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NANOTECHNOLOGY IN MITIGATION OF GREEN HOUSE GAS – CO2

[1]K. Umamakeshvari
Assistant Professor of Physics, Manonmaniam Sundaranar University
Tirunelveli,Tamil Nadu chitra.uma86@gmail.com

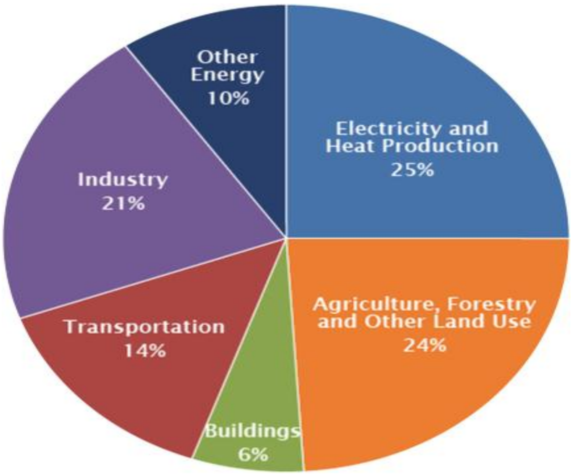
[2]Dr T .Manju, MSc.Med.Mphil.Ph.D.
Assistant Professor of Physics, Merit Arts and Science College, Idaikal, Pmbasamurdam, Tamil Nadu 627602.

1 Introduction:

Air pollution is one of the important factors in today's world. This paper is analysing the role of nanotechnology in bringing down the green house gases and its importance.Even if persons stop combusting fossil fuels and discharging CO2into the atmosphere, the average global temperature of the Earth will remain to increase for the rest of the centuryfor numerous factors. Firstly, the long lifetime of CO2 (estimated in the 100300 year range[1]) means that the excess atmospheric stocks (515 Gt Carbon)would continue to drive radiactive making and global warming form any decades[2].

2) Air Pollution / Green House Gas and statistics :

The atmosphere is a thin shell of gases, particles and clouds surrounding the planet. It is in this thin shell that we are dumping several billion tons of pollutants each year. The major sources of this pollution include fossil fuel combustion for power generation and transportation; cooking with solid fuels; and burning of forests and savannah. The ultimate by-product of all forms of burning is the emission of the colourless gas, carbon dioxide (CO2). But there are also products of incomplete combustion, such as CO and NOx, which can react with other gaseous species in the atmosphere. The net effect of these reactions is to produce ozone, another greenhouse gas. Energy consumption also leads to aerosol precursor gases (e.g., SO2) and primary aerosols in the atmosphere, which have direct negative impacts on human health and ecosystems.



3) Nano Technology

3.1) What is nano technology?:

Nanotechnology refers broadly to a field of applied science and technology whose unifying theme is the control of matter on the molecular level in scales smaller than 1 micrometre, normally 1 to 100 nanometers, and the fabrication of devices within that size range.[2].

i. Nanoscience and nanotechnology involve the ability to see and to control individual atoms and molecules. Everything on Earth is made up of atoms—the food we eat, the clothes we wear, the buildings and houses we live in, and our own bodies. It is important to distinguish here between 'nanoscience', and 'nanotechnology'. Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at larger scale. Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometre scale. [3]

ii. A nanometre is exceedingly small, only 10 atoms across. Something as small as an atom is impossible to see with the naked eye. In fact, it's impossible to see with the microscopes typically used in a high school science classes. The microscopes needed to see things at the nanoscale were invented relatively recently.

iii. Today's scientists and engineers are finding a wide variety of ways to deliberately make materials at the nanoscale to take advantage of their enhanced properties such as higher strength, lighter weight, increased control of light spectrum, and greater chemical reactivity than their larger-scale counterparts. All sorts of physical properties change and many biological systems function happens in this length scale.

3.2) Characteristics of Nanoparticle :

i. Nanomaterials have unique properties particularly because of the nanoscale features. Nanoparticles can exhibit totally novel characteristics due to their high surface/volume ratio which make them more reactive than bulk forms of the same materials

ii. A material (e.g. a metal) when in a nano-sized form can show properties which are totally different from those when the same material is in a non-nano form. The nanomaterial will manifest different physicochemical properties when its size decreased.

iii. Elemental characteristics can change rather markedly at the nanoscale range: some change color, some get better at conducting heat or reflecting light, some become stronger, and some change or enhance magnetic properties

`3.3) Classification of NanoMaterials:

i. Zero-dimensional (0D) nanostructures: In this, all of the three dimensions are in the nano metric range. Ex. Nano particles or well separated nano powders.

ii. One-dimensional (1D) nanostructure: In this, two dimensions are in the nano metric range and third dimension remains large. These structures have shape like rods. Ex. Nano tubes, Nano rods etc.

iii. Two-dimensional (2D) nanostructure: In this, only one dimension is in the nano metric range while other two dimensions remain large. These display plane like structures. Ex. Nano thin films, Nano coating, Nano layers etc.

iv. Three-dimensional (3D) nanostructure: In this, all three dimensions are outside the nano metric size range. It may consist of group of nano wires, nano tubes, or different distribution of nano particles.

