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Barriers and Prospects of Carbon Sequestration in India

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Carbon sequestration is considered a leading technology for reducing carbon dioxide (CO_2) emissions from fossil-fuel based electricity generating power plants and could permit the continued use of coal and gas whilst meeting greenhouse gas targets. India will become the world's third largest emitter of CO_2 by 2015. Considering the dependence of health of the Indian global economy, there is an imperative need to develop a global approach which could address the capturing and securely storing carbon dioxide emitted from an array of energy. Therefore technology such as carbon sequestration will deliver significant CO_2 reductions in a timely fashion. Considerable energy is required for the capture, compression, transport and storage steps. With the availability of potential technical storage methods for carbon sequestration like forest, mineral and geological storage options with India, it would facilitate achieving stabilization goal in the near future. This paper examines the potential carbon sequestration options available in India and evaluates them with respect to their strengths, weakness, threats and future prospects.

Key words : *Carbon sequestration, carbon capture and storage, carbon sources, CO_2 emission*

) Introduction

India's economy is growing at the rate around 9% r annum, while the country is emitting significant amounts greenhouse gases (GHGs) from fossil fuel use. The ternational Energy Agency (IEA) predicts that India will be the top three emitters of Greenhouse gases (GHG) in the orld by 2030[1]. Therefore, India is a priority target for CO_2 duction. However, almost half of India's households (56%) not have electricity, and women and girls spend a total of billion hours each year collecting firewood[2].

The vast majority of India's population (70%) lives rural areas and agriculture accounts for 35% Gross National oduct (GNP) and directly employs more than 60% of the dian population[1]. According to the Intergovernmental Panel Climate Change (IPCC), some of the most severe impacts climate change will hit India's agriculture and natural sources[3]. For example, Himalayan glaciers are amongst the stest retreating in the world; glacial melt water that feeds the ajor rivers on the sub-continent accounts for 37% of India's igated land, loss of this glacier melt water could cause water ortages for 500 million people[3].

A high proportion of India's energy comes from coal, country's escalating fuel needs raise concerns of supply. dian policymakers are taking a growing interest in promoting ergy efficiency and renewable, as demonstrated by the ational Action Plan on Climate Change[4]. The Indian vernment also plans to invest in several coal-fired Ultra-Mega Power Plants (UMPPs), with a power generating capacity of 4GW per unit accounting for 36GW overall. In 2006, the annual CO_2 emissions from large point sources in India was estimated to be 721 Metric tonne CO_2, and a report by the IEAGHG[5] noted that this was roughly half of total emissions, which were approximately 1343 Metric tonne in 2004. Over half of India's current CO_2 emissions are from large point sources[1]. Such sources could be a suitable point for capturing emissions, transporting them, and then storing them in different forms like geological, oceanic, mineral and forest as a mitigation strategy.

CO_2 is emitted principally from the burning of fossil fuels, in large combustion units used for electric power generation and in smaller, sources such as automobile engines and furnaces used in commercial buildings. CO_2 emissions also result from some industrial processes, burning of forests and land clearance. Carbon Capture and Storage (CCS) is most likely to be applied to large point sources of CO_2, which involves power plants and large industrial processes. These sources sometimes supply hydrogen as a fuel to the transportation, industrial and building, reducing emissions from the distributed sources. As illustrated in **Fig. 1,** there are three main components of the CCS process: capture, transport and storage. The capture step involves separating CO_2 from various gaseous products. The transport step involves carrying captured CO_2 to a suitable storage site located at a distance from the CO_2 source. Potential storage methods include injection into underground geological formations,

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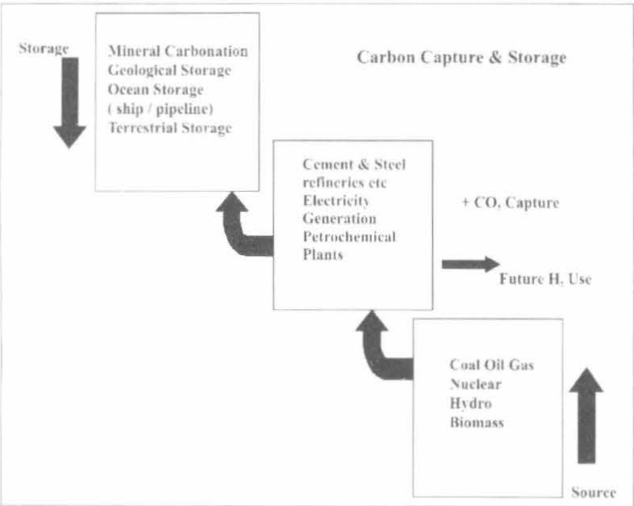

