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SUMMER INTERNSHIP REPORT
ON

Applications of Nano Technology in Energy Industry Currently employed & Future Prospects

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CERTIFICATE FROM GUIDE

It is certified that the project entitled "Applications of Nanotechnology in Energy Industry - Currently Employed and Future Prospects" was completed by Mr. Abhinav Gupta, under the supervision, of Shri Alok Sharma, Sr. Associate, and under the overall guidance of the undersigned, during the period w.e.f. June 1, 2013 to July 31, 2013. The same is hereby approved.

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ABSTRACT

From the evolution to the big bang, from the discovery of fire to that of petrol, energy has changed its course. However, the dire need for energy has never abated. Now, we, the humans don't eat raw flesh, we don't burn our naked bodies in scorching heat, furthermore, we just don't live to survive; we want to discover new energy resources, we need to look at some alternatives to not face a standstill and, to accomplish all this, we need a strong forefront that can aid in improvising the available resources. 'Necessity is the mother of all inventions'. We are fortunate enough to not take birth in Adam's age; hence we need not invent anything. This is where nanotechnology comes into picture, a very promising tool like a philosophers' stone for the entire energy industry. It has huge potential to enhance energy efficiency along the entire energy value chain and to economically leverage renewable energy production with new technological innovations. This will be beneficial in long run to achieve sustainable energy supply along with bringing down the greenhouse gas emissions under levels prescribed in Kyoto protocol to achieve the climate protection policy. What is required is to bridge the gap between nanotechnology research centers and energy industry to encourage extensive research to harness its full potential.

'A penny you save is a penny you earn', is germane in this facet as it's equally necessary to conserve energy in view of globally increasing energy demands with harnessing it for present needs. An epidemic imbalance in nature due to increasing emissions of CO_2, considerable climatic change with a rise of two degree Celsius in the average temperature of our planet, depleting fossil fuel reserves are desperately calling for some concrete steps to be taken for sustainable power generation. Most viable drug as a remedy as already stated, is nanotechnology, more comprehensively, innovations in nanotechnology, which need proper coordination and cooperation between government and private companies to harness full potential along with funding of research activities.

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ACRONYMS

ACCR	Aluminum Conductor Composite Reinforced
BP	British Petroleum
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CeO_2	Cerium Di Oxide
CER	Carbon Energy Credits
CNT	Carbon Nano Tubes
CO	Carbon Mono Oxide
CO_2	Carbon Di Oxide
EGE	European Group on Ethics
ELSA	Ethical Legal and Social Aspects
EOR	Enhanced Oil Recovery
EUR	Euro Dollar
FGD	Flue Gas Desulphurization
FSC	Fixed Site Carrier
Gg	Giga-Grams
GW	Giga-Watt
HEI	Health Effects Institute
HPC	Heated Pipe Coating
IEA	International Energy Agency

IGCC	Integrated Gasification Combined Cycle
KW-Hr	Kilo Watt Hour
KW/KG	Kilo Watt/Kilo Gram
LED	Light Emitting Diode
Mcf	Million Cubic Feet
MW	Mega Watt
NASA	National Aeronautics and Science Agency
NREL	National Renewable Energy Laboratory
OLED	Organic Light Emitting Diode
PPM	Parts Per Million
PSI	Pound/Square Inch
QDLED	Quantum Dot Light Emitting Diode
Rs	Indian Rupees
SC	Super Conductors
SINST	Smalley Institute for Nanoscale Science and Technology
TRL	Technology Readiness Level
UNFCC	United Nation Framework Convention on Climate Change
USD	United States Dollar
°C	Degree Celsius
°F	Degree Fahrenheit
Nm3/h	Newton Meter
C/KWh	Cents/Kilo Watt Hour

1. INTRODUCTION INTO NANOTECHNOLOGY

To secure sustainable global power supply in future, the foremost task is to exploit the available energy resources in a competent and environmental friendly way. Simultaneously, reducing the energy losses that come up during transportation from source to end consumer is also indispensable. Distribution losses have to be removed and done efficiently to reduce the total energy consumption in industry and private households.

Today many applications are employing different nanotechnologies to produce and provide clean and efficient energy supplies. Many applications have potential to abate the demand for electricity through energy savings by green buildings employing thermal insulation by nano materials, automobile fuel by reducing consumption of fuel by providing better efficiencies through nano catalysts added in fuel, etc. The adept energy generation along with technological innovations has led to less construction and maintenance costs by employing more efficient nano products in place of conventional materials.

Definition of nanotechnologies:

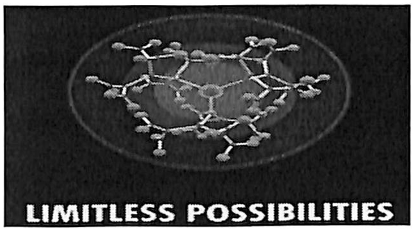
Till present date there is no official definition of nanotechnologies but it implies changes in structure at atomic or molecular level where the basic laws of physics and chemistry are not applicable. Material lies in category of nanomaterial if only at least one dimension is less than 100 nanometers.

The various innovative technologies are derived due to different properties of material as result of changes at atomic and molecular level. Slight changes made at atomic level changes the material completely which shows entirely different set of properties which is due to changes in ratio of surface-to-volume atoms and quantum-mechanical behavior of elements of the material.

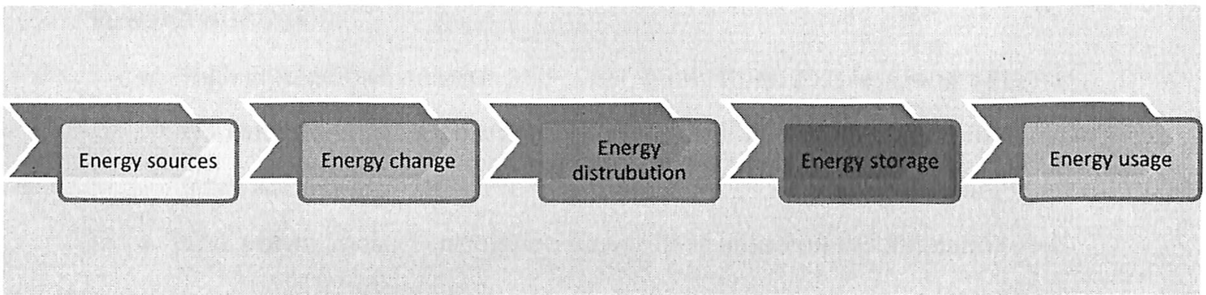
Changing the shape, structure and form of materials at this scale greatly impacts the characteristics of the final product, and thus the use. This is enabling materials to be engineered that are lighter, stronger, more durable, heat-, water- or fire-repellent, etc.

Nanotechnology is the art of manipulating the material at tiny scales generally at nano scale level (10^9). At this stage material starts exhibiting unique and surprising properties like increased electrical conductivity, less resistance, increased resistance, even strength of nano materials increase dramatically. For example, silver shows increased anti–microbial properties, inert materials like platinum and gold become catalysts, and stable materials like Aluminum become combustible. These new discoveries of unique properties have opened new fields for research and applications that have potential to improve quality of life in terms of energy, health, etc.

If someone asks me the area of science and engineering that will most likely make the breakthroughs of tomorrow, I would point to nanoscale science and engineering. Every research in nano science points to limitless possibilities.



Nanotechnology holds potential to bring change in the entire energy value chain.



Energy Sources:

- Renewables:
  - Solar photovoltaic: Nanostructured cells (thin film, quantum dots, multi junction, dye), antireflective coatings.
  - Wind energy: Nano composites for lighter and stronger rotor blades.
  - Geothermal: Nano coatings and composites for wear resistant drillings bits.
  - Hydro and tidal: Coatings for corrosion resistance.

- Fossil fuels:
  - Wear and tear resistance of oil and gas drilling equipment.
  - Nano particles for EOR.

Energy change:

- Turbines: Heat and corrosion protection of turbine blades for more efficient turbines through intermetallic coatings.
- Thermoelectric: nanostructured nano rods for efficient thermoelectric power generation.
- Fuel cells: Nano optimized membranes and electrodes for efficient fuel cells.
- Hydrogen generation: Nano catalysts for hydrogen generation.
- Combustion engines: Nano fuel born catalysts for fuel efficiency and wear and tear resistance.

Energy distribution:

- Power transmission:
  - High voltage transmission and super conductors: Loss less long distance transmission through high temperature optimized SC based on nanoscale interface design.
  - CNT power lines: Transmission power lines based on carbon nano tubes.

- Smart grids: Nano sensors based on magnetic sensing for highly efficient decentralized power distribution.

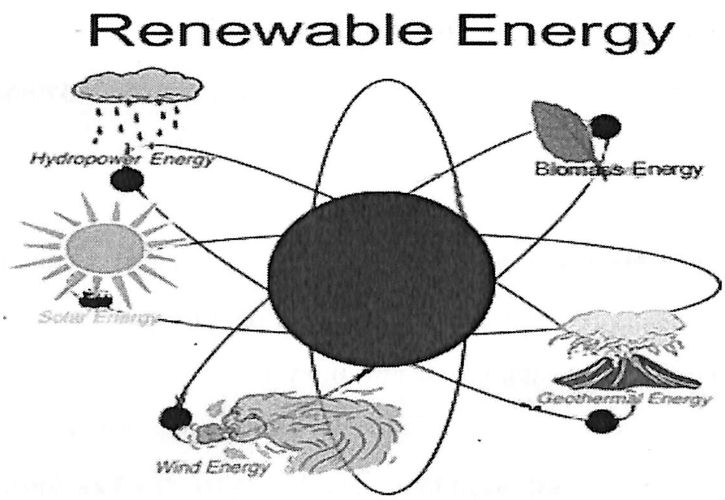
Energy storage:

- Batteries: Nanostructured flexible electrodes for optimized lithium ion batteries.
- Super capacitors: Nano materials for electrodes (CNT's, Caron aerogels) and electrolytes for higher energy densities.

Energy usage:

- Thermal insulation: Nano porous Aerogels, Thermo S for efficient thermal insulation of buildings and industrial processes.
- Light weight construction: Nano composites like CNT's and different metallic nano structured alloys for construction materials that can bear stress and strain far more than conventional materials.
- Lighting: Energy efficient LED's and OLED's.

Nanotechnology's will bring the much needed reform in sustainable energy generation through renewable resources bringing down the production costs and make it competitive against fossil fuels.



The following examples below are of interest with respect to energy sector:

- Chemical:
  - More efficient catalysts for fuel cells and for chemical conversion of fuels through different catalysts design.
  - High capacity batteries, super capacitors can be made through nano electrodes because of high surface area.
  - Nanomembranes those are corrosion resistant for application in fuel cells, batteries, etc. with corrosive electrolyte.

- Nanoparticles as powerful adsorbents like titanium dioxide to remove contaminants and nano silver ceramic filters are being employed for water purification purpose because of their antibacterial and antiviral properties.

➢ Mechanical:

- Nanocomposite materials for light and strong rotor blades for windmills.
- Nanomembranes for capturing CO_2 from flue gasses from thermal power plants.
- Wear and corrosion resistant nano layers for oil and gas equipment to increase their life span.

➢ Optical:

- Highly efficient solar cells through quantum dots and nano layers in stack cells.
- Anti-reflecting coating to increase the solar radiation capturing efficiency.
- Luminescent polymers for energy efficient LED's and OLED's.

➢ Electronic:

- Revolution in transmission through CNT's due to high electron conductivity.
- Super conductors for high voltage transmission.
- Enhanced thermoelectric for efficient power generation from waste heat through nano structured layers.
- Nanosensors for smart grids for efficient decentralized power generation.

➢ Thermal:

- Insulating nano structured layers for gas turbines blades.
- Improved heat exchangers with the use of highly heat conductive CNT's.
- Nanoporous aerogels for thermal insulation in buildings and industries to bring down the energy requirement.

2. INNOVATION POTENTIAL IN ENERGY INDUSTRY

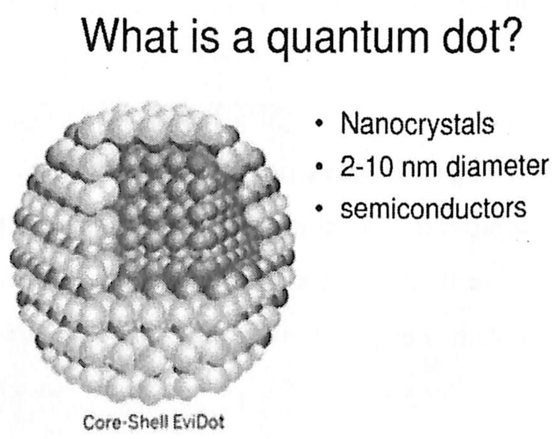
2.1 Energy sources:

2.1.1 Solar photovoltaics:

Everyday earth is hit by 165000 TW of solar power i.e. every day we are bathed in energy; hence among renewables solar energy has the highest potential. What are needed are effective solar energy collection, conversion, storage and distribution in a cost effective way.

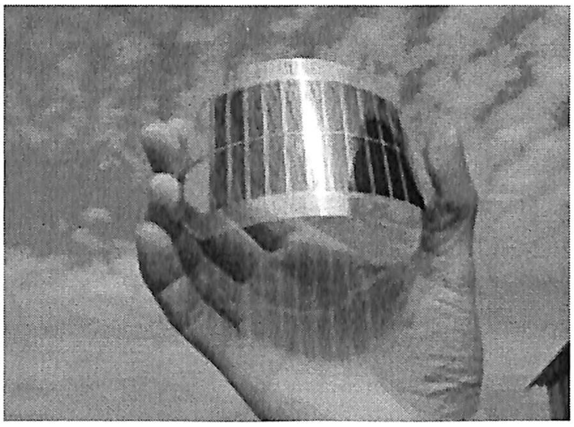
Solar photovoltaic technology today completely relies on crystalline silicon wafers that are quite expensive to produce and hence solar cells are employed for power generation in limited areas as their power generation is not in par with other conventional techniques which will change in coming years with breakthrough technology innovations in nanotechnology and due to rising costs of conventional generation techniques and associated higher environmental constraints.

