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Executive Summary of Analysis of Carbon Capture and Storage (CCS) Technology in the Context of Indian Power Sector

SUBMITTED TO:

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PROJECT COMPLETION REPORT

TECHNOLOGY SYSTEMS DEVELOPMENT (TSD) PROGRAMME OF DST

PROJECT TITLE

Analysis of Carbon Capture and Storage (CCS) Technology in the Context of Indian Power Sector

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EXECUTIVE SUMMARY

A. Introduction

The climate change and climate variability is evident world over, which can be attributed to global warming. According to the IPCC 2007 "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG [Green House Gas] concentrations in atmosphere." There are many greenhouse gases, of which CO2 is main component, is emitted by various industrial processes and burning of various types of carbonaceous fuels. In addition many natural phenomena, agriculture, live-stock also emit greenhouse gases.

The nature has its own mechanism (carbon cycle) to absorb carbon dioxide from atmosphere to sustain biosphere balance. However, since the beginning of the industrial revolution the GHG emissions to atmosphere is increasing due to use of fossil fuel by industry, thermal power generating stations, transport and logistics.

The UNFCCC was adopted in 1992 and has been ratified by 192 countries, including India. Its objective is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[1]

Power Sector is the largest consumer of coal accounting for about 70% of total coal consumption in the Indian economy. India being in an accelerated phase of economic growth, aiming to add more than 600,000 MW of power generation capacity in the next two decades needs special interventions to restrict CO_2 emission to minimize global warming. Despite emphasis on nuclear, hydro and renewable energy, fossil fuel power especially, coal based power will produce large share of power. Therefore, the clean coal technologies and "efficient and clean" combustion of coal are being developed to reduce CO_2 emission from the power sector. Carbon

http://www.fas.org/sgp/crs/misc/R40910.pdf

Capture and Storage (CCS) technology is emerging as a promising technology to reduce GHG emission by capturing CO2 from flue gas and storing it under the viable surface.

This project intends to define and carry out the research in a predetermined manner to achieve the research objectives under "**National Programme on Carbon Sequestration"** Research programme of DST and formulate policy recommendation for appropriate authority**.**

A.1. Objective

The key objective of the Research Project is "To study, analyze, evaluate and assess the importance and development of CCS technology in reducing the GHG emissions to restrain global warming and its economic implications."

In pursuing the above research objective, the study focused on the components of CCS technology with reference to power sector in detail so as to understand the feasibility of the concerned technologies; their applicability to the Indian Power Sector; and further applied research and demonstration project requirements to establish viability of this technology.

The scope of CCS Technology aims to:

- Enhancing efficiency of power plants by emerging technologies to reduce emission of CO2 per megawatt to reduce process load on capture technology;
- Capturing and Separating CO2 from the gas streams emitted from combustion;
- Transporting the captured CO2 to underground storage;
- Storing CO2 underground in deep saline aquifers, sedimentary basins, basalt formation and depleted Oil and Gas or Coal reservoirs. The potential areas in the country where CO2 can be stored, and how the storage can be conducted (trapping mechanism);
- Will the storage site be safe?

Thus the CCS, technology aims at reducing CO2 percentage in the atmosphere by storing the CO2 produced by the fossil fuel fired plants in secure sinks at affordable prices for hundreds of years.For the above purpose, the IRADe team conducted extensive literature review; carried structured interviews to assess the development and opinion of stakeholders on various aspects of carbon capture and storage technology, conducted, analyzed individually for major component of the project based on the scope of the project. The analysis included the assessment of general progress with a detailed description of relevant developments. A detailed description of the options, scenarios, present status, R&D road map etc. was analyzed. This includes description of a range of features like CCS technological status, Indian energy sector- potential sources of GHG, clean coal technologies, capture, transport and storage technologies, stakeholders view etc. It was assumed that India will take up CCS only after it is successfully demonstrated and implemented elsewhere in the world. However, India will continue the R & D work for CCS in order to develop clean technologies and explore business opportunities for CCS in order to develop clean technologies and explore business opportunities in CCS in future.

The aim of the research study was to conduct an analytical study of CCS technology for Indian power sector analyzing Potential sources of GHG emissions in Indian energy sector with focus on power sector, major fossil fuels (Hydrocarbons) used in India and their characteristics, thermal technologies for efficiency improvement and clean coal usage, Status and development of CCS technology ,CO2 capture technologies, CO2 transportation technologies ,CO2 storage locations and initial characteristics of the sites, economics and cross cutting issues, Roadmap of CCS R&D for India.