Fig. 1 : A schematic diagram of the possible carbon sequestration process, indicating the sources for which carbon sequestration might be relevant, as well as CO_2 transport and storage options

injection into the deep Ocean and industrial fixation. However, the technical maturity of specific CCS system components varies greatly.

1.1 Sources of CO_2

The attractiveness of CO_2 source for capture depends on its volume, concentration and partial pressure, integrated system aspects, and its proximity to a suitable reservoir. Emissions of CO_2 arise from a number of sources, like fossil fuel combustion in the power generation, industrial, residential and transport sectors. Technological changes in the production and nature of transport fuels, however, may eventually allow the capture of CO_2 from energy use in this sector.

Global emissions of CO_2 from fossil-fuel use in the year 2000 totalled to about 23.5 Gega tonne CO_2 yr^{-1} (6 Gega tonne C yr^{-1})[1]. Of this, close to 60% was attributed to large stationary emission sources (**Fig. 2**). Increased fuel utilization for electric power generation and transportation, resulted in energy related CO_2 emission. Increased demand for electricity for computers, electronics in homes and offices; demand for commercial lighting and cooling; substitution of electricity-intensive technologies, such as electric arc furnaces for steelmaking, in the industrial sector; and increased demand for transportation services have led to increased emissions of CO_2. Though not all these sources are capable of CO_2 capturing. Coal which is the most dominant fuel in the power sector, accounts for 38% of total electricity generated in the year 2000, followed by hydro power (17.5%), natural gas (17.3%), nuclear (16.8%), oil (9 %), and finally non-hydro renewable (1.6%)[6]. Fuel selection is greatly sector-specific

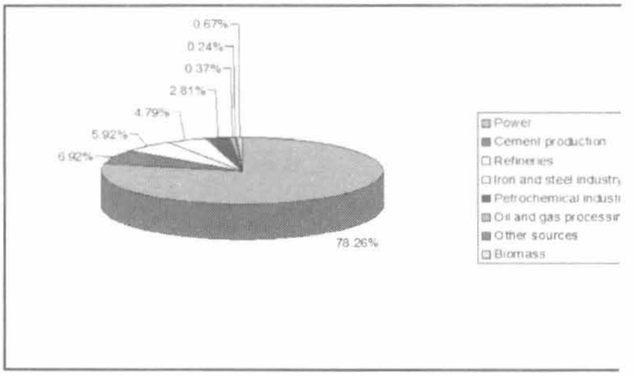

Fig. 2 : Profile by process or industrial activity of worldwi large stationary CO_2 sources with emissions of mo than 0.1 million tonne CO_2 per year (Data taken fro IPCC 2005[6])

like the use of blast furnaces in the iron and steel indus using coal and coke as their primary fuel for the production steel[7-8]. Refining industry on the other hand uses oil and g as their fuel. Cement manufacturing industries use fossil fu such as coal[9]. On the other hand, European ceme manufacturing processes utilize non fossil fuel based fu like tyres, sewage sludge and chemical-waste mixtures[9]. Ot countries like Scandinavia and Brazil, use biomass as a fue

The emission sources include mainly large station sources which involve the use of fossil fuel and biomass. F combustion activities, natural gas processing and industr processes are some of the large stationary sources resulti in CO_2 emission. Carbon dioxide emissions also take pl from a variety of industrial production processes involvi transformation of materials by chemical, biological and physi processes. [7, 9, 11, 12].