Nanodots or quantum dots are nanoscale semiconductor crystals which have unique electrical and optical properties which can be employed for more efficient lightening system along with their optical properties paving way for enhanced solar collection capacity. Maturity of quantum dots technology will help lower their production costs which have the potential to greatly increase the efficiency of solar energy systems. The improvements that can be realized by using quantum dots



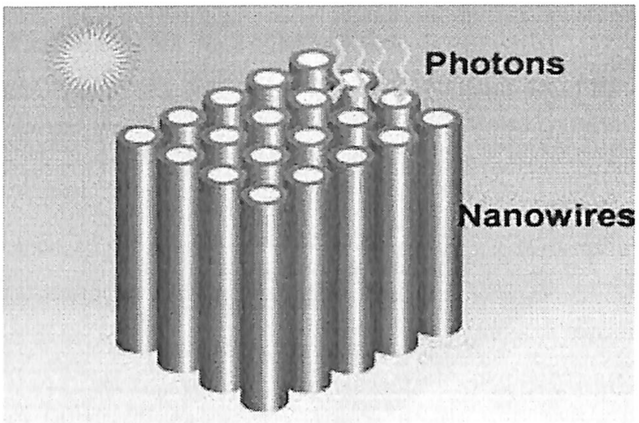
are stated below:

- High performance semiconductor quantum dots are active over the entire visible spectrum along with being active at the infrared region also, these combined with combined with conductive polymers are used to fabricate ultrahigh performance solar cells. The attribute of high efficiency is due to Nanodots that are active over greater portion of energy spectrum. Product like solar roofing tiles employing nanodots based on metal nanoparticles will be commercialized in the coming years.
- Konarka Technologies, one of the leading solar energy companies is making a photoactive nanoscale material which can be printed in flexible surfaces and can be even rolled. This material can be applied as paint on walls, roof tops or can be cut is specified shapes and put on bags of students or soldiers that can be very beneficial for various applications ranging from charging of gadgets to sending signals by soldier in battlefield. The products cost claimed by company is less than one third of conventional photovoltaic and projected capital costs is one fifth of conventional solar cells.(*www.konarka.com*)



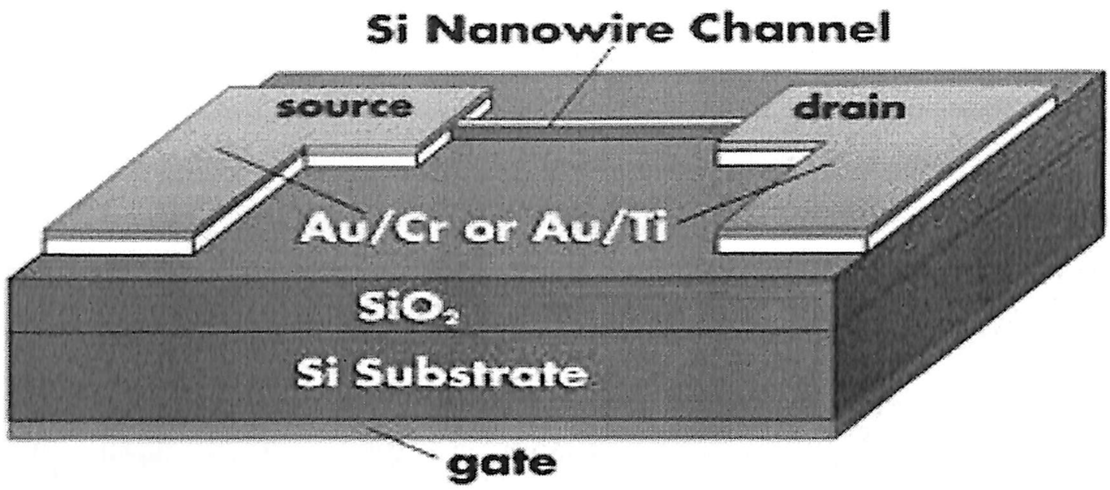
Scientists at U.S. Department of Energy's National Renewable Energy Laboratory (NREL) have produced solar cells with an efficiency of 18.2% using nanotechnologies which is quite competitive with conventional solar cells which have an efficiency of 14-15 %. The breakthrough in this technology will help reducing the cost of solar energy thus making it competitive enough for power generation. (*www.nrel.gov*)

They employ Silicon nanowire and nanopore arrays to tailor nanostructured surface which has potential to reduce the manufacturing costs and greatly enhance the power conversion efficiency of photovoltaic cells.



The problem they faced while fabricating photovoltaic with nanostructured silicon was that it exhibited lower conversion efficiencies due to enhanced photo carrier recombination associated with silicon nanowire. Extensive research showed that these Auger recombination associated with wafer based nanostructured silicon solar cells can be reduced by adjusting the junction doping concentration and they successfully designed and fabricated 18.2% 'black silicon' cell.
The researchers made nano islands of silver and fabricated them on silicon wafer and then immersed it in liquids that made billions of nano structured holes on the surface. When light falls on the surface with wavelength greater than he size of holes on the surface, it cannot recognize the change in density hence the light does not reflect back as wasted energy. This study helped them to fabricate photovoltaic which does not even need any antireflection coating layer thus reducing manufacturing cost as conventional solar cells need antireflection coating that boosts up manufacturing cost of solar cells. The results of research suggested efficient high surface area photovoltaic with nanostructured semiconductor absorbers.

** The paper, "An 18.2% efficient black silicon solar cell achieved through control of carrier recombination in nanostructures" by NREL confirms the findings.*



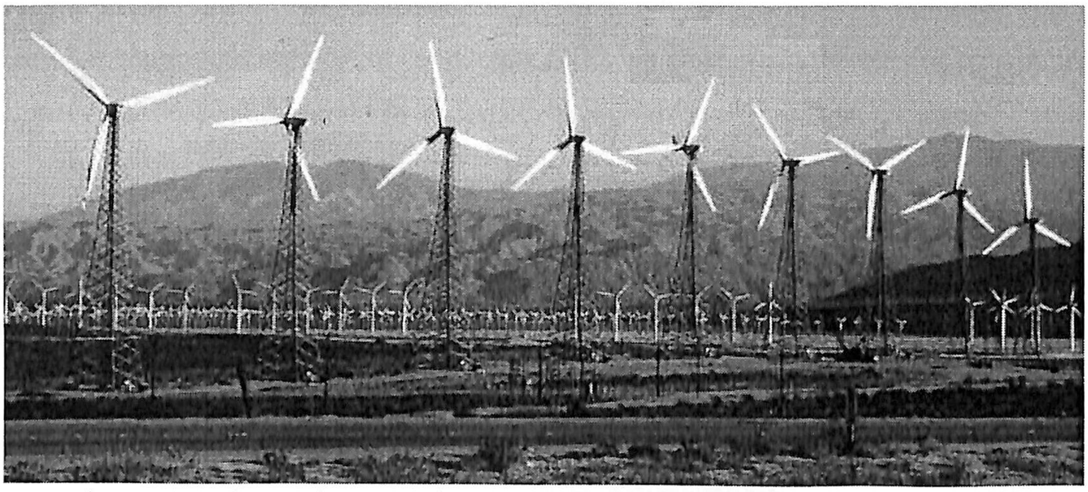
The study showed how surface area and doping concentration can improve performance of nano structured solar cell and how right combination of nano structures and good processing can reduce cost by cutting reflection of light.

This research helped to economically fabricate nanostructured black silicon cells with following advantages over conventional solar cells:

- Efficiency improved to 18.2 % which has made it competitive to other conventional power generation techniques and more research will lead to commercial fabrication of photovoltaic with efficiency greater than 20% with new nano wires being researched upon.
- Reduced the manufacturing costs by eliminating the need of antireflection layers used in conventional solar cells. With improvements in nanostructuring techniques commercially photovoltaics will be fabricated utilizing thin silicon wafer cells with less semiconductor material reducing the cost considerably.

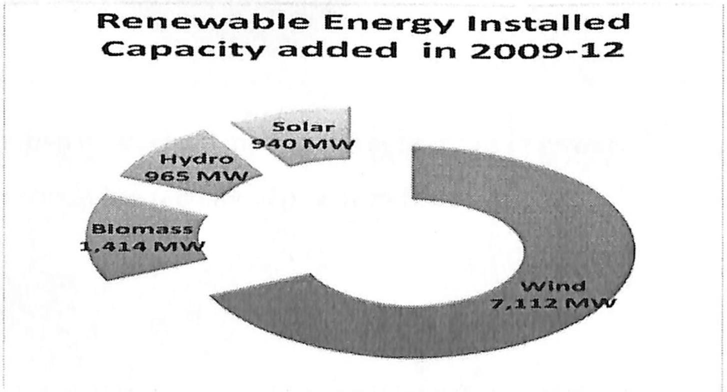
2.1.2 Wind Energy:

Global wind power market is around 27 billion $ which is expected to rise exponentially is coming years. Germany is the leading market of wind power where power generation through wind is at par with conventional power generation and they quote by 2015 power generated through wind energy would be cheaper than conventional power generation techniques. Around 50% of global wind power plants and machinery comes from Germany which accounts



for a very lucrative industry there employing 64000 employees and turnover of around 5 billion euros. This sector is showing double digit growth in various developing countries and this trend will continue and wind power market will grow.

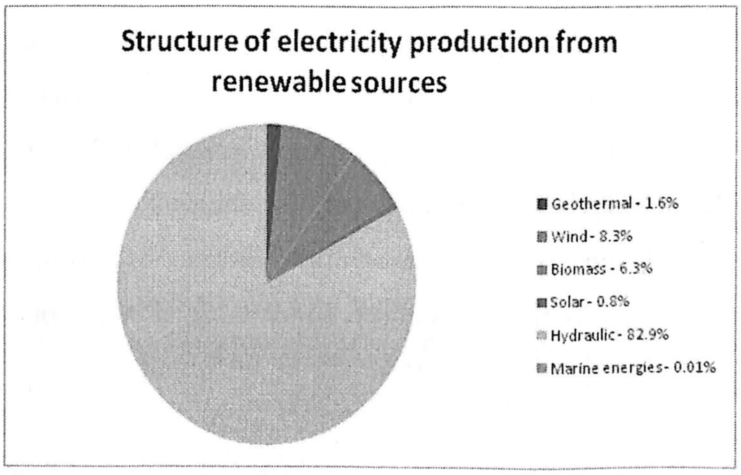
India has the fifth largest installed wind power capacity in the world with 19051.5 MW generation capacities and this sector is continuously growing in double digits. Among renewables in India wind power growth rate is highest in terms of installed capacity.



These days we are seeing the transition towards more powerful wind mills with large generation capacities but they pose new challenges on the mechanical load capacity of wind materials and composites being used for manufacturing parts of wind mill. Thus, CNTs play a very important role for making light weight high strength materials for rotor blades. Nano composites can also be used to counteract eddy currents developed in rotor vanes while revolving hence reduce the noise level of generators and optimize the energy output.

CNT's used in making nano structured composites can help save wind mills against lightening which are responsible for damage of 10 % of global windmills. 1% CNT's in composite polymers can provide continuous network of conducting CNT's which improve the electric conducting properties drastically and also these materials can provide electromagnetic shielding to wind mills.

Nanotechnologies have huge potential to contribute in wind power generation through optimization of wind power utilization by making high strength lightweight materials for making rotor blades through nanocomposites to improve efficiency, wear and tear resistant light weight coatings to improve upon the gear boxes and bearings which would considerably reduce the maintenance cost and improve the lifespan of windmill making the economics of power generation viable for investment and economical feeding of power to the grid.



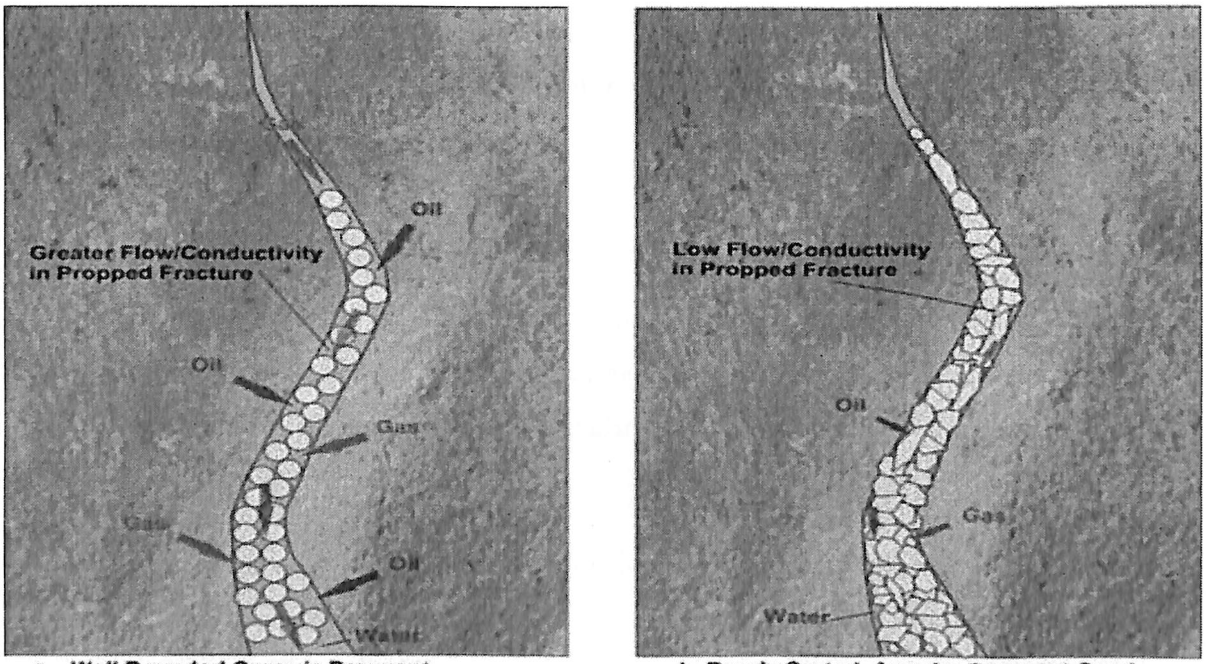
2.1.3 Fossil Fuels recovery:

Energy demands are continuously rising globally and particularly in energy hungry developing countries like China and India. Depleting oil and gas reserves globally are posing energy security problems among many countries who are thus trying to secure as much acreages possible globally to meet their energy demands. This situation is taking the price of fossil fuels to new heights and companies are trying to exploit the matured producing fields by employing new innovative EOR techniques being developed through nanotechnologies which have the potential to increase the recovery factor to around 60%. Still the depleted oil and gas fields contain more unrecoverable fossil energy than that has been exploited up till now which is encouraging big global oil and gas companies to do extensive research to develop applications of nanotechnologies for improvement of oil and gas production spending billions of dollars in annual budgets. In US a consortium "Nano for energy" is constituted by cooperation of Shell, BP and ConocoPhillips to develop new technologies employing nanoscience which are very promising like suspensions of nanoparticular natural silicates is being used for optimizing production by controlling viscosity of oil. Many nanoporous membranes and nanomaterials are developed which remove contaminants at well head and improve production. Very thin extremely hard coatings are developed employing nanoparticles that improve the mechanical strength of drill probes which has made possible exploitation in deep earth layers and also improved the economics of field development by reducing the maintenance costs.

Hydraulic fracturing applications:

Proppants are particles dispersed in formation along with injected fluids to keep the fractures open when there is no fluid injection because as pressure drops in reservoir the rocks will collapse in absence of proppants, which traps the left oil and gas that becomes unrecoverable. In hydraulic fracturing we need proppants to optimize production from unconventional oil and gas wells. Conventional proppants, which are made of sand grains and ceramics are not uniform in size, heavier, neither are strong enough to withstand the pressure and stress deep down the bore well hence new proppants are developed from nanotechnology research at Rice University's Smalley Institute for Nanoscale Science and Technology (SINST) in Houston.

Nano-proppants OxBall and OxFrac were developed which are stronger and lighter than previously used conventional proppants at SINST. Commercially these are being produced a Texas based company found by Andrew Barron, head of nano proppant research at Rice University. OxBall is heavier and slightly larger than OxFrac which is comparatively lighter and smaller employed for the same purpose with different scope of application. These proppants can be designed specifically for different reservoirs for maximum optimization.
For example Texas type oil employs OxBall and OxFrac for shale gas like Bamett.



a. Well Rounded Ceramic Proppant b. Poorly Sorted Angular Proppant Sand

OxBall currently is being used to enhance production from the deeper Haynesville and Eagle Ford plays.

The advantages of nano proppants over conventional is:

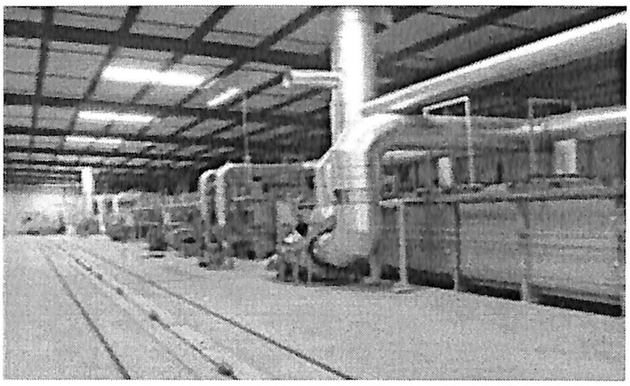
- They're uniform in size hence require less water, additives and chemicals thus reducing the operating cost.
- Conventional proppants travel just 80-100 feet in shale and tight sands reservoirs while these nano proppants being light and more buoyant can go more than 200 feet into the reservoir with attribute of being strong enough to bear the stress deep inside without collapsing.
- An optimally designed proppant suiting the reservoir can double the recovery along with reduced need of pressure, fluid and water which reduces the operating costs to large extent thus making small economically unviable reserves viable to exploit.

Magnetic Sensing:

Barron's team was successful in commercial production of ceramic based OxBall and OxFrac that can be specifically suited for different reservoirs. They were able produce hollow proppants which increased their buoyancy and also made them extra light enabling them to travel to deeper depths.