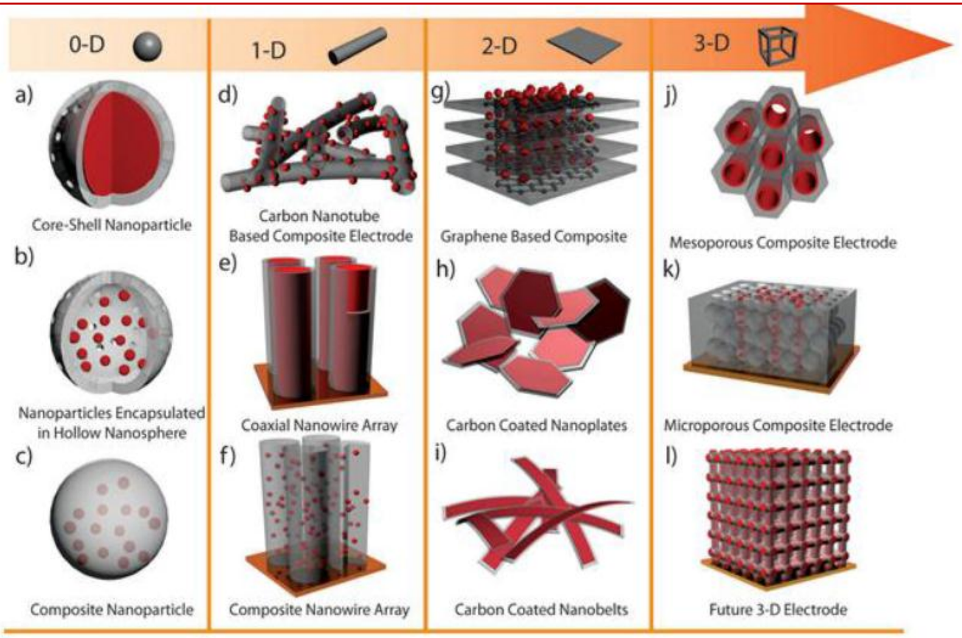


Figure 1. Nanomaterials are categorised according to their dimension

3.4) Nanomaterial synthesis:

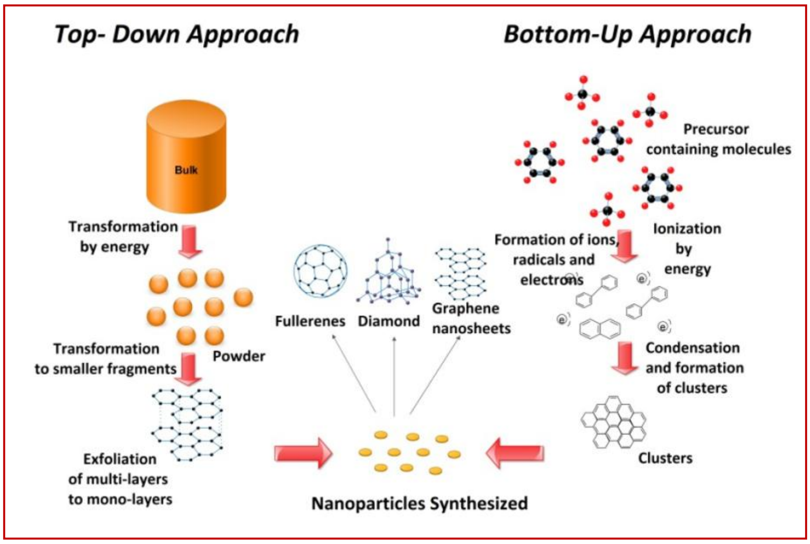
Routes for the synthesis of nanoparticles allows the control the particle size, particle geometry, doping ratio by different elements, and degree of particle agglomeration. Those particle parameters give the synthesized material new physical and chemical properties for different applications. A deep understanding of the synthetic approach is critical in order to manufacture new structures with unique properties. Basically, there are two types of approaches used for nanofabrication, namely

1. Bottom-up approach
2. Top-down approach

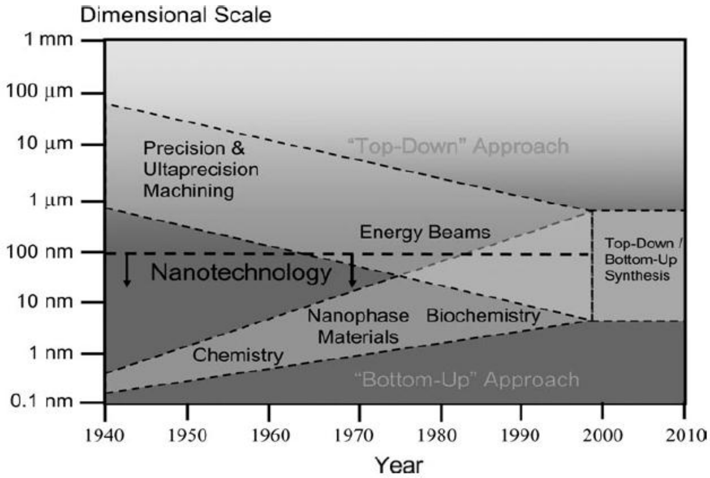
1. Bottom-up approach : A bottom up synthesis method implies that the nanostructures are synthesized onto the substrate by stacking atoms onto each other, which gives rise to crystal planes, crystal planes further stack onto each other, resulting in the synthesis of the nanostructures. A bottom-up approach can thus be viewed as an synthesis approach where the building blocks are added onto the substrate to form the nanostructures. This approach produces nanoparticles with fewer defects, homogenous chemical composition, less contamination, and particles with a narrow size distribution. Eg. sol-gel techniques, Supercritical fluid with a chemical reaction