1.2 CO_2 emission : future sources

The IPCC Special Report on Emission Scenari (SRES) projects the future emissions of CO_2 on the basis six illustrative scenarios where global CO_2 emissions ran from 29 to 44 Gega tonne CO_2 per year in 2020, and from to 84 Gega tonne CO_2 per year in 2050[3]. It is projected t in the South and East Asian countries the electric pov and industrial sectors will account as significant C emission sources by 2050, whereas in Europe there may a slight decrease in such sources. Great amount of CO_2 w be produced from higher number of plants installati making CO_2 sequestration process more feasit technology.

1.3 Energy and power sectors as major CO_2 sources in In

India depends largely on fossil fuel based ene input system in major industrial as well as domestic sect Coal is the main energy source in India dominating current Indian energy sector[1]. India has the world's fourth largest hard coal reserves and is the third largest coal producer after China and the USA. The IEA[1] predicts that the overall share of imports in Indian primary coal supply would increase from 12% in 2005 to 28% in 2030. CCS could play a major role in this sector particularly as regards upcoming power plants.

In terms of installed power-generating capacity, Indian power sector is ranked fifth in the world. In 2005, power stations emitted an average 943g of CO_2 per kWh of electricity produced in 2005[1]. This accounted for nearly 60% of India's total CO_2 emissions for the year 2005. In 2006, the Ministry of Power launched an initiative to develop Ultra Mega Power Plants (UMPPs) having a capacity of 4 GW. These UMPPs account for 257 Metric tonne CO_2 emissions and 36000 MWe installed capacity within 7-8 years[5]. These represent an example of a massive point source of CO_2 emissions[13] which may be considered as a globally competitive opportunity for CCS. However, India is still seriously struggling to provide electricity to all its citizens.

In India, oil and natural gas are among the main energy sources. The total oil production in the country from 2003 to 2008 is shown in **Fig. 3**. The total oil production in 2008 for India was 880,500 bbl/day. The total oil consumption of India from 2003 to 2008 is shown in **Fig. 4**. The total oil consumption in 2008 for India was 2.722 million bbl/day. According to the IEA[1] by the end of 2006, the current reserves accounted approximately 0.4% of the world's reserves. As a result of which India has to import about 100 million tonnes of crude oil from the Middle East. Though India's current oil import dependence is about 70%, which is projected to rise to 94% by 2030[1].

2.0 CO_2 capture and storage : general trends

CO_2 capture and storage process involves capturing CO_2 from large sources like power plants to produce a concentrated stream that can be easily transported to a CO_2

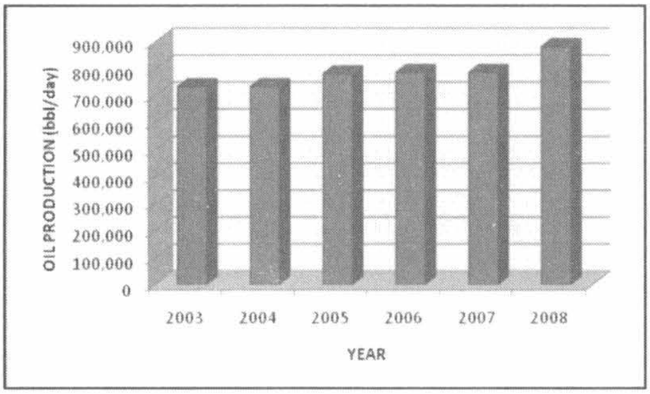

Fig. 3 : Total oil production in India [42]

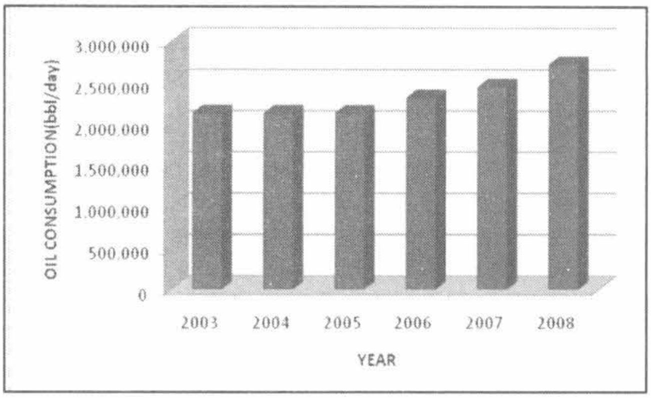

Fig. 4 : Total oil consumption in India[42]

storage site. This capturing technology is a way forward for development of new technology involving production of low-carbon or carbon-free electricity and fuels requirement for transportation, as well as for small-scale applications. Energy requirement for CO_2 capture operation systems reduces the overall efficiency of power generation leading to increase in the fuel requirements, solid waste generation and environmental impacts relative to the same type of plant without capture.