The next vision of Barron was to check how effective this hydraulic fracturing was in order to check the effectiveness of proppants to tell how successful their design was. To check this his team collaborated with David Potter at the University of Alberta to develop magnetic nanoparticles in structure of proppants that could be sensed through magnetic susceptibility during hydraulic fracturing to access the effectiveness during production or water flooding to check back flow of proppants.

Barron's effort led to establishment of company Oxane had already patented OxBall and OxFrac and were commercially producing nano proppants at manufacturing facility at Van Buren. Nanotechnology is rapidly moving into mainstream oil and gas operations increasing the initial production by up to 50%. Within a couple of years it will



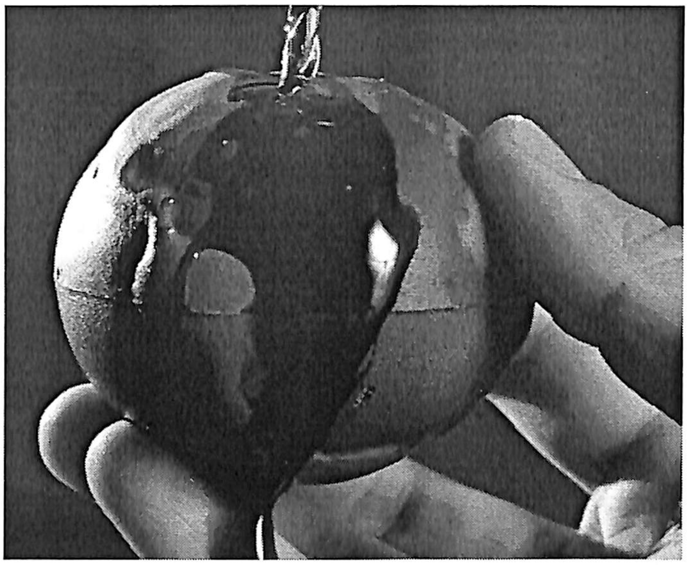
be possible to see in 3 dimensional space where the proppants are going providing the indication of porosity and permeability depending on the flow rate of proppants. Fast flow rate will indicate high porosity and permeability and vice versa. This will also help to create a 3 dimensional image model of reservoir depending on the porosity and permeability of the reservoir in real time.

The sensors would be mixed along with the proppants as low percentage additives which will add on to the cost but the additional information gained through the sensing of proppants and the 3 dimensional image of reservoir showing the porosity and permeability of rock would outweigh the incremental cost. Also the knowledge of reservoirs 3 dimensional model will help reduce pumping and fluid costs. Extensive research is being carried on the possibilities of magnetic sensing properties in various other applications.

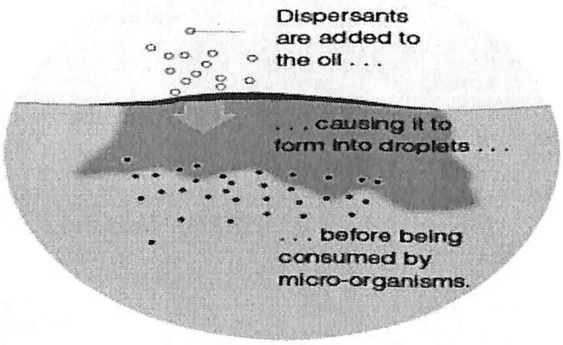
This technology will help in studying the permeability and fracture anisotropy of the reservoir giving information about the down hole conditions in real time along with exact location of proppant flow and how far the proppants have traveled down the fractured pores.

www.oxanematerials.com

2.1.4 Oil spill remediation:



In today's time where stringent environmental constraints exist, an oil spill can be a big problem, for the environment, ecology and for company itself. Huge penalties have to be paid by companies for oil spill as was the case with BP for oil spill in Gulf of Mexico. It tainted companies reputation, disturbed the ecology, aquatic life, environment along with huge payments made to US Government. To clean the mess of oil spill lot of techniques are used but those are not so effective, here nanotechnology paves the way for innovative oil spill remedy to reduce the impact of oil spill on environment and quickly accomplish the task of clean up in minimum cost expenditure.

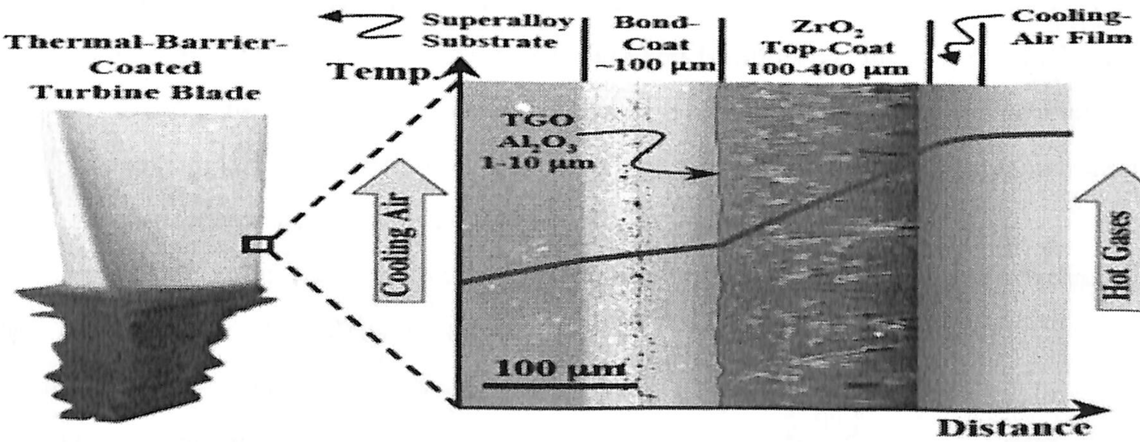


Patented nanotechnology SAM (Self assembled monolayer) has been developed using nanoparticles which can absorb 40 times its weight in oil. The material is hydrophobic hence spilled oil can be recovered for use which acts as benefit in cleanup efforts during oil spills. This technology tailors surface innovation at nano scale level to develop unique nanostructured hybrid materials serving as sorbent materials for environment. This substance has chemical foundations which serve as building blocks for more complex structures. The material has adhesion properties linking polymer to solid substrate. Advances in this technology has huge potential for reducing environmental damage if a spill occurs along with speedy remediation process with 100% recovery of spilled oil.

2.2 Energy change:

2.2.1 Thermal barrier layers for Turbines:

Turbines run at very high temperatures of around 1200°C, this requires thermal barrier insulations to be coated on turbine blades to protect against melting, cracks, wear and tear. Conventional thermal barrier layers being used are no so efficient and thus development of nanobased coating, with potential to bear temperatures up to 1500°C without any wear and tear. Researchers at University of California developed such a coating by mixing aluminum oxide with 5-10% CNT's and 5% finely milled niobium. This coating is 5 times more fracture resistant and also it transfers heat only along alignment of CNT's which makes it suitable for thermal heat barrier. This can lead to optimization of gas turbines by improving their efficiency beyond conventional achieved ranges. The quality required for such coating is they should have low heat conductivity and thermal expansion. The increase in efficiency of turbine would lead to greater power output, less maintenance cost thus improving the overall economics of the plant.



Similar nano coatings are being developed for application in coal fired thermal power plant's boilers and heat exchangers. The maintenance of boiler requires regular inspection and is highly cost incentive. Application of nanocoatings would increase the operating lifespan of these heat exchangers along with frequent inspection checks which would reduce the operating and maintenance cost considerably and improves efficiency of operations.

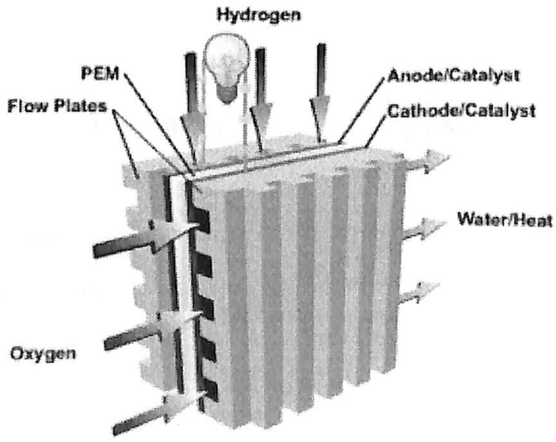
2.2.2 Fuel cells:

Fuel cells are not new, but the costs of materials and complex manufacturing processes they have limited their development. Nano engineering materials can help improve fuel cells efficiency in various ways, some examples are highlighted below:

- Fuel cells work by catalyzing the conversion of hydrogen into energy as the hydrogen passes through a catalyst medium. Designs for next generation fuel cells involve the use of a polymer as the structure membrane through which hydrogen passes and Catalysis occurs. Use of nano engineered membrane materials due to their high surface to volume ratio can increase the volume of hydrogen conversion and therefore lead to more energy.
- Nanoparticles of precious metals of various compositions have been optimized to act effectively in polymer electrolyte fuel cells. A design concept of the materials used to control and manipulate the structure of new materials to nano scale may lead to more powerful fuel cells than that are currently available and allow more efficient energy extraction from fossil fuels and carbon-neutral fuels. New material of electrodes allows more efficient direct use of natural gas or biogas (produced from waste) in fuel cells.
- The characteristics of high resistance CNTs with high tensile strength and light weight can be important for the composite components in fuel cells that are implemented in transportation applications where durability is important.

Umicore AG&CO.KG is worldwide leader in pioneering the next generation Proton Exchange Membrane Fuel Cell(PEMFC) which are environment friendly and also very efficient compared to conventional fuel cells. The application has been already successfully tested and the proton membrane the main component of this technology is being manufactured by Umicore.

www.umicore.de



2.2.3 Fuel born nano catalysts:

Catalysts are chemical compounds which when added speed up the chemical reaction by lowering down the activation energy required for the reaction by providing an alternate path for the reaction without being consumed during the course of reaction.

When catalysts are added to fuels which mix homogeneously they are known as fuel born catalysts and with advancements in field of nano science nano catalysts are developed which have potential to enhance the fuel combustion process improving the efficiency of engine and decrease the emissions of flue gases.

One such catalyst developed is Cerium Oxide (CeO_2) nanoparticles which have tendency to reduce carbon soot emission by completely burning the hydrocarbon thus leaving no hydrocarbon unburnt, improving the fuel efficiency. They even lower the temperature of carbon burning thus eliminating the deposited carbon particles within the combustion chamber improving the efficiency of engine.

Its working is based on the following facts:

- It provides highly active surface oxygen during reaction transformation that leads to reduction in activation energy required for the chemical reaction involving combustion of hydrocarbon.
- The reduced CeO_2 gets oxidized back to normal form because of its stable structure.
- It also helps in storage of oxygen during the reaction which is shown in the reaction below.

$$2CeO_2 \longrightarrow CeO_3 + O$$

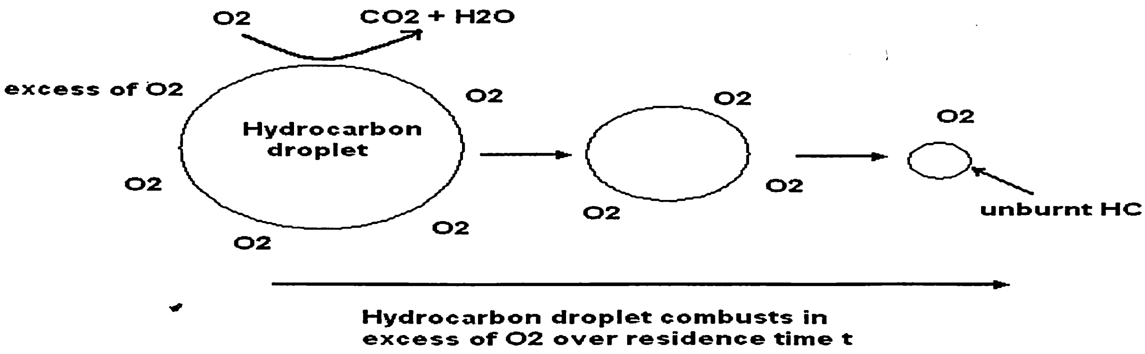
- The catalyst exhibits redox properties which are favorable for improved combustion shown in following reactions.

Hydrocarbon Combustion: $(2x+y)\ CeO_2 + CxHy \longrightarrow (2x+y)\ CeO_{3/2} + CO_2 + H_2O$

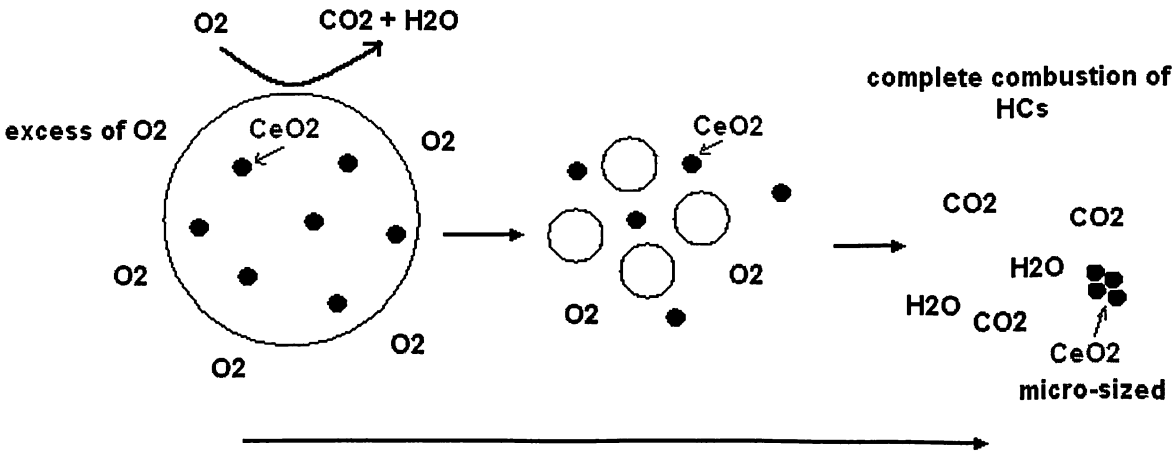
Soot Burning: $4CeO_2 + Csoot \longrightarrow 2Ce\ _2O_3 + CO_2$

NOx Reduction: $xCe\ _2O_3 + NOx \longrightarrow 2xCeO_2 + N_2$

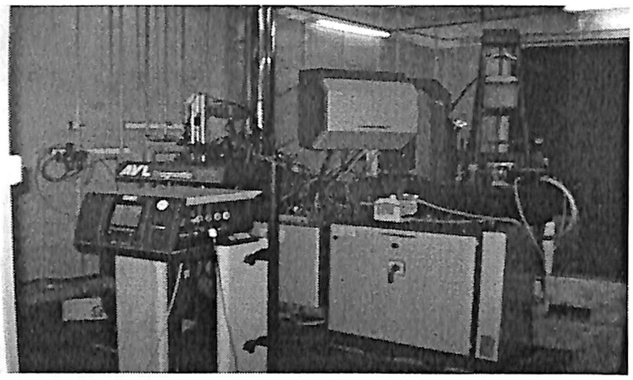
Fuel without nano CeO_2:



Fuel with nano CeO_2:



The nanoscale (10 nm across) particles of cerium oxide to catalyze the combustion reactions between diesel fuel and air Envirox™ Fuel Borne Catalyst, developed by Oxonica, Ltd., is an example of a commercially proven product using. The nano size op particles increases the surface area of catalysts thus requires small concentrations of 5 PPM. This nano CeO_2 catalyst was promoted as the best fuel additive for reducing emissions and for fuel efficiency by Health Effect Institute, US. It was tested at Institute of Transportation Engineering Hanoi University of Technology, Vietnam.