B. CCS Technology and Status

CO_2 capture & storage (CCS) is a 3-step process including CO_2 capture from power plants, industrial sources, and natural gas wells with high CO_2 content; **transportation** (usually via pipelines) to the storage site; and **geological storage** in deep saline formations, depleted oil/gas fields, un-mine-able coal seams, and enhanced oil or gas recovery (EOR or EGR) sites. In combustion processes, CO_2 can be captured either in pre-combustion mode (by fossil fuel treatment) or in post-combustion mode (from flue gas or by oxy-fuel).

Technologies for CCS are rather well known, but system integration and commercial demonstration are needed. If CCS is to play a significant role in the coming decades, demonstration must be accelerated. In particular, underground storage needs to be proven. Given the range of technologies under development, CCS demonstration would require at least ten major power plants (globally) with CCS to be in operation by 2025. Substantially larger demonstration budgets as well as private/public partnerships and outreach to emerging economies are essential. As CCS implies an incremental cost, economic incentives are needed for CCS to be commercially demonstrated and deployed. Major barriers to CCS deployment are cost, demonstration of commercially viable operation and safe permanent storage. The status of these three segments is described below.

B.1. CO2 Capture

Efficiency improvements in coal fired power plants will definitely help towards lowering CO_2 emissions; however, further steps are necessary in order to make significant reductions in CO_2 emissions. CCS offers a longer term option for achieving reduced CO_2 emissions from coal based power. The technologies basically involved are pre-combustion capture from the exhaust streams of coal combustion or gasification processes and geologically disposing of it so that it does not enter the atmosphere. Several projects are now underway to push this technology ahead in countries such as Australia, Canada, Germany, the UK, and the USA.

B.2. Carbon Transportation

Transport is that stage of carbon capture and storage that links sources of captured carbon dioxide and storage sites. In the context of long-distance movement of large quantities of carbon dioxide, pipeline transport is part of current practice. CO_2 is transported in three states: gas, liquid and solid. Commercial-scale transport uses tanks, pipelines and ships for gaseous and liquid carbon dioxide. The use of ships for transporting CO_2 across the sea is today in an embryonic stage. Worldwide there are only four small ships used for this purpose. These ships transport liquefied food- grade CO_2 from large point sources of concentrated carbon dioxide such as ammonia plants in northern Europe to coastal distribution terminals in the consuming regions.

B.3. Carbon Storage

The carbon storage is the critical component of the CCS technology. At this stage CO_2 emission to the atmosphere are finally restricted by storing the captured gas in the selected geological site. The concept emerged as the subsurface of the Earth is large carbon reservoir, where the coals, oil, gas organic-rich shales exists. The best sites for CO_2 storage from economic point of view are deep saline formations, depleted oil/gas fields, un-mineable coal seams, and enhanced oil or gas recovery (EOR or EGR) .The CO_2 is injected and stored into geological "storage reservoirs" using standard techniques that have been used in the oil and gas industry for many decades.

C. The Current Status of CCS:

While technologies of CCS are relatively mature individually, but to date there are no fully integrated, commercial scale CCS projects in operation. They are used in different context in various industries already around the world.

a. Capture Technology- Applied in chemical and refining industry for decades but integration in the context of power production still needs to be demonstrated.

b. Transportation of CO_2- Central utilities has more than 5000 Km of pipelines and proven successful for more than 30 yrs. in injection of CO_2 into oil fields for enhanced oil recovery.

c. Storage of CO_2- Operational worldwide for 10 years Norway, Canada, Algeria. The industry can build on knowledge obtained through geographical storage of natural gas. Yet, there is uncertainty in respect of storage in deep saline aquifers.

D. Potential sources of GHG emissions- Power

In the context of power, India is divided into five power regions namely Northern, Western, Southern, Eastern and North-Eastern. The resources (units) of power generation in the country are quite diversified. The coal is located mainly in the eastern, central regions and southern region (Andhra), lignite in the southern region, and big hydro-power which needs to be developed mainly in the northern and north-eastern region. In order to meet the growing needs of power it is essential to develop all the indigenous resources in an optimal manner using most efficient technologies and also keeping in view the GHG emission and environmental concerns.

The Installed Capacity in the country has increased from a mere 1,713 MW in December 1950 to 1,59,398 MW at the end of March, 2010 whereas during the same period the annual electricity generation has grown from about 5 BU to about 723.5 BU by March 2009. So far electricity generation achieved till 31.3.2010 is 771.5 BU as against of 789.5 BU target for 2009-10 which is approximately 97.7%.