CO_2 is separated at some large industrial plants such as natural gas processing and ammonia production facilities, to meet process demands and not for storage. CO_2 capture has also been applied to several small power plants. There are mainly three main CO_2 capturing processes for industrial and power plant applications : (1) Post combustion systems which involve separation of CO_2 from the flue gases produced by combustion of primary fuel like coal, natural gas and oil in air; (2) Oxy-fuel combustion system utilizing oxygen for combustion and producing mainly H_2O and CO_2, commonly called syngas which can be readily captured; and (3) Pre-combustion systems process involving combustion of primary fuel in a reactor producing separate streams of CO_2 and H_2 which can be used as a fuel.

2.1 CO_2 storage systems

2.1.1 Geological storage

Geological storage of CO_2 is quite widely regarded as a potentially important mitigation option for various reasons like: (1) various commercial projects have been successfully undertaken and demonstrated increasing the level of confidence in the technology; (2) broader aspect of mitigation options is required; and (3) large CO_2 emission reduction in the atmosphere. The technique is safe, environmentally sustainable, and cost-effective and has broad applications. To store CO_2 geologically, it is normally compressed to a dense fluid state typically known as supercritical.

Geological storage of CO_2 is undertaken in a variety of geological settings such as oil fields, depleted gas fields, deep coal seams and saline formations are all possible storage formations as illustrated in **Fig. 5**. Subsurface geological storage is possible bothonshore and offshore (continental shelf, some adjacent deep-marine sedimentary basins, storage in caverns, basalt and organic-rich shale's)[14].

Injection of CO_2 has been done at a relatively small scale to significantly decrease emissions from the existing stationary sources. The injection rates would have to be at par with other injection operations at present. Unminable coal seams act as a potential source to capture and store because CO_2 adsorbs to the surface of coal. However, it depends largely on various geological and physical factors like the permeability of the coal bed. The process releases methane, and the methane can be recovered. Saline aquifers have common occurrence with large potential storage volume, however, little geological information is available about them as compared to oil fields. Major disadvantage is the leakage of CO_2 back into the atmosphere may be a problem in saline aquifer storage.

CO_2 storage is an integral part of the CCS chain. Attempts have been made at evaluating the geological storage potential in India. Unminable coal seams could store approximately 5 Gega tonne of CO_2, depleted oil and gas reservoirs accounting for 7 Gega tonne of CO_2, in deep saline aquifers accounting for 360 Gega tonne of CO_2, and mineralization in basalt rocks accounting for 200 Gega tonne of CO_2[15].

2.1.2 Ocean sorage

Captured CO_2 can be injected into the ocean bed at great depth, where it would remain isolated from the atmosphere for many years. CO_2 is transported by pipeline or ship for its final release in the ocean bed. Small-scale field experiments along with various other theoretical calculations and laboratory modelling techniques for ocean storage of CO_2 have been studied, yet it has not been thoroughly tested. Several concepts have been proposed so far in respect to the disposal of CO_2 to the ocean/ sea bed like: (1) Lake deposits CO_2 directly onto the sea floor at depths greater than 3000 m, (2) Storage of CO_2 in solid clathrate hydrates [16, 17], (3) Conversion of CO_2 to bicarbonates and (4) Dissolution injects CO_2 at depths of 1000 m or more where the CO_2 dissolves.