Test results:

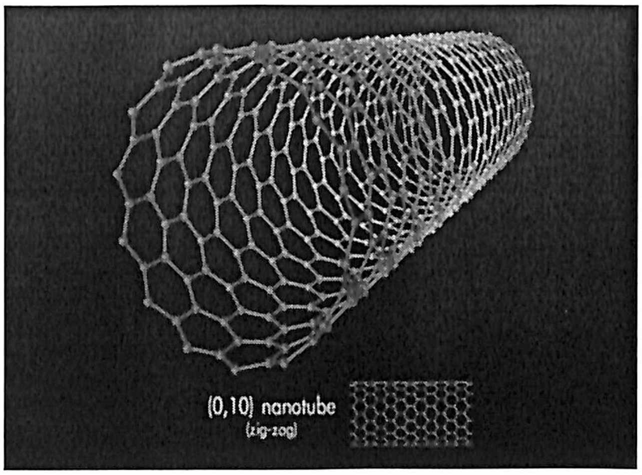
- The test claimed no adverse effects of nano CeO_2 on the engine.
- With additive fuel consumption reduced by about 8% after 56 hours of continuous running.
- Particulate emissions reduced by 10-20%.
- Carbon Monoxide emissions increased initially but reduced considerably after 20 hours indicating burning of carbon deposits in engine.

www.reinste.com, www.nstc.in

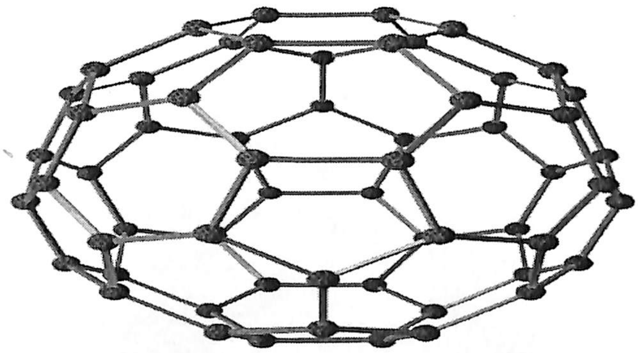
2.4 Energy distribution:

2.4.1 CNT power lines:

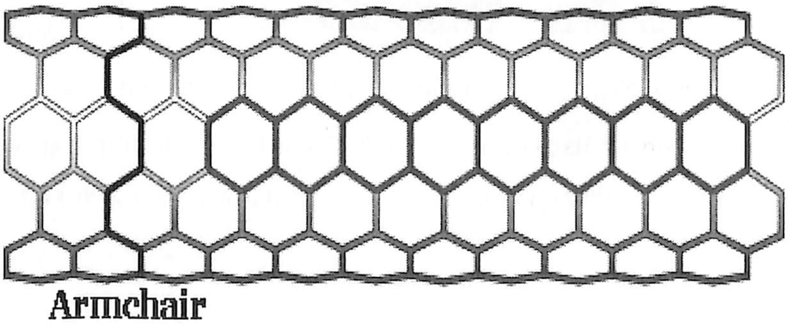
Carbon nanotube (CNT) is a kind of fullerene consisting of carbon molecule formed by carbon linkages in tubular forms. These have characteristics of being extremely light and strong. They are even many times more electrically conductive then conventionally used transmission wires like copper and steel with better tensile strength.



These carbon atoms can also link to form spherical balls nanostructures which may be filled with atoms known as buckyball which have excellent mechanical and semiconductor properties that have potential to change the conventional used semiconductor materials and also they are far more efficient than conventional semiconductors.

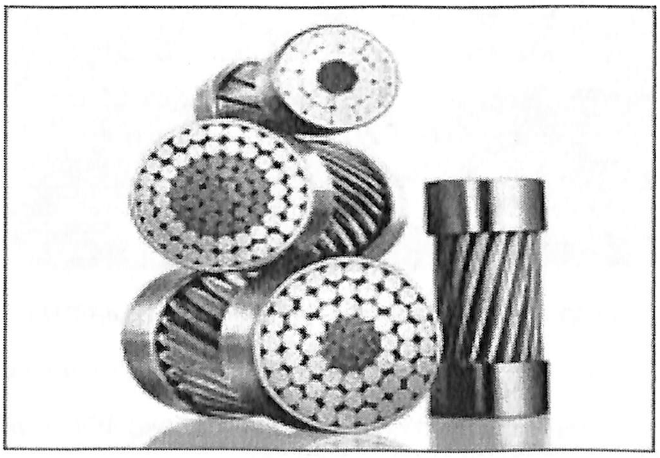


CNT's are manufactured in different forms like single walled CNT's and multi walled CNT's which show different properties from one another. A specific kind of CNT is Armchair CNT which has the



potential to completely change the conventional transmission network improving upon the efficiency levels of current transmission with zero loss. Armchair CNT's are highly conductive i.e., conducts electricity better than any molecule ever known to date along with 30-100 times stronger than steel thus improving upon the mechanical properties along with electrical.

Richard Smalley, Nobel Prize winner for invention of fullerenes described the full potential of Armchair CNT's calling it a miracle polymer in which electrons flows within Armchair much like coherent quantum particle resembling a photon of light travelling down the single mode fiber optic cable. Each Armchair can conduct 20 micro amperes of current i.e. if a half inch thick wire is made utilizing these tubes arranged in parallel to each other, it would be having 100 trillion conductors packed within the cable having capacity of carrying 2 billion amperes of current. Such a wire will be called Armchair quantum wire for which extensive research is being carried on to fabricate such a wire which will behave like a superconductor providing low loss high voltage power line.



3M corporation has developed a nanomaterial based metal matrix conductor known as aluminum conductor composite reinforced (ACCR) wire which has twice the transmission capacity than conventionally used aluminum conductor steel reinforced (ACSR) and also resists heat sag. If these wires replace the existing distribution network they can increase the capacity by 5 times at current price of ACSR wire. This wire is currently being used across U.S. by six major utilities. The ACCR wires retain their strengths at high temperatures also due to the fact that they are fabricated using nano crystalline aluminum oxide fibers embedded in high purity 3M aluminum.

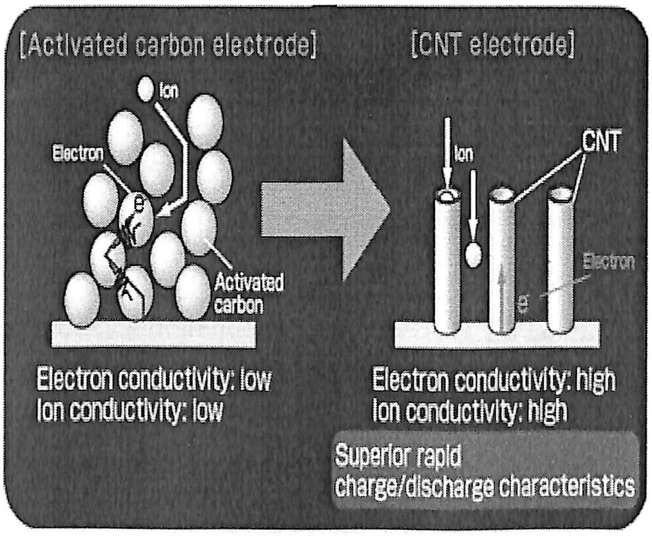
www.3m.com

2.5 Energy storage:

2.5.1 Batteries:

The lithium ion technology is very promising for energy storage exhibiting high cell voltage and power density. Nanotechnologies hold potential to increase efficiency and capacity of storage batteries by optimization using better nanostructured electrodes along with nanomaterials acting as electrolytes.

The issue regarding lithium ion batteries is battery capacity with quick charging and discharging characteristics. For quick charging and discharging we have to use thin active area which represents the energy capacity, hence charging and energy capacity both are related to thickness of active area which is a major issue associated with batteries.

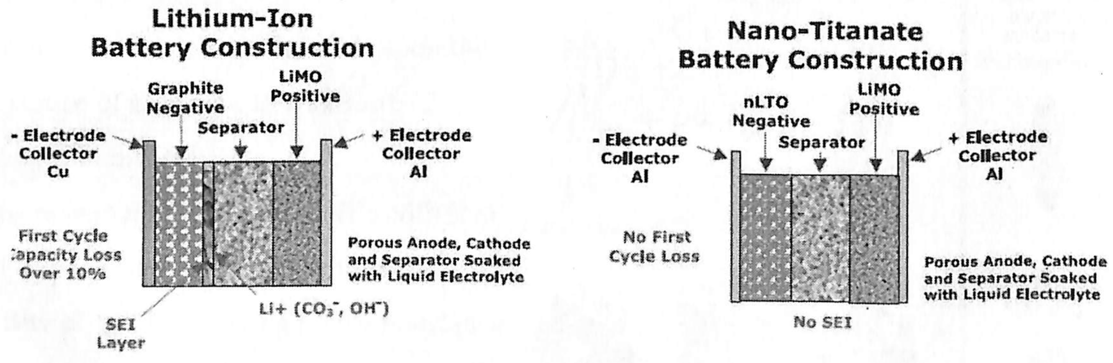


Another issue associated with batteries is power which depends on ion removal capacity of the electrolyte which has to be optimized for quick transfer of ions. Nano crystalline material or CNT's can be used to replace the conventional graphite or lithium electrodes to improve the energy capacity along with quick charging and discharging times. This is attributed to CNT's high surface to volume ratio which helps to provide large surface area to electrodes in thin electrode size which helps to mitigate both the issues. Also they are highly conductive with linear geometry which makes their surfaces accessible to electrolyte. These factors will help in fabricating high capacity batteries within small size that may be used for various applications which are unable to be developed because of the constraints associated with conventional batteries.

Other commercial applications include uninterruptible power supplies (UPS's) and emergency backup power (EBP) due to new advanced nano lithium titanate batteries with improved charge and discharge rates with high power capacity. These new technologies have made possible reliable UPS and EBP systems that can be used as part of distributed mini grids.

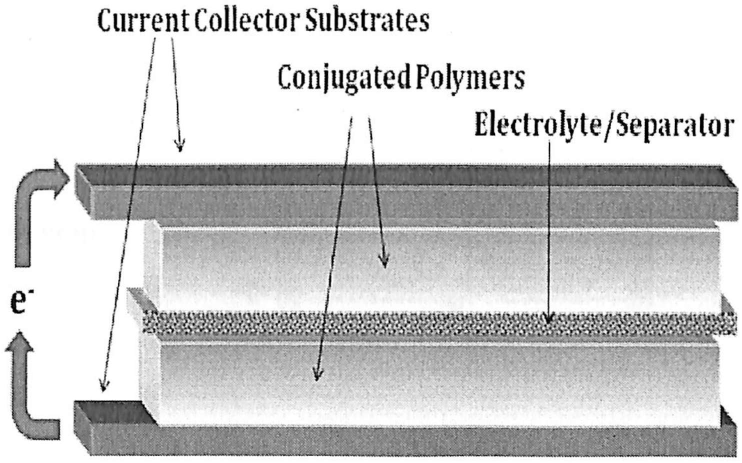
Richard Smalley said that by 2050 every business, building and residential house will have its own electrical storage device supplying uninterruptible power supply tackling all needs of consumer for all round 24 hours owing to a storage model employing nanotechnology. In today's time such devices employing conventional lithium ion batteries are not feasible because storing 100 KW-hrs of electrical energy would require space of about a room and would cost around $10,000, but with nanostructured batteries and more technological innovations in field of nanoscience the size of battery can shrink to the size of a washing machine costing less than $1000.

A nanotechnology company Altairnano developed a battery utilizing 25nm nanostructure lithium titanate as electrode which had increased charge and discharge rates dropping from hours to few minutes along with increased battery lifetime, around 10-20 times the conventional lithium ion battery. They provided enhanced power within a broader temperature range between -40°F to 152°F. This breakthrough technology would take the U.S. automobile industry towards next generation hybrid cars reducing dependence on fuel.



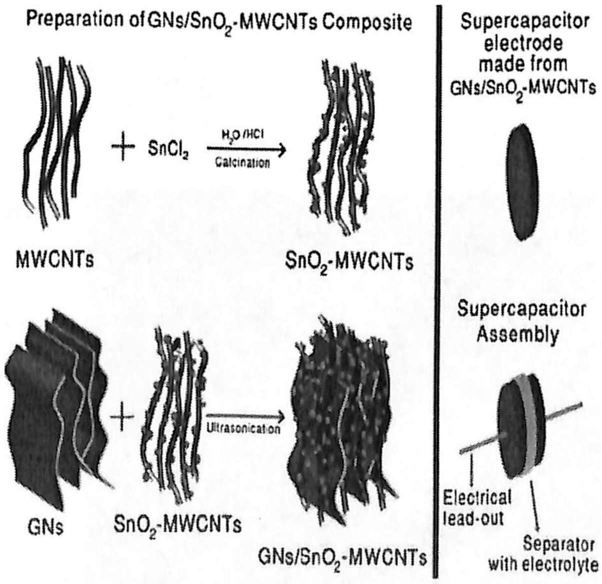
www.altairnano.com

2.5.2 Super capacitors:



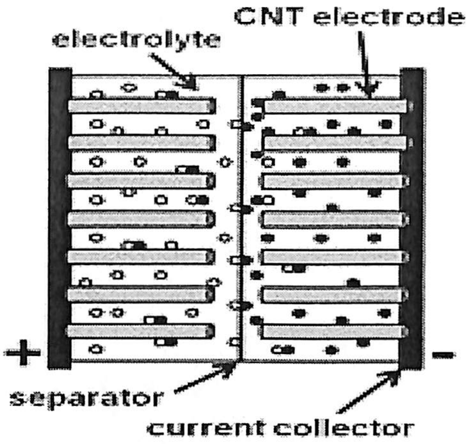
Super capacitors are high density, high powered double layered electrochemical capacitors consisting of two electrodes submersed in an electrolyte separated by a separator. Each electrode separator interface acts as a capacitor hence the complete cell may be assumed as two capacitors connected in series. In these remarkable performance enhancements will take place by nanostructuring and increasing the effective surface area.

High density super capacitors are being made employing carbon aerogels with capacity of 10KW/Kg. Apart from carbon aerogels super capacitors are also being made using CNT's because of their high electrical charge density along with superior surface area to volume ratio which has led to development of highly efficient super capacitors with increased circuit density. They have power density that is 10 times than secondary battery. The power density of capacitor is reciprocal of its internal resistance which in turn depends upon the resistance of electrode and currant collector interface.



New research employing MCNT's with thin walled separators are proving power density of 30KW/Kg owing to low resistance offered by MCNT's along with reduced resistance due to thin walled separator. These nanoscale capacitors are very cost effective along with small size that can be easily used in hybrid cars which have a potential to revolutionize the automobile industry.

To further enhance the performance of super capacitors electrolytes are being replaced by suitable organic polymer electrolytes employing nanostructured ceramic separator films. These films are being developed by a company Evonik and marketed under the trade name of Separion.



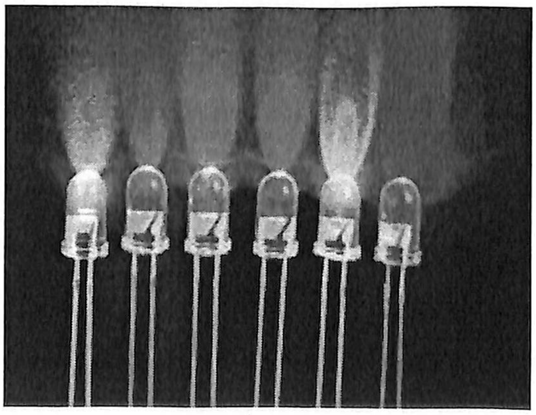
corporate.evonik.com

2.6 Energy usage:

Nanotechnologies have the potential to reduce energy consumption along with reducing emission of CO_2 by providing efficient energy usage. Considerable amount of energy savings can be done by using nano optimized products and technologies in every sector. Some of the examples are shown below:

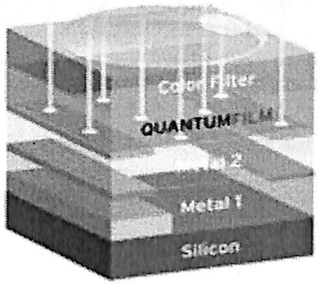
2.6.1 Efficient lighting:

Conventional incandescent lamps are not energy efficient and lose energy dissipating it in the form of heat. In U.S., 20% of total electricity is consumed in providing incandescent light hence energy efficient light emitting diodes (LED's) are quickly replacing conventional sources of light and giving tough competition to well established companies manufacturing incandescent lights.