2. Top-down Approach: A top down synthesis method implies that the nanostructures are synthesized by etching out crystals planes (removing crystal planes) which are already present on the substrate. A top-down approach can thus be viewed as an approach where the building blocks are removed from the substrate to form the nanostructure. Eg. vaporation/condensation, Laser Pyrolysis, Ionic/electronic irradiation

The bottom-up approach is more advantageous than the top-down approach because the former has a better chance of producing nanostructures with less defects, more homogenous chemical composition, and better short- and long-range ordering. An illustration of difference between top-down and bottom-up approaches are depicted in the figure [4]



In terms of the size of objects, both methods are very similar. Both approaches tend to converge in terms of the size range of objects. The former approach, however, tends to be more abundant based on the type of material, design varieties, and nanometric control, while the latter approach only makes the acquisition of materials of more importance, however, control may not be as strong. The convergence between the top-down and bottom-up routes to the exploitation of nanoscale phenomena is illustrated in Figure. [Roger W. Whatmore Ref.3]



3.5) Applications of Nanotechnology :

Nanotechnology has the potential to be the key to a brand new world in the fields of food and agriculture, energy, construction materials, pollution control, mechanical, medicine and electrical engineering. Although replication of natural systems is one of the most promising areas of this technology, scientists are still trying to grasp their astonishing complexities. Furthermore, nanotechnology and nanomaterials is a swiftly growing area of research where new properties of materials on the nano-scale can be utilized for the benefit of industrial and a number of capable developments exist that can potentially modify the service life and life-cycle cost of construction infrastructure to make a new world in future. [5]

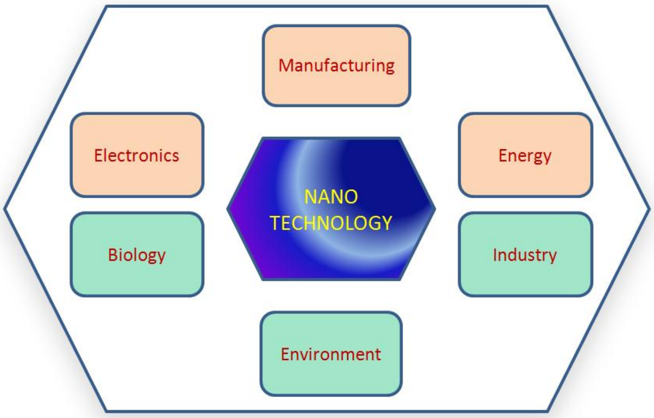


Figure 4: Nanotechnology Applications

3.6)Application of Nano Technology in mitigation of CO2 the GHG:

Nanotechnologies offer the ability to control matter at the nanoscale level to create materials with specific properties that can serve specific functions. This is particularly important in environmental issues where pollution often arises from the presence of a specific contaminant within a mixture of materials, being either in a solid, liquid or gas form. The small size of nanomaterials, together with their high surface-to-volume ratio, can lead to very sensitive detection. These properties will allow developing highly miniaturise, accurate and sensitive pollution-monitoring devices (“nano-sensors”) and help in the improvement of novel remediation technologies. Nanomaterials can also be engineered to actively interact with a pollutant and decompose it into less toxic species. Nanomaterials are excellent adsorbents, catalysts and sensors due to their large specific surface areas and high reactivates.

4.1) Automotive Sector:

4.1.1) CO2 Emission Norms : (Ref:15, 16 EU CO2 emission)

According to European commission for road transport, Cars are responsible for around 12% of total EU emissions of carbon dioxide (CO2), the main greenhouse gas. The EU first introduced mandatory CO2 standards for new passenger cars in 2009. The 2009 regulation set a 2015 target of 130 g/km for the fleet average of all manufacturers combined. Individual manufacturers were allowed a higher CO2 emission value, depending on the average vehicle weight of their fleet. The heavier the average weight of the cars sold by a manufacturer, the higher the CO2 level allowed. A similar CO2 standard for new light-commercial vehicles was introduced in 2011. It set a target of 175 g/km for 2017. [15]

The CO2 regulation for 2015 passenger cars has already led to noticeable results: the average CO2 emission level of new cars dropped from about 160 g/km in 2006 to 132 g/km in 2012 as measured over the European driving cycle, a 17 percent reduction. The annual reduction rate is about twice what it was before introduction of mandatory emission targets. For every 1g/km of CO2 that a manufacturer exceeds its average emissions target by, it will be charged with ‘Excess emission premium’ of €95 per vehicle.