CO_2 is captured, compressed and transported to the deep ocean for release at or above the sea floor[18,19]. CO_2 then dissolves into the surrounding sea water and becomes a part

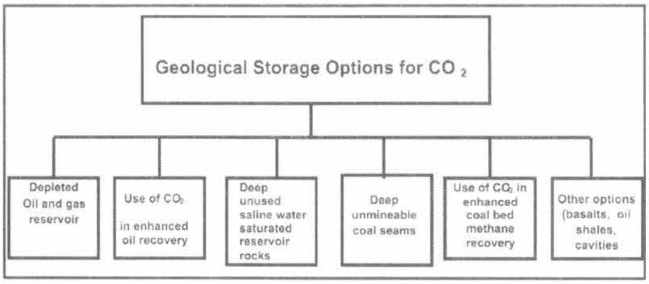

Fig. 5 : Options for storing CO_2 in deep underground geological formations

of the ocean carbon cycle[20]. Effectiveness of ocean storage depends on how long CO_2 remains isolated from the atmosphere. Release of CO_2 to the deep ocean results in eventually mixing of the gas throughout the oceans, finally affecting the concentration of CO_2 in the atmosphere. The main principle is the transfer of CO_2 to deep waters so that higher degree of isolation from the atmosphere could be achieved with an increase in the depth of the ocean.

2.1.2.1 CO_2 storage by dissolution of carbonate minerals

Increased sea water acidity resulting from CO_2 addition will be greatly neutralized by the slow natural dissolution of carbonate minerals in sea-floor sediments. This allows the ocean to absorb more CO_2 from the atmosphere with less of a change in ocean *p*H and carbonate ion concentration[21,22,23,24,25,26,27]. Carbonate neutralization approaches attempt to promote reaction in which limestone reacts with carbon dioxide and water to form calcium and bicarbonate ions in solution[23]. For each mole of $CaCO_3$ dissolved there would be 0.8 mole of additional CO_2 stored in sea water[23]. The environmental effects of oceanic storage are: (1) Large concentrations of CO_2 kill ocean organisms, (2) Storage is not a permanent option as dissolved CO_2 will eventually equilibrate with the atmosphere, (3) Acidity of the ocean water increases with formation of carbonic acid on reaction of CO_2 with H_2O, and (4) Effect on benthic life is poorly understood. Much more work is needed to define the extent of the potential problems.

2.1.3 Mineral storage

Carbon sequestration by reacting naturally occurring Mg and Ca containing minerals with CO_2 to form carbonates is called mineral sequestration. This process occurs naturally and is similar to the weathering of rock over geologic time frame. Carbonates formed have a lower energy state than CO_2, thus making the carbonation reaction thermodynamically favourable. The raw materials which are mainly magnesium and calcium based minerals are widely abundant and available. Carbonates are stable and thus the re-release of CO_2 into the atmosphere is not the matter of concern. Carbonation pathway is normally a slow process under ambient temperatures and pressure conditions. Therefore, the primary objective is to address and investigate an industrially applicable and environmentally feasible/ potential carbonation pathway that will allow mineral sequestration to be implemented at an economical platform. Mineral sequestration process involves reaction of CO_2 (exothermic reaction) with widely available and abundant metal oxides to produce a stable end product, carbonate.

The reaction rate can be accelerated by carrying out the reaction at higher temperatures, pressures, and by pre-treatment of the minerals. However this is an energy intensive method. According to IPCC, power plant equipped with Carbon Capture and Storage (CCS) utilizing mineral storage process would eventually require 60-180% more energy than a power plant without CCS.

2.1.3.1 Chemistry of mineral carbonation

Reaction of CO_2 with metal oxides results in the formation of the corresponding carbonate and subsequent heat is released according to the chemical reaction as shown below.

$$AO + CO_2 \rightarrow ACO_3 + \text{heat} \quad (1)$$

Where metal oxide is indicated as AO, A is the divalent metal, e.g., calcium, magnesium, or iron. Heat released during the reaction depends on the specific metal constituting the mineral as well as the mineral containing that metal oxide. The heat released during the combustion of elemental carbon is 393.8 kJ $mol^{-1}CO_2$. Following exothermic reaction takes place in few silicates mineral where the heat values are given per unit mol of CO_2. The reaction takes place under temperature (25°C) and pressure conditions (0.1 MPa) as described below[28].