LED's are made of semiconductor made at nanoscale level and trends suggest that these nanotechnology based lighting devices could reduce the global electricity consumption by around 10%.

New nano technological innovations have shown that Quantum dots (QD) are being employed for making more efficient lighting and displays by coating them on LED's. They emit specific color of light depending upon the size of the nano molecule used in semiconductor employing the QD. Light from QD is pure monochromatic light with slight variation in size changes the color of light emitted. LCD televisions today employ incandescent light that is filtered to emit different color light in which 2/3 light is absorbed by filter, whereas QDLED's do not require filters to produce different color lights, hence are much more energy efficient.

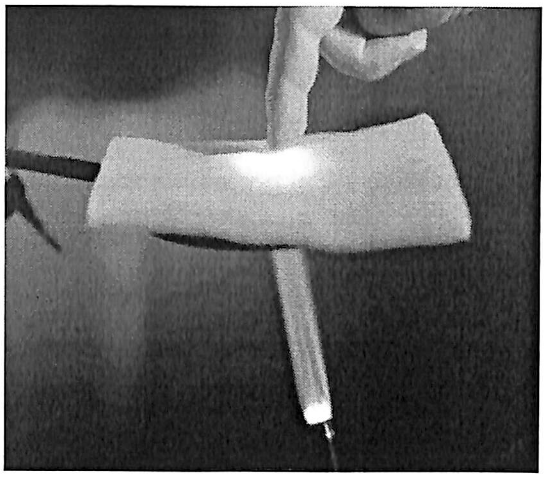


2.6.2 Thermal insulation:

The energy demand by industrial sector and residential homes and buildings has considerable share in total energy consumed worldwide. If energy saving is done in terms of energy required for heating and cooling purposes a lot of energy can be saved. This can be accomplished by using insulating coating that trap the energy inside i.e. blocks heat from outside atmosphere from getting inside thus energy required for cooling the building gets reduced. Many conventional coating are used for insulating purposes but they are not so effective. This is where nanotechnology holds the potential to provide nanostructured membranes that optimize the energy utilization and maximum energy saving can be done.

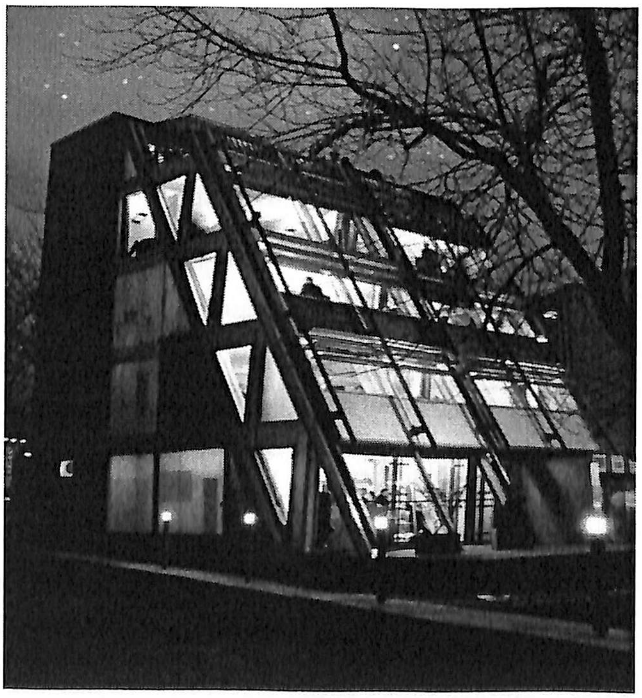
The reason behind such high efficiencies portrayed by nanostructured membranes is their high surface to volume ratio which helps them to trap air between the nano pores providing 30% more efficiencies than conventional insulators with half the thickness.

One such insulator is Aerogel which is the lightest material known up to date with 95% air. It is an ultra-low density solid and despite of being so light is extremely tough and can withstand 2000 times more weight than its own. Owing to such high porosity it very effective in providing insulation and also it can withstand temperatures as high as 3000°C which makes it suitable for wide range of applications. A 9 cm thick aerogel show an R- value of R-28 which is never heard for conventional insulators.



The major companies' commercially manufacturing aerogels are Cabot Corporation marketing it under the name of 'Nanogel', Aspen Aerogels, TAASI under the trade name 'Prstina' aerogels. Today many nanostructured insulating coatings are being manufactured commercially by many companies differing in specifications but proving the common end use of effective thermal insulation. Some of the products are:

- 3M Corporation has developed a rare of nanostructured window films that can reject up to 97% of infrared radiation along with 99% of UV radiation. These films are metal free hence no issue of corrosion arises.
- Degussa manufactures 'Adnano ITO', when applied to windows as transparent coating greatly reduces the energy consumption of air conditioner thus lowering the greenhouse gas emissions.



- Industrial Nanotechnology manufactures Nansulate home protect interior paint which provides a temperature difference of around 30°F for three coats. Another product Clear-Coat provides temperature difference of around 60°F. Nansulate PT is being applied to aluminum ceilings in Suvarnabhumi International Airport in Bangkok to reduce the utility costs but cutting down the energy consumption.
- HPC 'HyPerCoat' is currently being used by NASA. It comprises of ceramic-aluminum coating which can reduce the ambient temperature by around 40%. They are corrosion free and come with lifetime rust free warranty. HPC's 'Hypercoat' silver ceramic is used in engines to hold the heat in thus increasing the horse power.
- Nanopore Thermal Insulation fabricates a highly branched network of coating consisting of nanoparticles of size 2-20 nm using Silica, Titania and carbon. They claim R factor of R-40/inch which is highest for up to date known insulating coatings. The reason behind such high R factor lies behind low density, high surface area along with blend of infrared opacifiers which helps reducing he transfer.

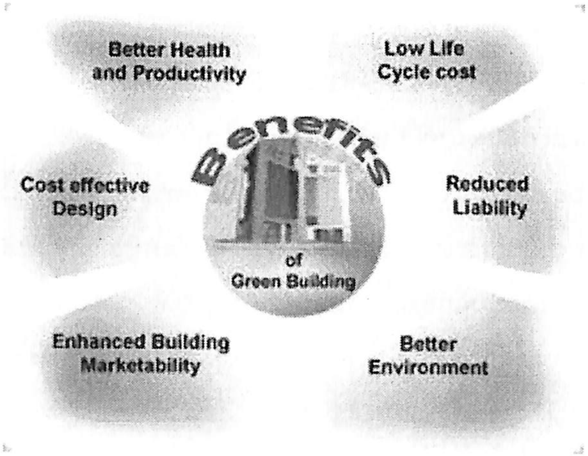
Insulating nanomaterials can be used by sandwiching between rigid panels, applied as thin films, or may be painted as coatings. Based on the above attributes insulating coatings have wide applications in various fields:

In green buildings:

- Insulating coating trap air at the molecular level, hence even a few thousands of an inch thick can have a dramatic effect. 'Nanoseal' is a company already making insulating paints for buildings. Their insulating coating is also being used on beer tanks by Corona in Mexico, resulting in a temperature differential of 36 degrees Fahrenheit after application of a coating just seven one thousands of an inch thick.
- In EU current building insulation is estimated to save about 12 quadrillion Btu annually or 42 percent of the energy that would be consumed without it. Building insulation reduces the amount of energy required to maintain a comfortable environment. Reduced energy consumption, in turn, means reduced carbon emissions from energy

production. Insulation is, in fact, the most cost-effective means of reducing carbon emissions available today.

- Improving on current building insulation could save even more energy and carbon emissions. EU households, for instance, are responsible for one quarter of EU carbon emissions, roughly 70 percent of which comes from meeting space heating needs. Space heating savings through better insulation in Germany, The Netherlands, Italy, UK, Spain and Ireland, would reduce EU carbon emissions by 100 million metric tons per year. Improved thermal insulation could meet over 25% of EU carbon reduction goals by 2010. In the U.S., improved insulation could save 2.2 quadrillion Btu of energy (3 percent of total energy use) and reduce carbon emissions by 294 billion pounds annually.



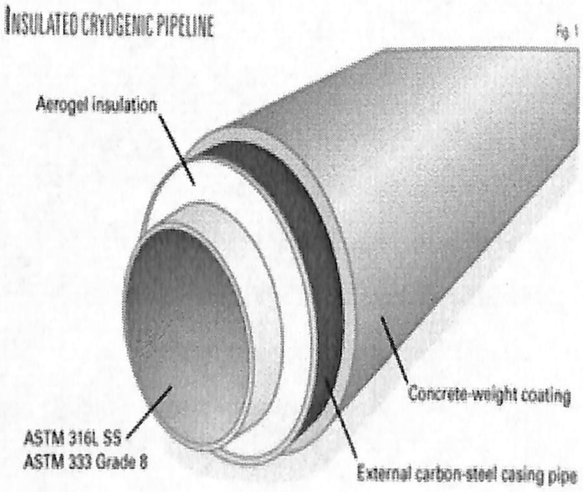
In providing insulation heated and cold pipelines:

- Super Therm® blocks 95% of Heat Load.
- 57% of heat transferred to pipeline is because of IR radiation and super therm blocks 99.5 % of IR.
- 40% of heat is provided to pipeline by visible light and super therm blocks 92% of this visible light. It leads to 22% total utility cost savings along with 40% heating and cooling cost savings.
- Super Insulation – Blocks 95% of Heat Load.

- Durability - Extremely Tough and Sturdy.
- Thus when heated pipelines are provided heat for transfer of viscous fluid or heavy crude they can provide 30% of energy savings which can greatly reduce the operating expenditure the firm has to incur in transporting heavy crude.
- Water and Moisture Barrier.
- Sound Deadening - 50%-68% tested.
- Class A Fire Rating - "0" Flame & Smoke.
- Resists Mold and Mildew.
- Environmentally Friendly – VOC Compliant.
- Long Life (15+ years).

The current practices for cryogenic pipelines involve the use of low-pressure or vacuum environments to achieve the thermal performance characteristics of the insulation systems. The new LNG pipeline technology uses the highly efficient insulation in an ambient environment. The nanoporous insulation is hydrophobic because the pour spaces are smaller than the molecules of water; therefore, the insulation does not absorb water. The insulation does not degrade in the presence of water or moisture, an important consideration for thermal efficiency and for operational maintenance.

Five days of data were collected during the partial and full flow conditions, and the information has been useful in understanding the dynamics of LNG flow in a cryogenic pipeline and in defining the requirements and details of the pipe-in-pipe configuration. The pipeline test revealed the advantages of the nanoporous aerogel insulation, as it proved to have high thermal insulating characteristics. It allows a smaller thickness as compared with conventional insulation systems, resulting in a reduction in the outer diameter for the pipe-in-pipe configuration. It is considered to be

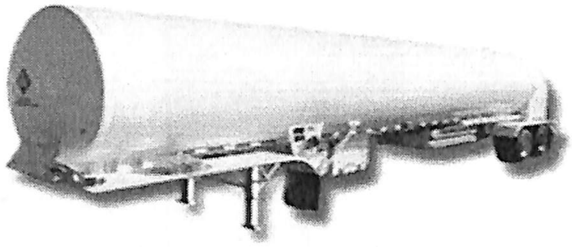


hydrophobic, in that the molecules of water are larger than the pore space of the insulation. It is an ideal insulation in marine environments because it sheds or repels water.

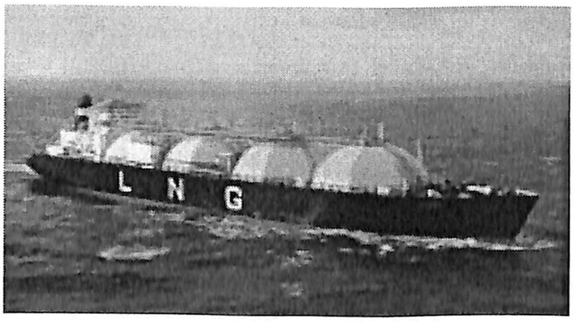
There is no need for a water stop required in common insulation systems because the aerogel insulation is contained within a Tyvek outer wrapping, and the aerogel is by definition hydrophobic.

In providing insulation to cryogenic tankers, boilers, shipment containers, rail cars:

- Trailers coated with Super therm proved temperature differential of over 30°F than uncoated trailers. Super therm coated trailers use 30% less fuel than uncoated ones.
- In cryogenic tankers they can trap the energy inside no letting outside heat inside and retaining the energy spent for cooling them thus saving energy costs up to 30%.



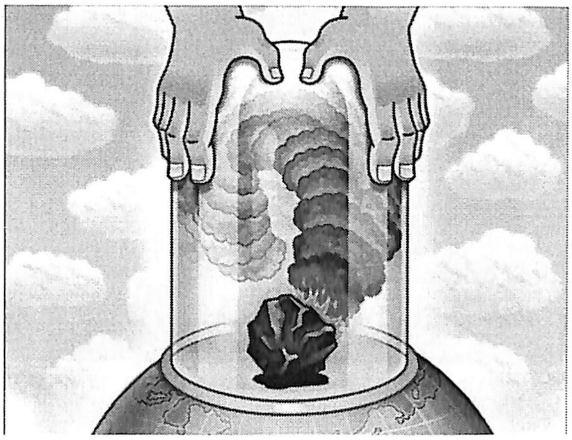
- The average efficiency of boilers range from 35 to 40% which can be easily increased to 45 to 50% by application of super therm greatly increasing the efficiency which results in higher cost saving, less operating expenditure, increasing the net revenue generated through increased production of electricity and savings in utility expenditure.
- For shipment containers and rail wagons application of super therm on roof tops helped in reducing the temperature to 80°F and utilized running the cooling system for just ½ hour to reach temperature of 77°F, thus by the end of test they were 30.5% more energy efficient.



In short the application of Super therm also leads to saving in fuel by 15 to 30%. With product and installation cost the ROI is less than a year excluding the reduced maintenance cost and increased life expectancy.

3. NANOGLOWA (Nano Membranes against Global Warming):

The inauguration of the first pilot carbon capture industry in Europe, based on large commercial power plants, employing advanced membrane separation technology was conducted.

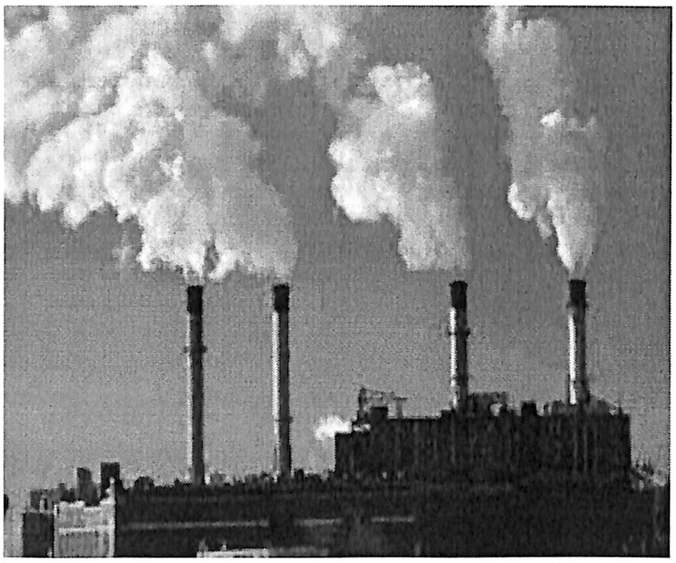


This event, in the center of Sines in Portugal, represents a technological breakthrough against global warming; the first results are very promising. The durability of the membranes exceeds expectations. Even after months of testing, degradation of membranes is minimal, while the performance is still satisfactory, a result that has come after several years of intense collaboration with the NanoGLOWA European project. Membrane technology is an attractive alternative for chemical capture because of its high reliability, high-efficiency energy, and small size. Many industries have recognized the potential of the new selective separation material.

NanoGLOWA, a project that involves 25 partners from 14 countries, began four years ago with the aim of sustainable capture carbon and storage (CCS) from commercial thermal power plants. For years, the membrane technology has been virtually ignored in what refers to the investigation of CCS. This is because that the membranes did not obtain good results in terms of selectivity, flux, and durability. Currently there are two membranes nanostructured that work well in these points.