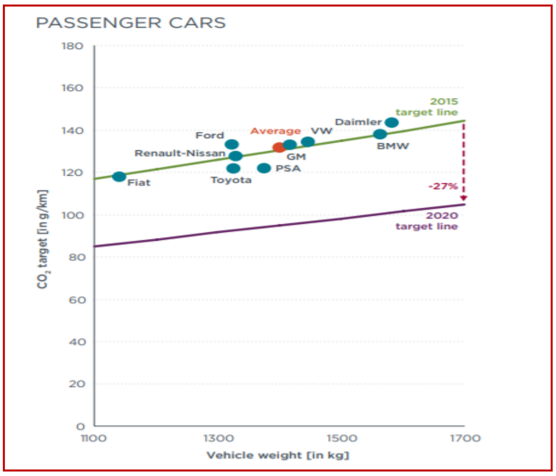


Figure 5. 2012 performance of key EU passenger car manufacturers, including 2015 and 2020 (effectively 2021) target lines. Data source: EEA. (Ref:16 EU CO2 emission)

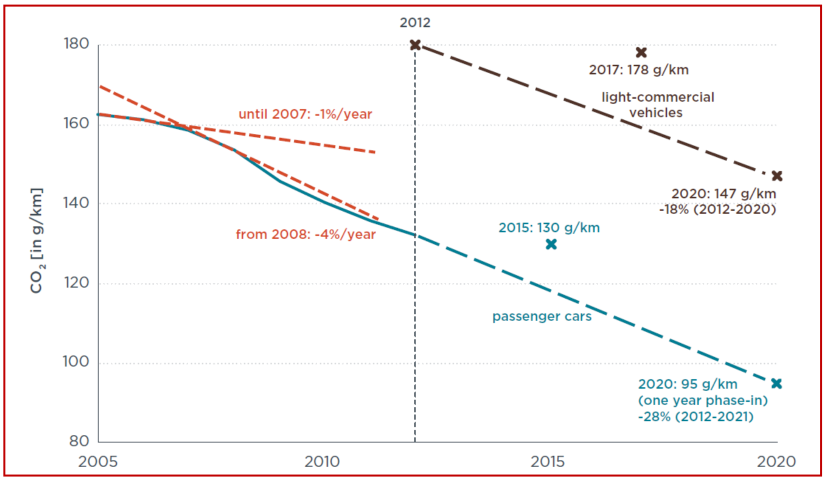


Figure 6. Historical development and future targets for CO2 emission levels of new passenger cars and light-commercial vehicles in the EU. Effects of phase-in, super-credits and eco-innovations not shown here. (Ref:16 EU CO2 emission)

4.1.2) Nanotechnology uses in Light weight vehicle design:

The amount of CO2 a car emits is directly related to the amount of fuel it consumes. And one of the factors attributed to the reduction of fuel consumption (i.e., improving fuel economy) is by minimizing the weight of the vehicles. Hence CO2 emission is directly related to the vehicle weight. The weight of the vehicles can be reduced by number of factors, such as improving structural stiffness, choosing alternate materials etc., The nanotechnology plays vital role in designing the higher strength structure with light weight materials.

4.1.2.a) Traditional materials used in automotive industry and progress towards nano materials :

The key materials used by the auto industry are high-strength steel (HSS), aluminum(Al), carbon fiber (CF) composites, and plastics which offer weight savings over traditional steel structures of up to 20% for HSS, 40% for Al, and up to 50% for CF composites.

Engineering plastics, although offering 20% weight savings, exhibit mechanical properties such as the strength, fracture and impact properties, modulus of elasticity, and shear modulus which are significantly lower than those of metals and hence, are inadequate for structural applications such as frame, drive module, or life capsule of the vehicle. These deficiencies frequently limit the use of polymers as high performance engineering materials.

[17] Historically Ford Motor Company (2010) estimated that improving fuel economy by 40% required vehicle weight reduction by approximately 340 kg without compromising safety. To achieve this goal, Ford launched intense R&D effort into developing and implementing lightweight composites and

coatings using nanomaterials . According to research completed by Garces et al., nanocomposite automotive components offer up to a 25% weight savings over the highly filled commodity plastics, and up to 80% over steel. It has been also demonstrated that an approximately 1.3%–1.8% reduction of CO2 emissions could be achieved from 5% reduction in vehicle weight, reaching up to 2.7%–3.6% at 10% vehicle weight reduction.

4.1.2.b) Polymer Nanocomposites:

Polymer nanocomposites are a new class of hybrid materials in which the traditional micro-sized fillers are substituted by nano-sized inorganic equivalents. These additives produce a drastically greater level of improvement of designated structural and functional properties of polymers than their micro-sized analogues.

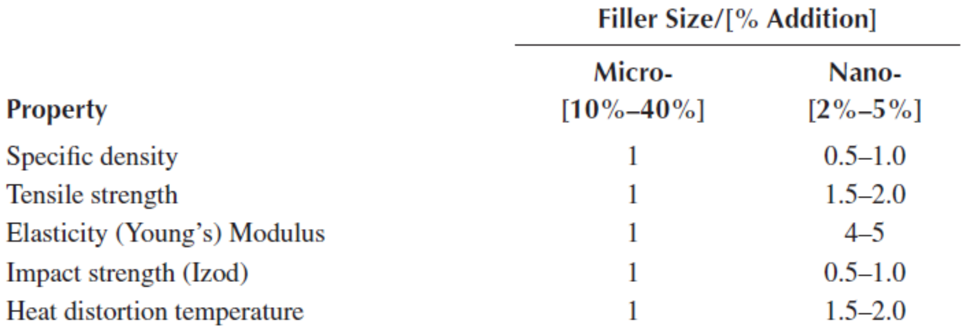
These are typically used in the form of nanoparticles, nanotubes, nanoplatelets, nanofibers, nanocubes, and other geometry materials dispersed in the host polymeric matrix. The resultant nano-composites exhibit superior mechanical, electrical, thermal,barrier properties, fire retardancy, impact resistance, and other physico-chemical properties not achievable through the addition of micro-sized fillers [13–16] making them suitable for replacing metals in automotive and other applications.