Olivine:

$$Mg_2SiO_4 + 2CO_2 \rightarrow 2\,MgCO_3 + SiO_2 + 89\,kJmol^{-1}\,CO_2 \quad (2)$$

Serpentine:

$$Mg_3Si_2O_5(OH)_4 + 3\,CO_2 \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O + 64\,kJ\,mol^{-1}\,CO_2 \quad (3)$$

Wollastonite:

$$CaSiO_3 + CO_2 \rightarrow CaCO_3 + SiO_2 + 90\,kJ\,mol^{-1}\,CO_2 \quad (4)$$

The reaction releases heat favouring the formation of carbonates at low temperature conditions. The reaction reverses under high temperature conditions favouring the calcinations process. Under ambient temperature and low partial pressure of CO_2 conditions, carbonation of minerals bearing the respective metal oxide occurs readily [28, 29]. Silica or carbonate layers formation on the mineral surface during carbonation hinders reaction[30] and rate of CO_2 uptake. The challenge for mineral carbonation is to find out ways to accelerate carbonation process for minimum energy and material losses.

India has about twenty-five major greenstone belts containing Ca, Fe and Mg silicate rich minerals such as olivine, serpentine, and pyroxene etc. The alkaline silicates may act as potential and feasible sinks to sequester CO_2 in the form of magnesium, iron or calcium carbonates.

2.1.4 Forests and carbon storage

Forests can store much carbon and their growth can be considered as a potential carbon sink. Fossil fuel emissions of carbon currently offset 310 million metric tons of U.S [31,32]. A carbon balance of near zero could be achieved by large forested landscape over long period of time [33, 34].

In India the effects of climate on carbon reserves in cultivated soils has been studied in the past[35]. Several investigations and studies based on Indian forest carbon pools [36,37,38] and litter fall studies[39] are widely available and reported in literature. However, soil organic carbon (SOC) pool estimates based on Indian database with reference to forest types have not been undertaken for research so far. The total SOC stocks in India range from a wide range of 23.4–47.5 Pg C[39, 40]and 5.4–6.7 Pg C[36, 39]. However, India lack carbon inventories to monitor and enhance carbon sequestration potential of forests. Attempts at macro level have been made in India to carry out carbon sequestration studies[36-41]. However, attempts to assess the biomass and soil carbon sequestration at micro-level are still lacking.

3.0 Effectivenss of various sequestration options

CO_2 is released directly to the atmosphere mainly from human sources by burning of fossil fuels. Various anthropogenic sources release GHG to the atmosphere. By using a combination of several mitigation methods it is possible to achieve reduction of these emissions as illustrated in **Table 1**. The relationship between the concentration of CO_2 in the atmosphere and the storage of CO_2 can be clearly studied by understanding the relation between the stock of CO_2 stored and its flow in the respective reservoir.

The stock or amount of CO_2 stored over particular time frame in a given reservoir can be calculated by noting the difference between the current CO_2 stock and the rate at which CO_2 is being added or released. As far as the input storage rate of CO_2 in the reservoir exceeds the amount it is released back, CO_2 will certainly be accumulated in the given reservoir formation.

4.0 Summary

The various strengths, weaknesses, threats and future prospects of carbon sequestration technologies in

Table 1: CO_2 storage potential of various options

Sino	Storage Option	CO_2 Stock	Storage Potential
1	Terrestrial biosphere	Stores and releases both natural and fossil fuel CO_2 through the global carbon cycle.	99% is stored for decades to centuries, although the average lifetime will be towards the lower end of that range.
2	Oceans storage	Absorb and release natural and fossil fuel CO_2 according to the dynamics of the global carbon cycle	Fraction retained by ocean storage at 3,000 m depth could be around85% after 500 years
3	Geological storage	CO_2 has been in natural geological reservoirs for millions of years.	Fraction retained exceeds 99% over 1000 years
4	Mineral Carbonation	Carbonation reaction between CO_2 and mineral rock.	Fraction retained of early100% for exceptionally long times in carbonate rock.
5	Converting carbon dioxide into other forms	Chemical reaction	Result in very small net storage of CO_2. 99% of the carbon will be retained in the product for periods in the order of weeks to months, depending on the product.