3.1 *Objectives:*

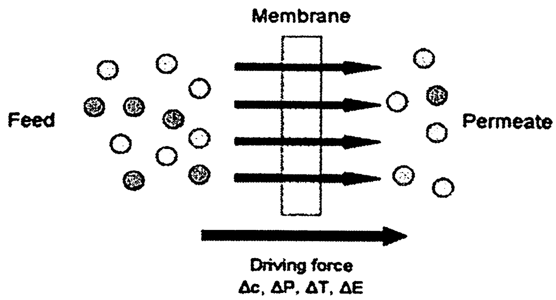
The objective of this project is to develop optimal nanostructured membranes and installations for different applications in the capture of CO_2 from power plants. The application in the processes of separation of gases, such as CO_2 capture at power plants offers the possibility of reducing CO_2 emissions as required by the Kyoto Protocol. The main innovation is the industrial application of membranes in cost effective way for the removal of CO_2 from flue gases. This will result in a reduction of energy consumption for CO_2 separation priced below 20 euros / ton. The performance of the membrane as a result of the project should be increased substantially, resulting in a cost price factor of 5 compared to current membranes. This progress will be achieved through radical innovations in membrane technology. Smart modules design, for a long life, low degradation and pollution combined with the integrated performance monitoring are being developed and tested in the laboratory and in the field. The liquefaction of gases after the separation, will benefit in the reduction of transport costs, is another innovation. Field testing with the future end users is facilitated by this project.



** Kyoto protocol is an international treaty against climate change.*

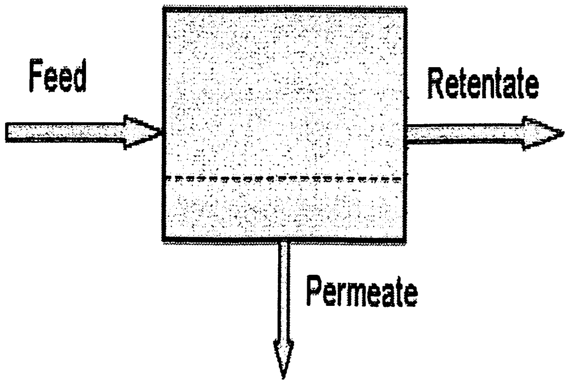
3.2 Membrane technology:

The membrane technology: membranes act as filters that divide a feed stream in two streams: a retained and a stream of permeate. Depending on which of the two is needed, both are regarded as the "product" of the separation process.



Selectivity of membranes

The performance of a membrane is determined by two factors, namely, its permeability and selectivity. Permeability is the volume of gas flowing through the membrane per unit area and time. Selectivity, also known as separation factor, is the difference in the permeability of the components of interest. If, for example, the permeability of the component A is three times greater than the B component, the current of permeate contains three times more of the components A and the selectivity of A over B is 3. The permeability of gases and therefore selectivity among the different gases depends largely on the type of material used for the membrane.

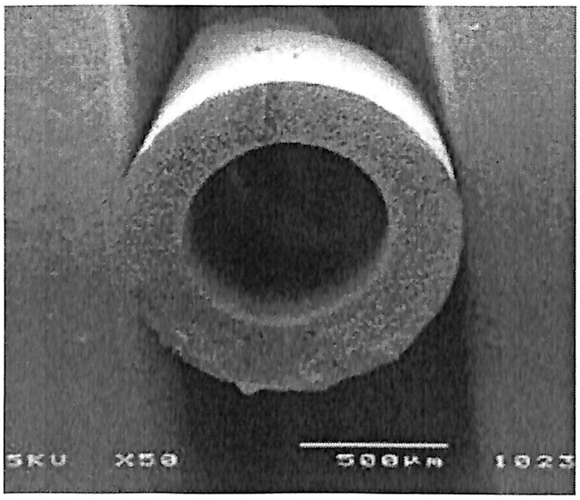


The working principle of membranes

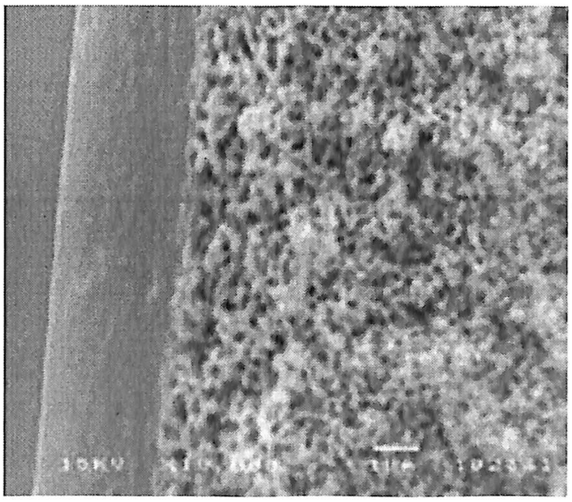
The two main classes in the science of membrane are organic membranes (e.g., plastics, carbon) and inorganic membranes (ceramic). Both kinds of material have been under investigation in NanoGLOWA. Of the five types of membranes, two types to have the most optimum performance are: ***Diffusion Transport Membrane*** and ***Fixed Site Carrier Membranes***. These two membranes have been integrated into modules and have been used in industrial tests.

Diffusion Transport Membranes:

These membranes are developed by the University of Twente. They can be used for separation of CO_2 only or both CO_2 and water. Within NanoGLOWA, hollow fibers have been developed with sufficient thermal, mechanical and chemical resistance. Hollow fibers have a very high packing density (m^2 / m^3) which makes them very suitable for CO_2 capture in the processes of separation by membranes. A photo of a hollow fiber (left) and the selective coating (on the right) can be seen below.



Hollow fiber

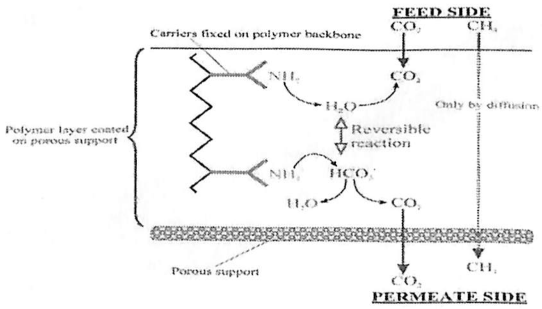


Selective coating

Diffusion Transport Membranes have been used in the module of Parker.

Fixed Site Carrier Membranes:

The Fixed Site Carrier membranes are developed by the Norway University of science and technology. They use a chemical chain reaction to select CO_2 from the flue gas stream. FSC membranes have been developed as flat sheet membranes. *FSC membranes have been used in the modules of Yodfat.*

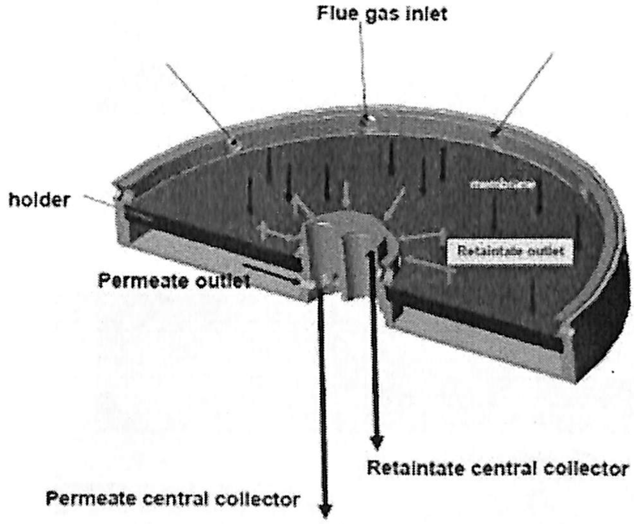


Chemical reaction

3.3 Membrane Modules:

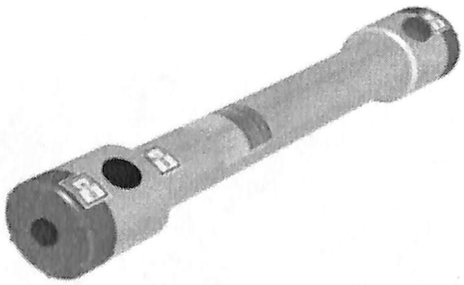
The membranes developed were assimilated into modules for easy installation and maintenance into the gas streams. Two modules were developed for the membranes by different companies:

Yodfat Module:



Yodfat Engineers Ltd. has developed the module to accommodate the flat sheets of FSC membranes. Flue gas enters from the outside through the disc, flows inward and the selected gas penetrates through the membrane. Both currents of gas (permeated and retained) are collected separately in the center of the disk. Disk of a single membrane can be assembled to form multiple disk modules. *Yodfat Engineers Ltd. built a module based on the flat sheet Fixed Site Carrier membranes.*

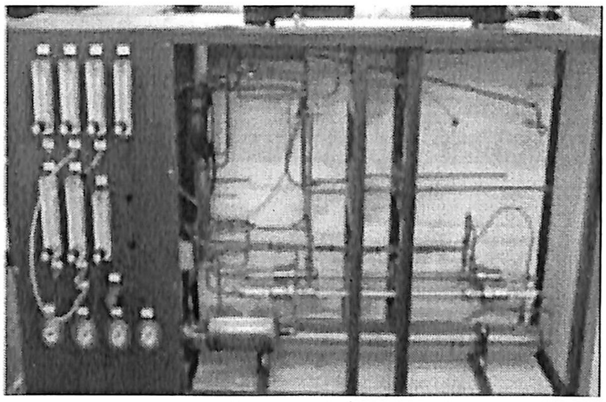
Parker module:



The membrane module for dissemination by Parker filtration and separation BV transport is based on an existing commercial module developed previously for separation of gas which contains fibers that separate oxygen from the air. The module is suitable for fibers which are fed from the inside with a diameter of 0, 45 mm. The modules can be adapted to different lengths of fiber. The performance and the recovery rate can be controlled by the flow rate.

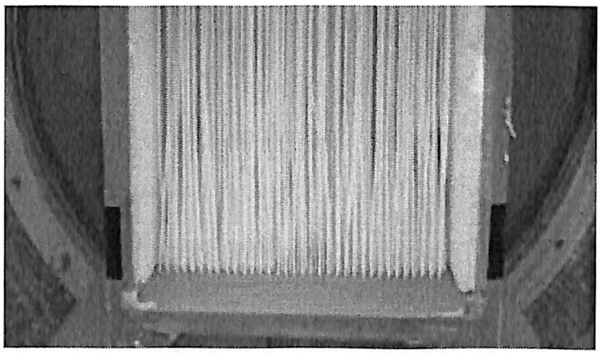
3.4 Laboratory Tests:

- *Italy, ITM-CNR:*



In ITM-CNR, all five types of membranes have been tested based upon the selectivity and permeability. The experiments were carried out with pure gases, for the evaluation of ideal permeability and selectivity, and with "NanoGLOWA gas mixture" (17% CO2, 78% N2, 5% O2) to evaluate the actual selectivity.

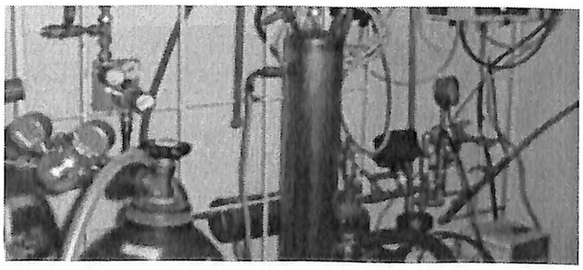
- *The Netherlands, KEMA:*



Using a mini flue gas desulphurization unit (FGD) experiments complementary to those at IchP were carried out at KEMA. Hollow fiber modules and helically wound modules are very popular, primarily for reasons of density of packing and maturity.

Use of the simulator of combustion gas in KEMA, the Netherlands, selectivity and permeability were measured to operate a module of hollow fiber membrane as in realistic flue gas. In addition, analysis of the performance and durability of effects on SO and NOx pollution were done.

- *Poland, ICHP:*



In ICHP, experimental modules were tested in slightly different conditions than in KEMA. Here, the flow was lower than in KEMA. In Warsaw, Poland, at the

Research Institute of Industrial Chemistry, dedicated medium-scale test rig was built to exactly test these membranes. Performance and the accurate assessment of durability of operation with carefully constructed artificial flue gas confirmed certain promising properties in laboratory scale.

3.5 Pilot-plants:

Distinctive membrane materials were tested separating CO_2 from the flue gases along with durability and efficiency of separation in the long run. Pilot installations were tested continuously for several months which resulted in additional information gathered around fouling, pretreatment, the consumption of energy and longer life, and as such, the membrane and related technologies. After several years of lab testing, membrane modules have been installed in operating power plants to test the working of the membranes in an actual flue gas stream.

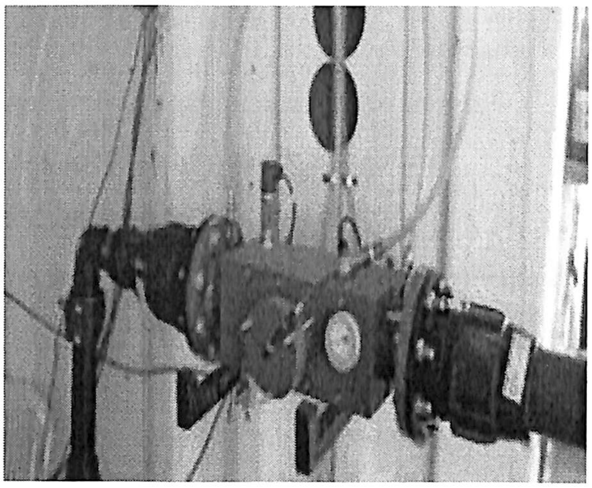
In the course of the project, three major energy suppliers decided to install pilot plants - in the thermal plants using coal for E.ON in Gelsenkirchen (DE), EdP in Sines (PT), and IEC in Rothenberg (IL). These efficient industrial facilities are a world novelty:

- *Rothenberg, Israel:*

  IEC Rothenberg power station is located on the southern coast of Israel, in Ashkelon. Rothenberg is composed of two 575 MW coal-fired units without FGD initiated in 1990 and 1991 and two 550 MW coal-fired units with FGD was initiated in 2000 and 2001. Each of the 550 MW units produced 1,600,000 Nm m^3 / h gas from combustion. Durability tests were carried out in the power plant using a stream of bypass coming downstream from the desulfurization unit. These tests were conducted, in different conditions and with different combinations of membrane modules. The results of these small scale tests were satisfactory, while the conditions (e.g., humidity, SO_2) were very hard.

The test device is connected to both branches of the FGD developed by Parker and Haffman.



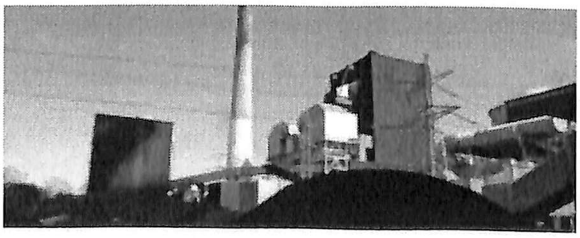
Parker Module

- *Sines, Portugal:*

Sines power plant is located on the southwest coast of Portugal, in the Alentejo region, 6 km southeast of Sines and about 150 kilometers south of Lisbon. It is a power plant using conventional pulverized coal with four independent electricity generating units, each with a nominal power of 314 MW (gross) and flow of 1.125.000 Nm^3 /h flue combustion gases. The first unit started in industrial service in 1985 and the last in 1989. The plant will host tests of relatively large scale to a maximum of six months. Design pilot membrane module and test equipment are on their way.

- *Scholven, Germany:*

This lignite-fired power plant of E.On is located in Schkopau. With an average flue gas flow of 2,000,000 Nm^3/h, the two turbines produce a power output of 450 MW each.