Several studies [Ref:9,10] have indicated that carbon nanotubes (CNTs), clay nanocomposites with polyamide (PA), Mg, Al, Si, and TiO2 nanomaterials have lighter weight and have higher thermal properties which can enhance the overall strength and durability of automobiles over a longer period.

The use of strong lightweight nanocomposites is additionally anticipated to facilitate optimized car body designs leading to lowering the drag coefficient due to an estimated gain of 10% in aerodynamic flow improvement which can, in turn, produce an associated 20% reduction of rolling resistance of tires and 7.5% increase in average power train efficiency.

The below table provides an outline of gains in nanocomposites properties in comparison with the counterpart micro-filler reinforced composites.

Table-1 : Gains in Nanocomposite properties versus Standard Composites:



	Filler Size/[% Addition]	
Property	Micro- [10%–40%]	Nano- [2%–5%]
Specific density	1	0.5–1.0
Tensile strength	1	1.5–2.0
Elasticity (Young's) Modulus	1	4–5
Impact strength (Izod)	1	0.5–1.0
Heat distortion temperature	1	1.5–2.0

Source: Adapted from Presting, H. and Koning, U. 2003. *J. Mater. Sci. Eng.* 23, 737.

The key categories of automotive applications of polymeric nanocomposites to date are body frames, interior and exterior body parts, power train, suspension and breaking systems, exhaust systems, fuel and other fluid lines, paints and coatings, lubrication, tires, and electrical/electronic equipment.

Nanotechnology and nanomaterials are of great importance to the automotive industry to improve the performance of automobiles as well as meet both consumer needs and regulatory requirements. According to an estimate, nanotechnology and nanomaterials enabled products utilized in the automobile industry for 2010 was around $246 million and by 2015, estimates are up to $888 million (conservative) and $1.852 billion (optimistic) [Ref:13].

4.1.3) Nanotechnology for an Efficient Engine :

Inorder to have environmental friendly technology, the most highlighted issue in the transportation industry is the reduction of pollutants emissions from the engines. One of the ways to reduce the GreenHouse Gas emission, is by improving the efficiency of the engine.

The energy output out of fuel in a car engine, 33% is spent in exhaust, 29% in cooling and 38% in mechanical energy, of which friction losses account for 33% and air resistance for 5%. [Ref:21 sciencedaily] . By comparison, an electric car has only half the friction loss of that of a car with a conventional internal combustion engine. Annual friction loss in an average car worldwide amounts to 11,860 MJ: of this, 35% is spent in overcoming rolling resistance in the wheels, 35% in the engine itself, 15% in the gearbox and 15% in braking. With current technology, only 21.5% of the energy output of the fuel is used to actually move the car; the rest is wasted.

[Ref:7 Mohammad]The frictional loss in the engine could be reduced with the help of aluminium nanomaterials coating. Reference [Re :21] conducted an experiment by adding the Al2O3 nanoparticles at various temperatures. Results showed that addition of nanomaterial enhanced the thermal conductivity by about 4.5% and 4.2% at temperatures of 50 °C and 30 °C respectively. Nonetheless, during the operation, the maximum amount of Al2O3 nanoparticles was about 1.5 vol% [Ref:22, Kole]. Another experimental study [Ref:25, Kulkarni] revealed that with increased Al2O3 nanoparticle concentration, the heat exchange efficiency of the engine is increased, as shown in Figure 8. This also indicated that with the enhancement of Al2O3 nanoparticle concentration the cooling effect of the engine will be enhanced.

The use of Nanofluid not only enhances the thermal conductivity of the vehicle engine, but also helps to mitigate the pollutant emissions. [Ref:23, Soukht Saraee]. An experimental study, was performed by adding silver nanoparticles to pure diesel fuel. From the result evaluation, it was concluded that the inclusion of the nanomaterial greatly reduced the emission rates ofNOx and CO by up to 13 and 20.5%, respectively . Similarly, another study [Ref:24, Mitchell] reveals, with the inclusion of aluminium nanoparticles in diesel fuel, the smoke concentrations were significantly reduced as compared to the normal diesel fuel. Hence, it could be understood that usage of nanomaterials in vehicle engine, contributes for the reduction of emission of hazardous gases. Some of the nanofluids which could be beneficial for the vehicle cooling system and engine performance, are listed in the below table.

Table -2: Benefits of nanofluids for vehicle system cooling and engine performance.

Sl.No	**Nano Fluid**	**Benefits**	**Reference**
1	Nanodiamond–engine oil	Nanofluid improves the engine performance by increasing the engine power by about 1.15% and reducing the fuel consumption by about 1.27% Compared to simple engine oil.	12
2	Al2O3−water, Al2O3−EG, Al2O3−EG/water (5–20 vol% of EG)	Heat transfer performance was enhanced about 40% with the addition of 1.0 vol% of nanoparticles of Al2O compared to the pure fluid.	18
3	CuO−water, Fe2O3−water	0.65 vol% CuO−water nanoparticles enhanced the heat transfer coefficient by up to 9%.	19
4	SiO2−water, TiO2−water	The maximum Nusselt number improvements for SiO2 and TiO2 nanofluids were 22.5% and 11%, respectively	20

4.1.4) Nanotechnology for alternative propulsion system- The Hydrogen Fuel Cell:

b. Industrial emission and CCS(Carbon Capture and Storage):

About one-fifth of U.S. greenhouse gas emissions come directly from industrial sources, such as manufacturing, food processing, mining, and construction. These direct emissions result from diverse processes, including the on-site combustion of fossil fuels for heat and power, non-energy use of fossil fuels, and chemical processes used in iron, steel, and cement production.