Table 2: Overview of carbon storage technologies in India

Property	Terrestrial biosphere	Deep ocean	Geological reservoirs	Mineral Carbonation
STRENGTHS				
CO_2 sequestered or stored	Stock changes can be monitored over time.	Injected carbon can be measured	Injected carbon can be measured	Injected carbon can be measured.
Ownership	Stocks have discrete location	Stocks will be mobile and may reside in international waters.	Stocks may reside inreservoirs and differ from surface boundaries.	Stocks have a discrete location
Management decisions	Storage will be subject to continuing decisions about land use priorities.	Once injected, no further human decisions on maintenance.	Once injected, human decisions to influence continued storage involve monitoring and perhaps maintenance, unless storage interferes with resource recovery.	Once injected, human decisions to influence continued storage involve monitoring and perhaps maintenance, unless storage interferes with resource recovery.
Monitoring	Changes in stocks can be monitored.	Changes in stocks can be modelled.	CO_2 release might be detected by physical monitoring.	Changes in stocks can be monitored
Time scale with expected high values for fraction CO_2 retained	Decades	Centuries	Very small leakage	Centuries

...contd

Table 2 (...contd)

THREATS	1. Due to these horrible large-scale forest fires, the forest themselves become the sources of high CO_2 emissions in the atmosphere, thus adding to the problem of global warming. So it is certainly not very much exciting to rely upon the terrestrial ecosystems for a future reliable source of Carbon Sink	1. The injection of a few $GtCO_2$ would produce a measurable change in ocean chemistry in the region of injection, whereas the injection of hundreds of $GtCO_2$ would produce larger changes in the region of injection and eventually produce measurable changes over the entire ocean volume. 2. Adding CO_2 can harm marine organisms. Effects of elevated CO_2 levels includes reduced rates of calcification, reproduction, growth, circulatory oxygen supply and mobility, as well as increased mortality over time.	1. Injection well failures or leakage up abandoned wells could create a sudden and rapid release of CO_2. and can be dangers to human life and health. 2. Leakage may also occur through undetected faults, fractures or through leaking.. It may affect drinking- water aquifers and ecosystems 3. Groundwater can be affected both by CO_2 leaking 4. Acidification of soils and displacement of oxygen in soils.	1. The mineral carbonation process would require 1.6 to3.7 tonnes of silicates per tonne of CO_2 to be mined, and produce 2.6 to 4.7 of materials to tonnes be disposed per tonne of tonne of CO_2 stored as carbonates. This would have environ-mental impact similar to surface mining operations. 2. Serpentine often contains chrysotile, therefore demands monitoring and mitigation measures 3. The environmental impact of mining, waste disposal and product storage could also limit potential. 4. Leaching could also cause containment problem.
WEAKNESS				
Cost	Low-cost	Costs for deep ocean disposal of liquid CO_2 are estimated at US$40-80/ton.	High-cost	Low-cost
Time	Lifetimes of 10–100 years	The time it takes water in the deeper oceans to circulate to the surface has been estimated to be in the order of 1600 years, varying upon currents and other changing conditions.	CO2 retained in appropriately selected and manage dgeological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years.	Fraction of carbon dioxide stored through mineral carbonation that is retained after 1000 years is virtually certain to be 100%.
Source of CO2	Non- Point Source	Point /stationary Source	Point/stationary Sources	Point Source
FUTURE PROSPECTS	1. Terrestrial and agro-forestry modelling studies to enhance sequestration rate of CO2 in ecosystem can be explored in future. 2. Regenerative carbon dioxide removal by chemical and biological	1. Iron Fertilization implies the introduction of iron to the upper ocean to increase productivity of marine food chain which in turn increases sequestration from atmosphere into the	1. Evaluation of Basalt Formations of India for environmentally safe and irreversible long time storage of CO2. 2. Scoping studies for CO2 injection for EOR in various	1.Materials Research for Cost Effective Carbon Capture Process Development 2. Biomimetic sequestration implies the use of a particular aspect of biological process for resolving

Table 2 (contd...)

