, lightweight Nano composites and

energy efficient nanomaterial for thermal insulation. According to International Energy Agency (IEA), improved energy efficiency will help in saving 20% of current energy consumption [18]. Nanotechnology enables more energy at less cost. Advantages observed from the design of Nanotechnology based products for renewable

Energy are:

- An improved efficiency of lighting and heating
- Better electrical storage capacity.
- A reduction in the amount of pollution from the use of energy

4 Applications of nanotechnology in Energy Sector

Energy production and power transmission

Nanotechnology serves the dual purpose of exploiting the traditional energy source in more efficient and environment friendly manner as well as developing the technology to generate energy through sustainable energy

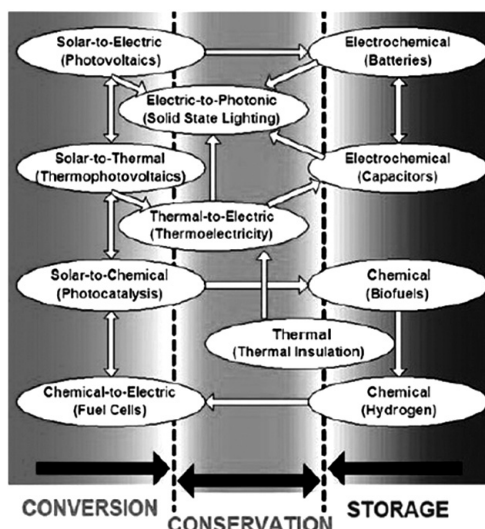


Fig. 5: Portfolio of solar/thermal/electrochemical energy conversion, storage, and conservation technologies, and their interactions [14].

sources as biomass wind and solar power.

Energy transmission is equally important and thus to reduce the losses, nanotechnology offers viable solution to manage power grid as well as load changing and decentralization of feed in stations.

Energy storage & conversion

Energy storage and its delivery on demand is the requirement of many sustainable energy resources as solar power delivers significant power only for a particular time. The present source of energy as fossil fuels are not able to fulfill the growing demand of energy. Nanotechnology will make new type of energy stores for batteries and chemical

stores such as hydrogen.

Trends in energy applications:

Electrically conducting composites, hybrid systems, conducting polymers, fuel cells / batteries, can be applied for energy applications. Two types are being investigated, Polymer itself can be made electrically conducting, or conducting ions can be added to the polymer [13].

Smart Window based on Nanotechnology are energy efficient

Windows are necessary part of building as it maintains a connectivity to world around and enables the natural light to pass through it. Energy balance in the building is critically affected by the presence of windows. With the help of nanotechnology, at the flick of a switch enable windows to change their color—a small voltage application to electrochromic glass changes from transparent to translucent (and vice versa) as lithium ions and associated electrons migrate from the counter electrode to an electrochromic electrode layer [15]. Smart window thus provides efficient solution for cooling and light in building hence artificial shades can be reduced in number.

Aerogels make Thermal Insulation more energy efficient.

Aerogels are solid nano porous substances with extremely low density (as low as 3 kg/m^3) and very good thermal insulation properties (low thermal conductivities near to $0.004 \text{ Wm}^{-1}\text{K}^{-1}$, i.e. 8–10 times lower than mineral wool) [15]. Aerogels are free of toxic and do not have risk of burning with fire also mechanical stability factor is high. Although traditionally its production is expensive yet research is on to develop a new production method that allows the material to be made in a cost-effective way.

Efficient fuel as Nanomaterial makes construction Lightweight.

Nanostructured metal or polymer matrix composites make the design of product with extremely low weight. The word monodispersive refers to families of particles whose diameters only vary by a few percent. These particles can be converted into a close packed structure analogous to a simple close packed crystal. It is possible to obtain a long-range ($>1 \text{ mm}$) ordered silica nanoparticles so that radiation can be diffracted from them [16]. Some of the advantages offered by new low weight design are higher resistance against fatigue, better formability and higher strength-to-weight ratio than conventional composite materials owing to the large interfacial area between reinforcement and matrix structure [15]. New electrical, optical, thermal and magnetic properties are visible.

Nano fluid also enable to create lighter and smaller heat

exchange systems where thermal properties can be improved without affecting flow properties by addition of a very small quantity (<1 % by volume) of nanoparticles to a traditional heat transfer fluid[15].

Solar Power is abundant resource for renewable efficient energy

There are limitations with conventional solar cells as their conversion efficiency is limited by the factor that to absorb enough light layer thickness shall be of micrometer range while the charge carrier collection is better if the active layer is thinner. Nanomaterial-enabled solar cells can improve the efficiency by using nanomaterial which absorb light efficiently; they include quantum dots, plasmonically active metallic nanoparticles and nanowires.