In addition, industry generates indirect emissions from the centrally generated electricity it consumes. The industrial sector makes up about one quarter of total U.S. electricity sales. If direct and indirect emissions are combined, the industrial sector is the largest emitting sector in the U.S. economy, responsible for 29.3 percent of total emissions

Other industrial sectors, such as refineries and cement kilns, have been regulated for certain pollutants, including particulate matter (PM), sulfur dioxide (SO2), and dioxides of nitrogen (NOx), since the Clean Air Act became law in 1970.

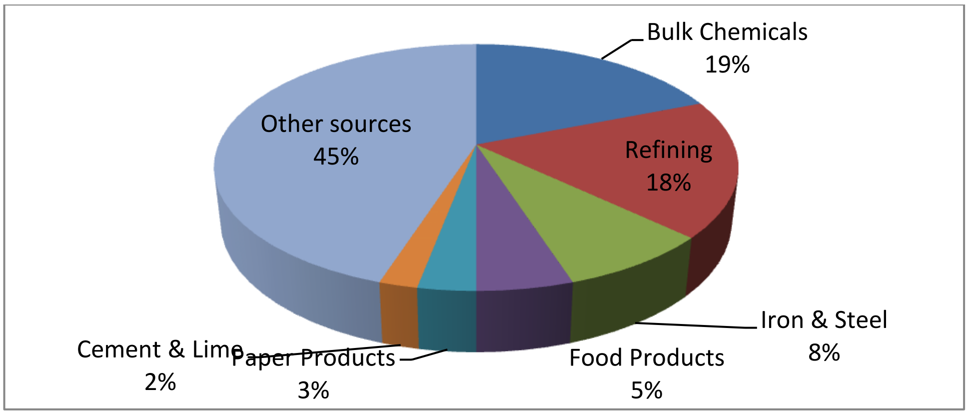


Figure 7: Energy related CO2 emissions from industries – 2019 [Source: Annual Energy Outlook (U.S. Energy Information Administration, 2020)]

There are many ways to reduce greenhouse gas emissions from the industrial sector, including energy efficiency, fuel switching, combined heat and power, use of renewable energy, and the more efficient use and recycling of materials. Many industrial processes have no existing low-emission alternative and will require carbon capture and storage to reduce emissions over the long term.

Carbon capture & Storage (CSS) :

CCS technology involves separation of CO2 from other gases emitted by power plants and industrial facilities. After transportation of the captured CO2 by pipeline or ship to an appropriate facility, the captured CO2 can either be re-used or stored underground. [Ref:26, Chouliaras]. Three basic techniques are used to capture CO2, viz, pre-combustion, post-combustion and oxy-fuel combustion and the process flow is depicted in the figure:

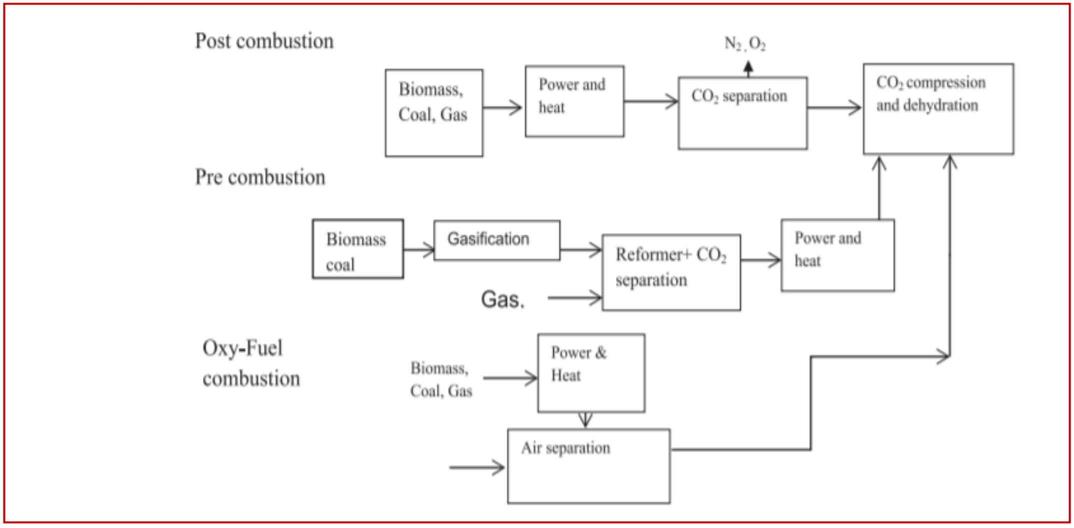


Figure 8 Carbon capture and storage methods [Ref:27, Ravinder Kumar]

Pre-combustion technology captures CO2 before the combustion in an energy plant, resulting in a cleaner fuel in the combustion process, thus in less CO2 emissions. It is mainly used in new power plants, since it is relatively expensive to adapt into existing infrastructure.