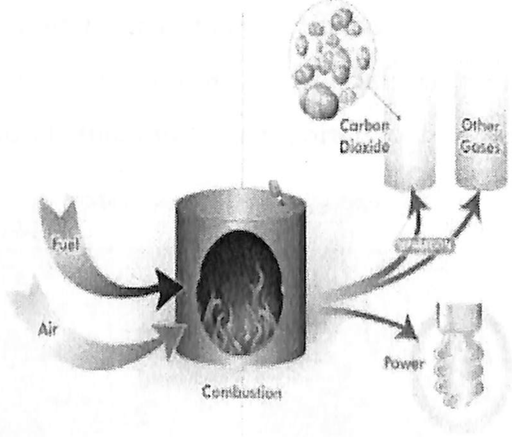


To comply with requirements beyond Kyoto, the best way to reduce CO_2 emissions from power plants that burn fossil is in the capture of CO_2. The existing methods as adsorption and non-selective cooling are not very profitable and consume a lot of energy: up to 25% of the production of the power plant. Reduction of CO_2 emissions by gas separation through membranes does not currently exist in industrial applications. The potential of the technology is substantial. Major prevailing bottlenecks are the availability of adequate and reliable membranes at an acceptable price level. The module enables the very functioning of the membrane in the target application, and aims to provide the best operation conditions for given gas composition and pressures, while interfacing with the application's process. Focused international and interdisciplinary research and development has now succeeded in raising the Technology Readiness Level (TRL) of this CO_2 capture.

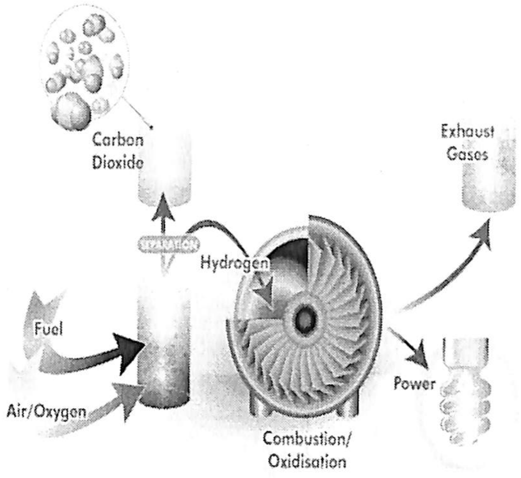
3.6 Other CCS Techniques:

There are three different types of technologies for Carbon capture: post-combustion, pre-combustion, and oxy-combustion:

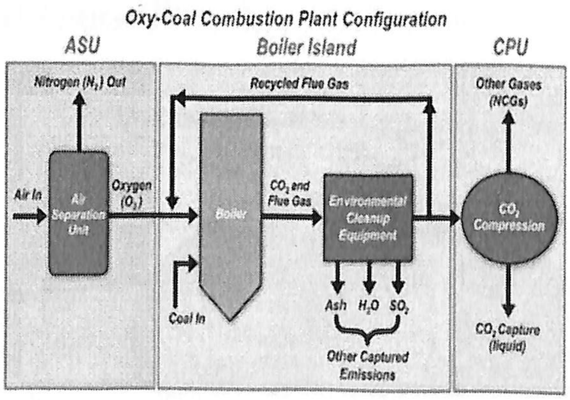
- *Post-combustion capture*: CO_2 is removed after combustion of the fossil fuel; this technique is applied to fossil fuels power plants. Here, carbon dioxide is captured from flue gases at power plants or other sources of emission. The technology is well known and is currently used in other industrial applications, although not on the same scale that might be necessary in a power station at commercial level.

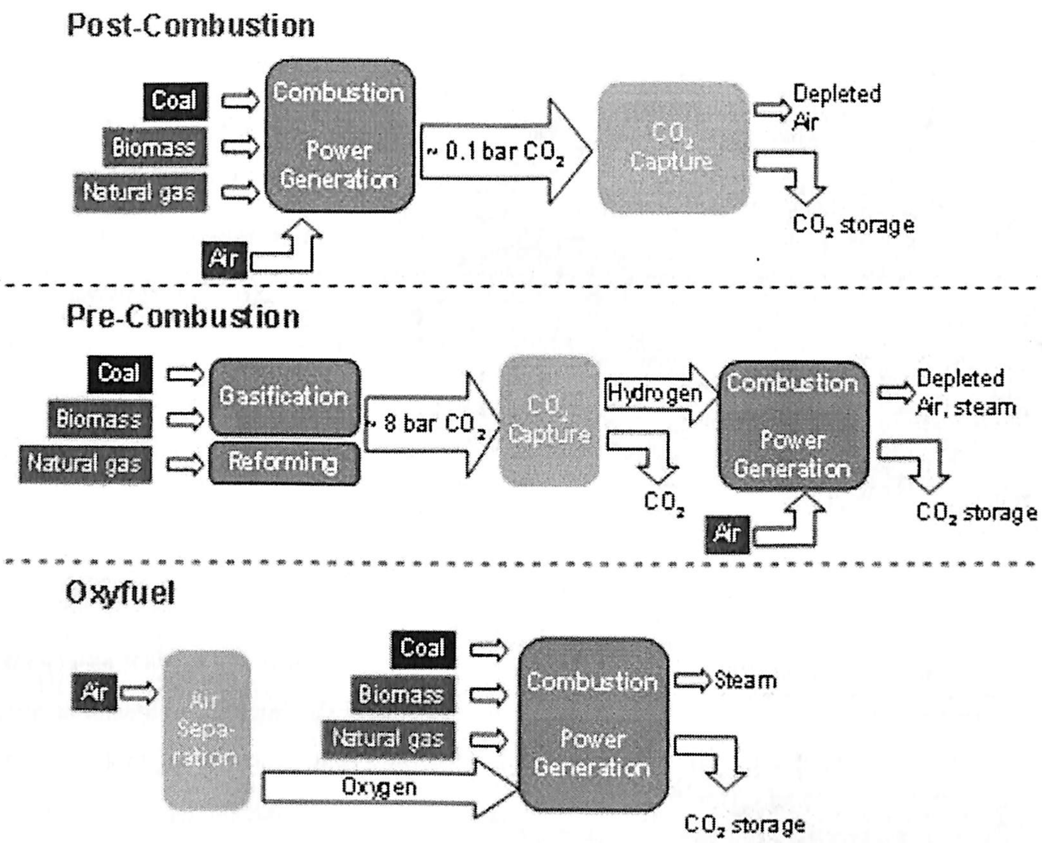


- *Pre-combustion capture*: Pre-combustion technology is widely applied in fertilizer, chemical, gaseous fuel (H_2, CH_4), and energy production. In these cases, the fossil fuel is partially oxidized, for example, in a gasifier producing syngas (CO and H_2O) which is transformed to CO_2 and H_2. Resulting CO_2 can be captured from an exhaust stream which is relatively pure.H_2 is used as fuel while carbon dioxide is removed before combustion takes place. This scheme applies to new plants that burn fossil fuels, or for the existing plants. The capture before the expansion, i.e., from the gas pressure, is standard in almost all industrial processes of CO_2 capture, to the same scale, as required for utility power plants.

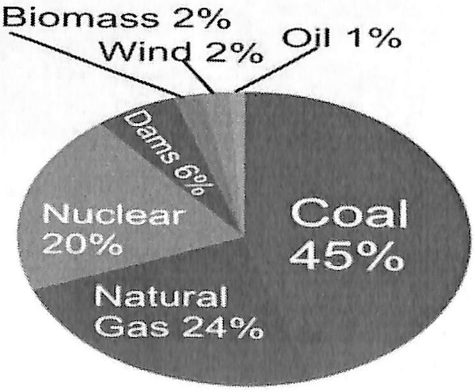


- *Oxy-fuel combustion*: The fuel is burned in oxygen instead of air. To limit the resulting flame temperatures to levels common during conventional combustion, flue gas is cooled, recirculated and injected into the combustion chamber. Flue gas is mainly composed of carbon dioxide and water vapor, the latter of which is condensed by cooling. The result is a stream of pure carbon dioxide that can be transported to the site of storage. Power plant employing oxy combustion is sometimes referred to as "zero emission "cycles, since the stored CO2 is not a fraction removed from the flue gas stream (as in the cases of pre- and post-combustion capture), but flue gas itself. The technique is promising, but the first step of air separation requires lots of energy.



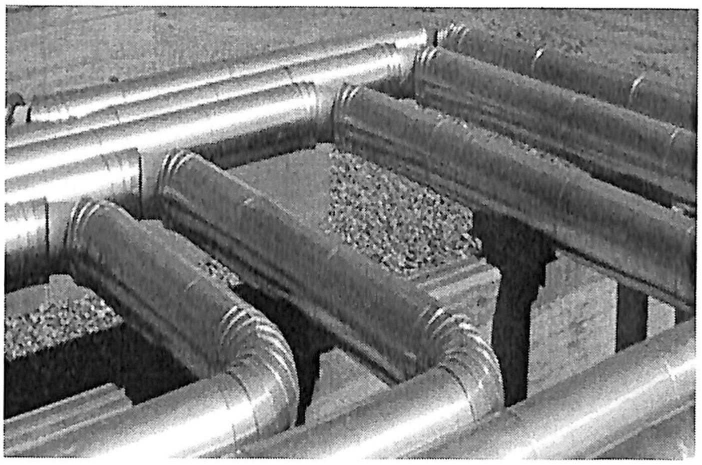


Coal is a vital fuel in most of the world. Burning coal without increasing the levels of carbon dioxide is an important technological challenge that is being approached. 23% of primary energy needs are met by coal and 39% of electricity is generated from coal. Around 70% of the world production of steel depends on raw material coal. Coal is the source of fossil fuel which is widely distributed globally. The International Energy Agency (IEA) foresees an increase to 45% in its use from 2000 to 2020. Burning coal produces nearly 14 million tons of carbon dioxide each year that is released into the environment.



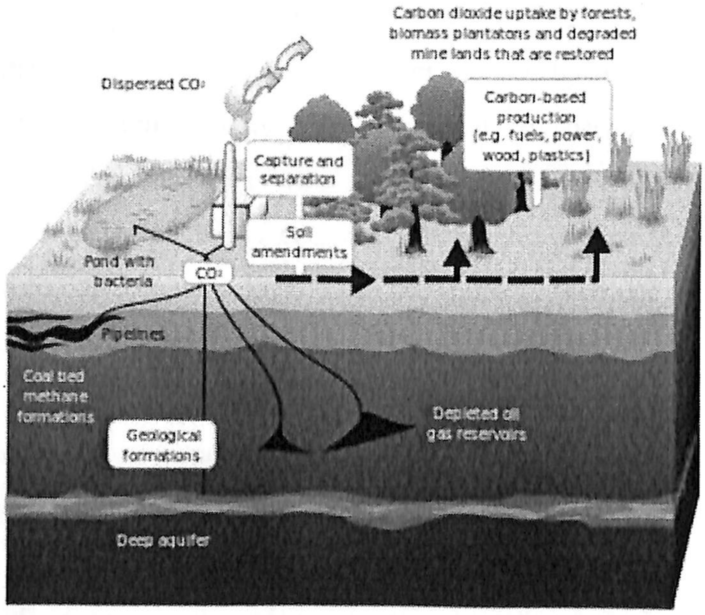
3.7 Storage & sequestration of carbon dioxide:

CO_2 is transported through pipes to storage sites which can be depleted deposits of oil and gas or geological sites, saline aquifers. Research on geo sequestration is ongoing in various parts of the world. The main potential appears to be deep saline aquifers and depleted oil and gas fields.



Pipelines for transporting CO_2

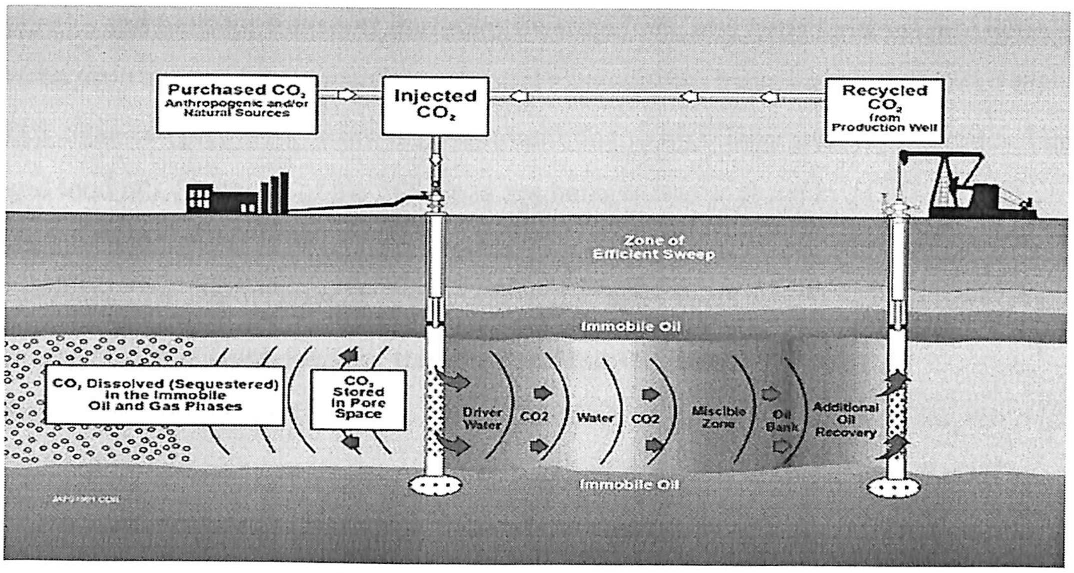
Storage on a large scale of CO_2 from power generation will require an extensive network of gas pipelines in densely populated areas, this has security implications. Given that rock strata have held CO_2 and methane for millions of years there seems no reason that carefully-chosen ones cannot hold sequestered CO_2. However, the eruption of a million tons of CO_2 from Lake Nyos in Cameroon in 1986 asphyxiated 1700 people, so the consequences of major release of heavier-than-air gas are potentially serious. Research on geo sequestration is ongoing in several parts of the world. The main potential appears to be deep saline aquifers and depleted oil and gas fields.



First CO_2 storage on an industrial scale in the world was done in the field of Norway's Sleipner gas in the North Sea, where about one million tons per year of liquid compressed CO_2 separated from methane is injected into a deep reservoir (saline aquifer) to a kilometer below the bottom of the sea and remains safely in place. The $80 million incremental cost of the sequestration project was paid in 18 months on the basis of the fiscal savings of $50 per ton of carbon. Overall Utsira sandstone formation there, about a mile below the sea floor, is said to be capable of storing 600 billion tons of CO_2. Gorgon natural gas from West Australia project is expected to capture and geo sequester CO_2 to reduce project 13.3 to 5.3 million tons of CO_2 emissions per year.

3.8 End use of captured carbon dioxide:

- The most useful way to reduce CO_2 emissions is EOR. In United States, more than 6,200 kilometers of pipelines are there for transporting up to 72 million tons of CO_2 every year that the oil industry uses for enhanced oil recovery. This produces 281.000 barrels of national oil per day, or 6 percent of U.S. crude oil production. The EOR industry has captured, transported and injected large amounts of CO_2 for oil recovery for more than four decades without major accidents, serious injury or death. EOR technology has the potential to recover at least another 26 billion barrels of oil in US, and improvement of technology could double this. US in 2011, created an initiative for the improved recovery of national petroleum (Neori) to help realize the full potential of CO_2-EOR as national energy security, economic and environmental strategy.
  Captured carbon dioxide gas can be put to good use, even on commercial terms for enhanced recovery of oil (EOR). This is well demonstrated in West Texas, and today 5800 km of pipelines connect oilfields to a number of sources of carbon dioxide in the United States. Operators inject more than 1.6 billion cubic feet per day of naturally-sourced CO_2 into Permian Basin oil fields to produce 170,000 barrels of incremental oil per day from dozens of fields.



EnCana Corp, a Canadian company, injects about 95 million cubic feet (4,935 metric tons) per day of CO_2 into Weyburn, a 55-year-old field, to recover an incremental 130 million barrels of oil via miscible or near-miscible displacement. The CO_2 is sourced from the lignite-fired Dakota Gasification Company synthetic fuels plant in North Dakota, and delivered via a 205-mile pipeline. EnCana estimates that as much as 585 billion cubic feet (30 million metric tons) of CO_2 will be permanently sequestered underground through the project, while boosting the synthetic fuel plant's revenues by about $30 million per year and extending the field's life by 20 to 25 years.