Nanoparticles of Nano films, nanotubes and semi conductors are used to fabricate new solar cells by embedding in a charge transfer medium. Films formed by sintering of nonmetric particles of TiO₂ (diameter 10-20 nm) combine transparency, high surface area, good electrical conductivity and excellent stability and are ideal for photovoltaic applications[9]. Charge carrier collection can be improved by designing nanostructures which exhibit short collection paths with reduced recombination losses[15]. This enables to reduce the need to active material also the level of purity for active material is relaxed. Indium tin oxide can be replaced by Graphene, a scarce material generally used to fabricate transparent electrodes in solar cells and LCD displays[15]. The fabrication and Characterization of the nanostructured smart coating materials and their compatibility with other layers in the overall smart coating device [11].

In the area of solar photovoltaic, nanomaterial have been used in designing light-trapping schemes for inorganic as well as organic solar cells [11]. Plasmonic solar cells category of solar cells has attracted much interest in which metallic nanoparticles are incorporated to enhance their energy conversion efficiency [11].

Production of electricity from waste material

Thermoelectric material enables the conversion of heat to electricity by recycling.

The energy contained into it for example by means of hot exhaust streams. Traditionally it is restricted due to low efficiency but with advent of nanotechnology recently developed nanostructured thermoelectric, is yielding much better performance than traditional alternative. Some of the interesting application areas include the transformation of low-grade solar thermal or geothermal energy, or the

use of human body heat to power portable electronics [15].

Generating Power from Wind

Wind power generation depends blade length of wind turbine. Nano composite material provide robust blades which have very good strength-to-weight and good stiffness-to-weight ratio which enable to make longer and stronger blades. Nanolubricants enable to minimize energy losses hence overall efficiency is increased.

Using your Body as power source to empower personal electronics device

Nano generator device is used to generate mechanical energy from movement such as bending and stretching of nanostructured piezoelectric material such as zinc oxide nanowires. Converting this mechanical energy into electrical energy which is used to empower LCD displays or LED further development will lead to empowerment of portable devices.

Transmission losses of Electricity

Grids involved in transmission need to be capable to do massive transmission at longer distances with minimum losses. Presently copper-based grid losses electricity through leakage at 5% per 100 miles of transmission. Nanostructured carbon nanotube which is 10 times better conductor than copper and has very good strength can minimize the leakage losses to negligible. Good insulation prevents up to 7% of energy losses during transmission. Carbon Nano composites which can work as nanodielectric material has been highly successful as dielectric insulating material.

Storage of hydrogen at high pressure

Hydrogen, which has high energy density but low energy density in volume, has been posing a big challenge when we think of its storage. Nanocomposite have been used to construct storage tanks with exceptional strength. Research is going on in the area where hydrogen reversibly interacts with solid as magnesium and thus reduce the dimension to Nano scale for storage medium. This will make storage process free from release of high temperature and will make charging and discharging faster.

Reducing charge time for mobile

Nanostructured electrodes when used in batteries improve charging and discharging of mobile. Charging time is reduced to seconds or minutes as it depend on storage capacity. Nanostructured electrodes are robust towards the changes occur while intercalation and de-intercalation of ions hence battery life cycle is improved, also nano tech is compatible with wide range of batteries as lithium-ion and

nickel-metal hydride batteries.

Nanotech improve catalysis

Catalysts used in chemical reactions work more effectively if the specific surface area is larger. Nanoscale catalysts with larger surface area are more preferable over catalysts made of larger particles, also nanotech assists synthesis process of catalyst particle such that most of activity grow on particle surface. Activity like the electrolytic production of hydrogen from water or converting of hydrogen to electricity in a fuel cell can made more effective and economical.

5. FUTURE PRESPECTIVES

In the future much is expected from Molecular Nanotechnology to make chemical reactions happen under programmed control. In theory, this allows to build a large range of molecular shapes. To make the creation of new materials a more planned activity, several companies are offering SW for the modeling and simulation of chemical and biochemical substances and a few start-up companies are working to develop specialized SW for nanotechnology.

6. CONCLUSION

The area of nanotechnology is a fast growing one, and many materials are newly introduced or dramatically improved by it.

Trends in energy applications can be summarized as

1. Requirement of sustainable energy production and consumption.
2. Generate system for energy security
3. Produce energy and transform.
4. Future use of energy by storage: Polymer matrix composites may be applied in energy storage for mobile as well as electrical transport technologies.
5. Avoiding misuse of Energy: For the energy sector Nano composites can be used to improve the features of electrical cables.
6. Polymers to be used in energy applications including electrically conducting composites; fuel cells / batteries; hybrid systems. For these two types are being investigated. The polymer can be made electrically conducting, or conducting ions can be added to the polymer. This is area for future innovation.

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