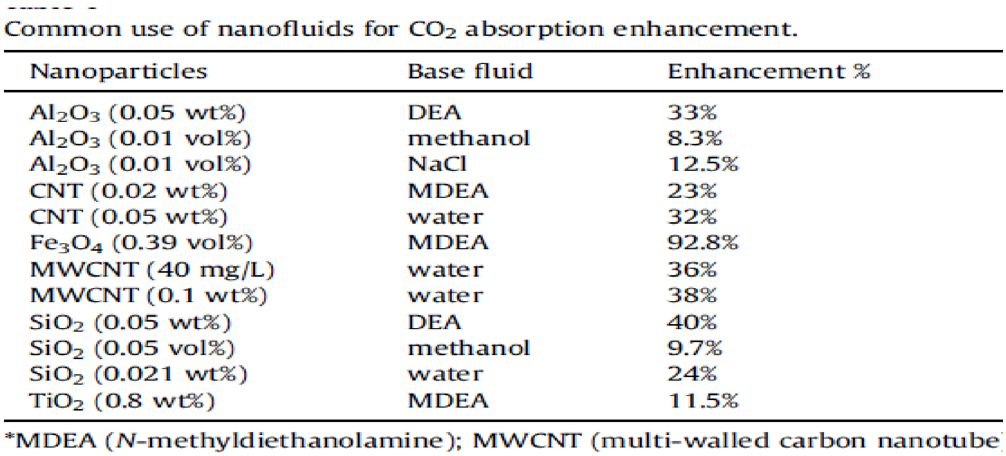
Post-combustion technology captures the CO2 after the combustion process in a power plant and can be applied in new and already existing plants, since the adaptation is relatively cheap, for the reason why only the processor needs to be adapted for the CO2 capturing.

Oxy-combustion technology is based on the principle that if a power plant is fired with high-purified oxygen instead of air, the flue gas is mainly composed of CO2 and H2O. There are technical challenges in the adaptation of existing plants, because the heat transfer characteristics can change and the purification of oxygen on a larger scale might not be up to the standards for a medium oxy-combustion plant.

CO2 absorption enhancement by nanofluids:

Nanofluids have been paid extensive attention for heat and mass transfer enhancement as the next-generation working fluids. Several methods for CO2 absorption using nanofluids have been extensively investigated including absorption, membrane gas absorption, membrane separation. The influence factors including the nanofluids type, nanoparticle size and volume percent, pressure, temperature, and CO2 concentration are considered in this section.[Ref:38, Zhien]

A large number of metallic and non-metallic nanofluids are used to capture CO2. Table-5 lists the enhancement results of CO2 absorption using different nanofluids.



Common use of nanofluids for CO_2 absorption enhancement.

Nanoparticles	Base fluid	Enhancement %
Al_2O_3 (0.05 wt%)	DEA	33%
Al_2O_3 (0.01 vol%)	methanol	8.3%
Al_2O_3 (0.01 vol%)	NaCl	12.5%
CNT (0.02 wt%)	MDEA	23%
CNT (0.05 wt%)	water	32%
Fe_3O_4 (0.39 vol%)	MDEA	92.8%
MWCNT (40 mg/L)	water	36%
MWCNT (0.1 wt%)	water	38%
SiO_2 (0.05 wt%)	DEA	40%
SiO_2 (0.05 vol%)	methanol	9.7%
SiO_2 (0.021 wt%)	water	24%
TiO_2 (0.8 wt%)	MDEA	11.5%

*MDEA (*N*-methyldiethanolamine); MWCNT (multi-walled carbon nanotube

Table-5 .[38]

Case Study :

Jung Yuel conducted study [Ref:39] on “CO2 absorption characteristics of nanoparticle suspensions in methanol” while trying to enhance CO2 absorption rate in the energy efficient way. In that study, the basic rectisol process of extracting CO2 from feed gas, methanol was used as base fluid absorbent and the absorbent needed to be maintained around -40degC to increase the absorption rate according to the Henry's solubility law. Jung Yuel [Ref:39]could enhance the CO2 absorption rate by ~8.3% with the addition of nanofluids in the base fluid, provided, the absorbent not necessarily to be maintained in such a very low temperature of -40degC as per the original process and there by the energy required to maintain such a low temperature was saved. According to their study, the following important points were observed.

Observation :

Sl. No	Factor affecting CO2 absorption	Observation
1	Dispersion stability	Stable suspension of the nanoparticles is required Hydrodynamic diameter of the nanoparticles suspended in nanofluids should be below the critical size to be suspended stably in the base fluid. Figure:B1 If the nanoparticle size exceeds its critical size, the nanoparticle will be sedimented due to the gravitational force. The critical size ‘G’ for the dispersion stability can be determined by considering the repulsion force due to the Coulomb force and the attraction one due to the van der Waals force. $$G' = \frac{1}{3}\pi\left(\rho_p - \rho_{bf}\right) g \sqrt{\frac{2r^5\tau_p}{3\mu k_B T}}$$ where ρ_p and ρ_{bf} are the densities of particle and base fluid, μ is the viscosity of the base fluid, r is the radius of the particle, τ_p (= l_{np} /u_{Br} , *lnp* is the mean free path of the nanoparticle and u_{Br} is its Brownian velocity) the relaxation time of particle which is the period between consecutive collisions or encounters with another particle, k_B is the Boltz mann constant, T is the temperature, and ‘g’ is the acceleration due to gravity.