- The injection of carbon dioxide in deep exploitable coal layers where it is adsorbed to displace methane is another potential use or elimination strategies. Currently the economies of the extraction of coal-bed methane are not favorable, but the potential is great as more and more coal seam gas is being tapped.
- Recycling of CO_2 can offer a response to the global challenge of significantly reducing emissions of greenhouse gases from major stationary emitters (industrial) in the short and medium term, but is usually considered a technology category different from the CCS and is under development. Such as Bio CCS algae synthesis, uses CO_2 from thermal power station as raw material for the production of oil rich algae which produces oil for

plastics and fuels for transport (including aviation fuel), and nutritional values allows it to be used as feed for farm animals. Capital expenditures incurred in synthesis of Bio CCS algae can provide a return on investment due to high value products (plastics, fuels and food oil). Synthesis of Bio CCS algae are being tested in three large thermal power stations of Australia (Tarong, Queensland; Eraring, NSW; Loy Yang, Victoria) using CO_2 (and other greenhouse gases) as raw material to grow rich biomass of algae oil for the production of plastics, fuels for transport and nutritious food.

- Another potentially useful way to deal with industrial sources of CO_2 is to convert it into hydrocarbons which can be stored, reused as fuel or for the manufacture of plastics. There are a number of research projects of this possibility.
- Other uses include the production of stable carbonates from silicates. This process is still in the phase of research and development.
- A process proven to produce a hydrocarbon is to make methanol. Methanol synthesized fairly easily from CO_2 and H_2 (see green methanol synthesis).The idea of a methanol economy is based on this fact.
- CO_2 in bulk for the beverage market has become one of the most popular, profitable and reliable supply of carbonation for the end user.

3.9 Costs associated with CCS:

In 2005, for IGCC capture and sequestration cost was 1.0-3.2 c / kWh, which increases the price of electricity for IGCC by 21-78% to 05.05 to 09.01 c / kWh. It included energy penalty of 14-25% and mitigation cost of $14-53 / ton CO_2. These figures included up to $5 per ton for CO_2 transport and up to $8.30 / ton CO_2 for geological sequestration.

In 2009, the International Energy Agency (IEA) estimated CCS cost around $40 - 90 / ton of CO_2 but foresees it fall to $35-60 / ton by 2030, and McKinseys estimated CCS cost to tune of EUR 60-90 / ton which would fall to 30 to 45 euros / ton by 2030.

The International Energy Agency (IEA) says that CCS could reduce global emissions of carbon dioxide by 19%, and the fight against climate change could cost 70 percent more without CCS. There are several reasons why CCS is expected to cause such increases in energy prices. Firstly, the increase of the energy needs for capture and compression of CO_2 significantly increases the operating costs of CCS-equipped plants. In addition, investment and capital costs are also high. The process would increase the need for fuel for a plant with CCS by 25% in case of coal operated plant while 15% for a gas plant. The cost of this extra fuel, as well as storage and other system costs are estimated to increase the costs of energy for a power plant with CCS by 30-60%, depending on the specific circumstances. Pre-commercial CCS demonstration projects tend to be more expensive than mature CCS technology and total additional costs of an early large-scale CCS demonstration project are estimated to be €0.5-1.1 billion per project over the project lifetime.

3.10 Efficiency of NanoGlowa over conventional techniques:

NanoGlowa objective is to develop optimal nanostructured membranes and installations for CO_2 capture from power plants below 20 euro/ton with a build-in, smart, diagnostic technique. The 'scrubbing' technology is far from being energy- or cost-effective, as it can consume up to 25% of the energy actually produced, and large installations as well as chemicals are needed, says the NanoGlowa team. But CO_2 separation through membranes, on the other hand, would consume only up to 8% of the energy produced, and bring down installation costs. The nano structured membranes could reduce the emissions by up to 90% of conventional thermal power plants.

On the other hand CCS technologies impose huge operating costs and the loss of energy efficiency without concomitant benefit to the operator, although the external costs will offset in due course of time taking into account the carbon taxes or CERs and eventually will change the economics of burning coal.

CCS energy penalty is usually put in 20-30% of electricity production, although there are no existing complete commercial systems in operation, this is not yet been confirmed. Figures from the United States and Europe suggest small or even insignificant proportion.

Carbon capture and storage is a cost effective and affordable way to help secure low-carbon energy supplies. The cost of reducing carbon dioxide is considerably higher without CCS, up to 70% higher than international level (according to the IEA) The cost of individual CCS project can vary substantially depending on the source of the carbon dioxide to be captured, the distance to the storage site and the characteristics of the storage site.

But NanoGlowa membranes for capturing CO_2 are effective at low costs and can make CCS economically feasible for commercial implementation in power sector.

3.11 Economics for market development in India:

According to Report on National Action Plan for operationalizing Clean Development Mechanism (CDM) by Planning Commission, Govt. of India, the total CO_2-equivalent emissions in 1990 were 10, 01, 352 Gg (Giga-grams), Thus there exists a great opportunity awaiting for India in carbon trading which is estimated to go up to $100 billion by 2010. In the new regime, the country could emerge as one of the largest beneficiaries accounting for 25 per cent of the total world carbon trade, says a recent World Bank report. The countries like US, Germany, Japan and China are likely to be the biggest buyers of carbon credits which are beneficial for India to a great extent.

UNFCC Carbon Energy Credits (CERs) - Cost idea:

Cost of 1 ton of CO_2 emission reduction is only a few dollars for many developing countries or around 20 to 30 USD while for developed countries it ranges from 153 USD to 234 USD.

India Industry pocketed Rs 1,500 crores in the year 2005 just by selling carbon credits to developed-country clients. Various projects would create up to 306 million tradable CERs.

**In 2006, about $5.5 billion of carbon offsets were purchased in the compliance market, representing about 1.6 billion metric tons of CO_2 reductions.*

**1 carbon offset is 1 ton of CO_2.*

Analysts claim if more companies absorb clean technologies, total CERs with India could touch 500 million. Of the 391 projects sanctioned, the UNFCC has registered 114 from India, the highest for any country. India's average annual CERs stand at 12.6% or 11.5 million.

Total emissions for 2010 are estimated to be 33.376 billion tons, researchers said in the study, published in the journal Nature Climate Change. Out of this, India accounted for 1970 million tons of CO_2 ie 5.9% of total global CO_2 emissions. 498.655780 million tons of emissions from thermal power plants generating electricity during year 2010.

If NanoGlowa ie. nano structured membranes are used for CO_2 capture in existing thermal power plants, working at efficiency of 90% then captured CO2 will be around 448.790202 million tons. This would amount to around 448.790202 million CER's generating revenue of 11.219755 billion USD (at 25 USD per CER for developing countries) along with 22.78 % reduction in CO_2 emissions in India.

Apart from revenue generated from carbon credits, the captured CO_2 can be used for other commercial purposes which are stated above.

One such end use is EOR which can use substantial amount of CO_2 and also generate revenue by commercial selling. This would also help is sequestration of CO_2 in underground depleted oil and gas fields which is the most convenient way of storing CO_2 safely being employed by developed countries particularly by US.

CO_2 for commercial purpose cost around $45 per metric ton ($2.38 per Mcf) delivered at pressures around 2,200 psi to the field, constant and real. The additional revenue generated by selling of CO_2 for commercial EOR purpose could fetch another 20.1955591 billion USD (at 45$ per ton of CO_2).

**Another study carried out by Advanced Resources International (ARI) for DOE-NETL concluded that CO_2 EOR could provide a large, value-added market for the sale of CO_2. Emissions from new coal-fired power plants will be around 7.5 billion metric tons between now and 2030. It puts the value of that market at 260 billion.*

3.12 Limitations in implementation:

- Huge upfront investment is needed at power plant which would offset in due course of time through CERs and commercial selling of CO_2.
- For transporting CO_2 to depleted oil and gas fields large investment is needed for CO_2 pipelines, but this would be made by operator operating the field whose investment would offset by the incremental oil and gas that would be extracted by EOR.
- The whole process from carbon capture to transportation to storage would need vast investment, planning and coordination between power plant operating companies and operators of oil and gas fields.

** 1 Gg (Giga-grams) is 1000 tons.*

** 1 metric ton of CO_2 equals 19.25 thousand cubic feet (Mcf) at standard conditions of 14.7 psi and 70^{o} F.*

4. ENVIRONMENT AND HUMAN SAFETY:

Artificial nanomaterials (EN) present great opportunities for industrial growth and development, and a lot of promise for the enrichment of the lives of the citizens, in energy, electronics and many other areas. However, there are significant gaps in our knowledge about the potential hazardous effects on human health and the environment.

Due to its extremely small size and relatively large surface areas, nanomaterials can interact with the environment in ways that differ from conventional materials. Potentially harmful effects of nanotechnology could result from the nature of the nanoparticles and products made with them. Some materials, practically inert in its massive form, are novel but have potentially toxic properties in different nano scales.

Given that human health and environmental safety are of utmost importance, the effects of artificial nanomaterials and nanoparticles should be investigated thoroughly with a better understanding of the toxicology of nanoparticles and potential hazards in order to minimize their effect on consumers, workers and the environment. This will be useful for public and occupational health, as well as the successfulness and the sustainability of the nanotechnology industry.

Silver nanoparticles, for instance, are proven antibacterial agents incorporated into many nanotech paints and coatings. Samsung even coats some of its appliances with silver nanoparticles to kill germs. But concerns that nanosilver could accumulate in the environment, killing beneficial bacteria and aquatic organisms, as well as human health concerns, have led the U.S. Environmental Protection Agency (EPA) to make products containing silver nanoparticles the subject of the first EPA regulations applying to nanotechnology. Now, any company looking to sell products advertised as germ-killing and containing nanosilver or similar nanoparticles will first have to provide scientific evidence that the product does not pose an environmental risk. But the EPA has long regulated silver because it is a heavy metal known to cause health and environmental problems in sufficient quantities

There has been comparatively few studies about the risks of artificial nanoparticles and also there is no legal requirement to carry out such studies, and little funding is allocated to them. The poor results to date are neither conclusive nor consistent. For example, evidence indicates that the nanoparticles in the lungs may cause more severe than toxic damage conventional powders. Nanotechnologies can speed up the cleaning of the contamination of the soil and water, but in the process may damage the ecology of the local soil. The impacts of the large quantities of nanomaterials in the environment or human health have not been studied, and there are no studies on the accumulation or other impacts in the long term.

Nanotechnology risk assessment research for establishing the potential impacts of nanoparticles on human health and the environment should be undertaken as it 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.

5. ETHICAL, LEGAL & SOCIAL ASPECTS:

Since nanotechnology is so novel and complex, we can have real difficulties to highlight, quantify and manage potential risks that might be involved. As for all applications of nanotechnology, the main concerns focus on the potential of health and environmental risks of nanoparticles and nanomaterials and corresponding ELSA issues.

While most current ethical issues can be considered at present as lack of knowledge about many nano-applications, is more than likely that the widespread use of nano products in the middle term will be to raise the issues of data protection and privacy. Finally, although some scientists in nanotechnology they think that the contentious human improvement scenarios are far, suitable and the responsible questions need to be done seriously.

In 2007, the European Group on ethics in science and new technologies (EGE), a consultative body of the President of the EC, published a document of opinion on potential and impact on conducting research in both its security and its ethical, legal and social aspects.

A key cooperation between European trade union organizations, environmental NGOs and universities, which got together to formulate balanced position statements on nanotechnologies, came from **NANOCAP (European trade union and environmental NGO positions in the debate on nanotechnologies, http://www.nanocap.eu)**. The project deepened the understanding of environmental, occupational health, potential safety risks and ethical aspects of nanotechnology.

As a result, five European NGOs adopted a position on the responsible development of nanotechnology and the European Trade Union Confederation adopted a resolution representing 60 million workers in Europe. This joint effort was pressingly required by the rapid growth of many nano technological disciplines, the introduction of nano products onto the market, and the far-reaching effects that these developments may have on our society.

6. Conclusion:

The benefits that nanotechnology can offer to the energy industry are potentially enormous. As widely illustrated in the study, some nanotechnology applications are now available on the market, while others could come from the implementation of solutions developed by various pilot testing undergone under several research projects. This has led to breakthrough in numerous sectors now employing pioneering nano technologies, thanks to Nanotechnology Revolution.

The state-of-the-art technologies for photovoltaics, wind turbines, power transmission, and energy storage already rely on nanotechnology solutions which will bring down the manufacturing costs and bring power generation through renewables at par with power generated by conventional fossil fuel power plants. Other technologies and further elaboration will be required prior to direct use.

Efficient lighting, thermal insulation will help in conserving energy and in turn would help reduce greenhouse gas emission along with improving the operating efficiencies of existing conventional power plants.

The new membranes of modern generation for the separation of gases would help in capturing carbon dioxide economically and then using it for EOR techniques. This would help in reducing CO_2 emissions into the atmosphere which would help achieving the objectives of Kyoto protocol for climate change. At present the greatest challenge being faced is how to control CO_2 emissions which is increasing at an alarming rate, growing the global temperature which has colossal adverse effects.

At present research is being carried out globally under various research projects and promising results have been obtained from laboratory experiments, but field tests are still very limited. The future of nanotechnology appears to be bright. However, several issues must be considered and appropriate actions should be taken to transform a great opportunity into reality. There is dire need to improve convergence between the top down and the approaches from below upwards (i.e., miniaturization) between research and commercial exploitation, in view of funding and investment for targeting business correctly.

7. References:

- Applications of nanotechnology: Energy (Part 1), Luisa Filipponi & Duncan Sutherland, (iNANO), University of Aarhus, Denmark.
- Applications of nanotechnology: Energy (Part 2), Luisa Filipponi & Duncan Sutherland, (iNANO), University of Aarhus, Denmark.
- Nanotechnology White Paper, U.S. Environmental Protection Agency, February 2007.
- Nanotechnology and Energy, Republic of Africa, February 2011.
- Nanotechnology and the Energy Industry-Today and Tomorrow, Smalley Institute, April 30, 2010.
- Application of Nanotechnologies in Energy Sector, HESSEN, Hessian Ministry of Economy & Transportation.
- Current and Future Nanotech Application in Oil Industry, American Journal of Applied Sciences, 2012 Science Publication.
- Can Nanotechnology Provide a New Approach to Oil & Shale Gas Production? Andrew R Barron, Rice University.
- Successful European Nanotechnology Research, Unit G.4, Directorate General for Research and Innovation, European Commission.
- Nanotechnology for Green Building, Dr. George Erin, 2007 Green Technology Forum.
- Nanotechnology Applications in Energy Sector, Reinste.
- Nanotechnology Developments in India: A Status Report, Project Report No. 2006ST21:D5, April 2009.
- Innovative Coating Technologies, Superior Products International II, Inc.
- Nanotechnology-enhanced Thin-film Solar Cells, Ying Guo & Lu Huang.
- Potential Impacts of Nanotechnology on Energy Transmission Applications and Needs, U.S. Environmental Science Division.
- NanoGlowa Post Combustion CO_2 Capture Membranes, KEMA, Abu Dhabi, May 2011.
- CO_2 Capture and Storage, European Commission.

- A Model of CO_2 Flood Enhanced Oil Recovery with Application to Oil Price Influence on CO_2 Storage Costs, Sean T Macoy, Carnegie Mellon University, Pittsburgh, U.S.A.
- Prospects for Carbon Capture and Storage Technologies, Soren Andersen & Richard Newell.
- Market-based Post 2012 Climate Regime: Carbon Credits for NAMAs, Republic of Korea.
- Enhanced Oil Recovery using CO_2 in the European Energy System, Institute for Energy Petten, The Netherlands, December 2005.
- Untapped Domestic Energy Supply and Long Term Carbon Storage Solutions, NETL.
- Challenges on Membrane Upscaling For Industrial Testing, Professor May-Britt Hag, Department of Chemical Engineering, NTNU.
- www.hessen.nanotech.de
- www.powermag.com
- www.corporate.evonik.com
- www.altairnano.com
- www.3m.com
- www.umicore.de
- www.oxanematerials.com
- www.nrel.gov
- www.konarka.com
- www.nanoglowa.com
- www.nano.com