	means are other areas that can be explored for further research. 3.Micro-algae and Microbial Fixation of CO_2 from Industrial effluents as well as adaptive response of microalgae to high CO_2 coupled with high temperature and reduced pH posses a great potential in the future. 4. Enhancing carbon storage in degraded dry lands could have direct environmental, economic and social benefits for local people. It could increase benefits for farmers as well as mitigate global warming, at least in the coming decades until alternative energy sources are developed. 5. The wasteland available for forestation is quite large,30×10^6 ha. An energy plantation can be used for power generation in applications, instance :Co-firing in fossil fuel fired power in agriculture and generation,Cogeneration forestry processing facilities, Stand alone grid connected biomass based power stations that consider energy plantation feed stocks along with other agriculture residues, like baggase, wood waste, rice hull, etc.	oceans. This technology proves to be beneficial in future. 2. Marine plankton growth is enhanced by for physically distributing the iron particles in other wise nutrient rich but iron deficient ocean water using suitable delivering systems based on biomaterials. 3. Studies of the response of biological systems in the deep sea to added CO_2, including studies that are longer in duration and larger in scale than yet performed. 4. Research facilities: Research facilities where ocean storage concepts can be applied and their effectiveness and impacts assessed in situ at small- scale on a continuing basis for the purposes of both scientific research and technology development. 5. Investigation and development of technology for working and the development in the deep sea, of pipes,nozzles, diffusers which can be deployed in the deep sea with assured flow and be operated and maintained cost-effectively. 6. Development of techniques and sensors to detect CO_2 plumes and their biological and geochemical consequences.	specific fields proves to be beneficial. 3. Research on underground disposaland coal bed methane needs to be undertaken. 4. Collaborative research on screening criteria development for Geological sequestration in Saline aquifers needs to be initiated. 5. More research needs to be carried out in future geophysical sounding and deep resistivity surveys using Schumberger method for preparation of 2D and 3D models of subsurface lithography up to the depth of 800 m. 6. The Central Ground Water Board and Geological Survey of India have established the presence of saline aquifers up to depths of $\geq$ 300m belowground level in the Ganga basin. Deep Resistivity studies carried out at different sites in various regions have shown the presence of saline aquifers at depths of 800m and beyond. 7. The sale of the methane can be used to offset a portion of the cost of the CO_2 storage. 8. There is strong evidence that storage of CO_2 in geological storage sites will be long term.	a specific non biological problem. The Carbonic Anhydrase (CA) is used as a catalyst for the conversion of CO_2 into bicarbonates and later to carbonates oramino acids. This new area can be explored for research 3. The carbonates formed are stable and the disposal is therefore permanent. There is no chance of the carbon dioxide escaping into the atmosphere. 4. Carbonate is the lowest energy state of carbon, not carbon dioxide. 5. Mineral carbonation occurs naturally on a geological time scales and would eventually absorb all the additional carbon dioxide. 6. The process is just speeding up one that occurs in nature. The minerals are readily accessible in locations near high- density power generation centres. There is potential to produce value-added by products. 7. The process is compatible with both technologies under development and current power systems. Predicted cost is not unreasonable. 8. No heat required reaction is exothermic.

Indian perspective are illustrated in **Table 2**. CCS technology involves various components like carbon capture and sequestration, transportation of CO_2 via pipeline and injection into geological formations. These are well proven in India but the number of such final CCS projects is very small as compared to what is currently required to achieve significant CO_2 emission reductions in the atmosphere. New technologies that make CCS much cheaper would be more helpful in getting it adopted quickly in terms of economics of the technology. India has low oil resources, therefore, enhanced oil recovery (EOR), and cannot be completely adopted for future sequestration in India.

In order to mitigate adverse affect of climate change, India needs to adopt a sustainable development approach by making use of environmental friendly technologies. Energy efficient technologies in conjugation with sustainable pathway will help to reduce the vulnerability of natural as well as other socio-economic system. In Indian context, an amalgation of both geological and mineral sequestration technology should be promoted and considered for future mitigation of GHG emissions. However, a tailored approach for overcoming the adverse response of various anthropogenic emissions is needed for a large country size, like India. Though it is impossible to project how many Indian CCS plants will be installed on short term basis but in the long term, it can be realized if we start taking the right steps now.

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Corrigendum

Please refer the article titled "Modeling and Simulation of Road Traffic Noise Using Artificial Neural Network and Regression" authored by M. Honarmand and S.M. Mousavi, published in Volume 56 No. 1, p. 1-6, January 2014 of *Journal of Environmental Science & Engineering*. In this context, the readers of the journal are requested to kindly read the revised article being published in the following pages.

The inconvenience caused is regretted.

- Editor, JESE