2	Absorbent amount (Methanol)	The effective absorption ratio decreases with increasing absorbent amount because the effects of the Brownian motion and the mixing flow due to the nanoparticles decrease. Figure:B2.
3	Particle concentration on absorption rate and amount (Alumina)	Addition of alumina nano particle with methanol improves the abosorption rate. Optimal amount of nanoparticle is required. Not less and not more. If it is more, nano particle's 'Brownian motion' is affected due to inter nano-particle interaction . 0.01% vol provides maximum absorption.
4	Phenomenon behind improved CO2 absorption	The hydrodynamic effect model proposes that the particles may increase the specific interfacial area by covering the bubble surface and preventing the coalescence of the bubbles, resulting in smaller bubbles. Mass transfer enhancement, mainly due to the velocity disturbance field in the fluid created by the motion of the nanoparticles. Enhanced CO2 absorption was induced by both of mixing and breaking of gas-bubbles due to the motion of nanoparticles.

Output graphs:

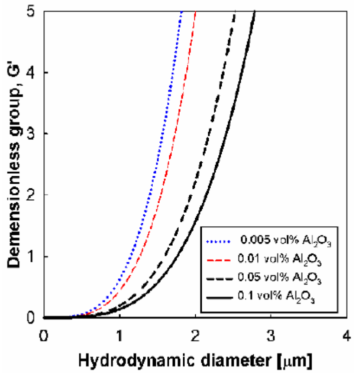
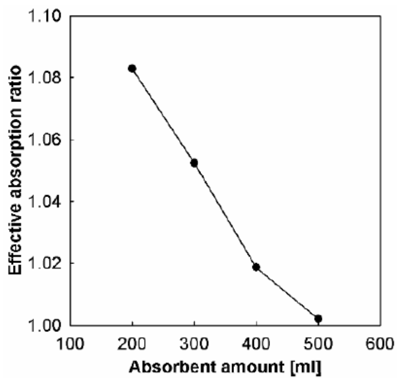
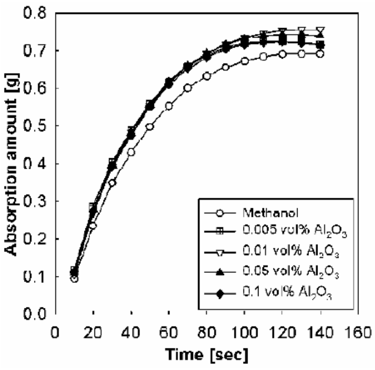
		

Figure:B1 Critical size of the particles for good dispersion stability in alumina/methanol nanofluids.	Figure :B2 Effective absorption ratio depending on the absorbent amount for the 0.01 vol% of alumina particles.	Figure: B3 Effective absorption ratio depending on the particle concentration

c.Nanotechnology in enhanced Renewable energy application:

Unlike the combustion of coal, natural gas, and distillate fuel-which produces carbon dioxide-wind, solar, and hydroelectric energy systems emit no GHG because their fuel or energy source is carbonfree. Thus, the amount of GHG emitted into the atmosphere can be reduced only when fossil-fuel generation is avoided or replaced by renewable systems or other non-GHG-emitting electric generation systems.

Solar Energy :

In the area of clean energy generation (without GHG), the greatest application of nanotechnology seems to be in the area of efficiently harnessing solar energy using PV cells. Efficient PV system has a lot of potentials for overcoming the energy supply challenges.

PV cells are made out of semi-conducting materials such as crystalline silicon which is presently considered the most efficient material. When light of the right band gap energy hits the cells, they absorb solar radiation in form of photon which knocks out electrons in the silicon. Addition of different impurities in the silicon such as phosphorus or boron, results in the creation of electric fields which acts as diodes by allowing electrons to flow in one direction resulting in electrical energy generation. The current drawback in the use of solar cells are the high cost of manufacturing which reflects in the present high cost of conventional PV cells. The efficiency of solar energy absorption is also currently very poor (less than 40%) with only a fraction of the absorbed energy converted into electrical energy. Alternative material such as TiO2 which results in cheaper PV cells has even lower conversion efficiency. Nanotechnology can be used to introduce alternative materials and fabrication methods to produce cost effective PV cells with acceptable if not higher energy conversion efficiency.

Classic nanostructures such as carbon nanotubes (CNT), fullerenes and quantum dots are being used to make solar cells lighter, cheaper and more efficient. The increased surface area to volume ratio of nanoparticles enhances solar radiation collection by exposing more conducting surfaces to solar radiation. Also the use of nanomaterials such as lead selenide results in more electrons (and therefore more electricity) to be released when hit by a photon of light. Structural properties of PV cells are additionally being modified using nanotechnology.

Wind Energy:

Nanotechnology is also used in improving the efficiency of windmills. An epoxy-containing carbon nanotubes is now used to make stronger and lighter windmill blades resulting longer blades which increase the amount of electricity generated by such windmills. The wind turbine life span can also be increased by using nano paints.

Geothermal Energy:

Geothermal energy generation is also enhanced by nanotechnology. In conventional geothermal energy production, cold fluids are injected into naturally heated hot rocks usually found over 1500m below the earth surface. The heated fluid is then extracted and used to generate electricity. Nanotechnology is now helping to make geothermal energy more practical by allowing efficient energy production closer to the surface and at lower temperatures. The heat-retaining properties of the fluid are also being enhanced with nanoparticles.

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