Growth in demand has exceeded the supply and power shortages persist. The power supply position at the end of 2009-10 indicates an energy deficit of 11% on all India basis, varying from 4.6% lowest in eastern region to about 16 % highest in the Western region. Similarly over all peak shortage has been 13.3% varying in the range of 7.4% in the southern region to about 25.4% in the North eastern region.

However, power sector being the largest source of GHG emissions due to the major part of base load electricity supplied by the fossil fuel fired power plants requires immediate attention. The possible solutions to reduce the GHG emissions from the fossil fuel fired power plants are:

- Increase the overall efficiency of the power plants by timely maintenance and reduction of wastage
- Application of new technologies and retrofitting of the old power plants
- Shifting base load generation from fossil fuel fired power plants to renewable energy based power plants
- Application of CCS technologies to existing power plants and essentially incorporating these technologies to the upcoming new power plants

Future projections are done up to 15th five year plan (2031-32) under two scenarios of 8% and 9% GDP growthas per the report of Integrated Energy Policy (2006), which has following details.

D.1. Sources of Data:

The actual data for the purposes of further analysis in respect of Installed capacity, Electricity generation by different modes has been taken from CEA publications for the end of 10th plan (2006-07) and first 3 years of 11th plan i.e. 2007-08, 2008-09 and 2009-10. Based on this data source wise operating parameters of various generating capacities i.e. Hydro, Thermal, Nuclear etc has been worked out and used for further calculations of capacity additions, installed capacity requirement and generation etc for the period of 12th five year plan to 15th five year plan.

The report of Integrated Energy Policy published in 2006 have carried out various energy sector projections up to the year 2031-32 under GDP growth rate scenarios of 8% and 9%. As per these the installed capacity of power plants in country will increase to increase from about 115,000 MW at the end of 11th plan to about 382,000 MW in the year 2031-32 under 8% scenario to about 479,000 MW under 9% scenario, in spite of high hydro, nuclear and gas capacity development. However, this will depend upon availability of natural gas and also nuclear fuel and capability to execute such large capacities The future projections of source wise capacity addition and calculation of CO_2 emissions are done up to end of 15th five year plan (2031-32) under these two scenarios :

Head	8% GDP Growth	9% GDP Growth
Capacity Addition	89 GW (12th five year plan) to 202 GW(15th five year plan)	117 GW (12th five year plan) to 276 GW(15th five year plan)
Installed Capacity	326 GW (12th five year plan) to 794 GW(15th five year	354 GW (12th five year plan) to 978 GW(15th five year

	plan)	plan)
CO2 Emissions	1141 Mt CO2 (12th five year plan) to 2800 Mt CO2 (15th five year plan)	1280 Mt CO2 (12th five year plan) to 3474 Mt CO2 (15th five year plan)

Table D-1 Power Sector Forecast (12th & 15th Five Year Plan)

The above mentioned projections shows under 8% GDP growth scenario the CO_2 emissions will increase from 788 Mt CO_2 at the end of 11th plan to about 2800 Mt CO_2 at the end of 15th plan i.e nearly 3.5 times. Similarly in case of 9 % scenario CO_2 emissions will further be further higher at 3474 Mt CO_2 i.e. nearly 4.4 times the levels at the end of 11th plan. Keeping in view the global concern on Climate change way and means have to be found for reduction of GHG emissions by fossil fuel based thermal power plants. These options are discussed in subsequent paragraphs.

E. Fossil fuel resources and likely CO2 emissions and storage sites

E.1. Coal

Coal resources determine the likely CO2 emissions in future. Although coal can be imported, transportation costs are high. Moreover old coal fields can also serve as CO2 storage sites. As per the estimates of Geological Survey of India, the coal reserves of India stand at 267 Billion Tonnes as on 01.04.2009 with more than 87% of these being of the non-coking grade. The geographical distribution of these coal reserves is primarily in the states of Bihar, Jharkhand, West Bengal, Orissa, Madhya Pradesh, Chattisgarh, Maharashtra and Andhra Pradesh. The total coal production in the country during 2008-09 was 493 MT, of which about 355 MT was used for power sector (excluding captive power plants). In addition to this, about 20 MT was imported for Power Sector. The total coal availability from domestic sources is expected to be 482 MT per annum by 2011-12. This includes coal production from captive mines.

E.2. Lignite

The geological reserves of lignite have been estimated to be about 35.6 BT. Lignite is available at limited locations such as Neyveli in Tamil Nadu, Kutchh, Surat and Akrimota in Gujarat and Barsingsar, Bikaner, Palana, Bithnok in Rajasthan. Since, lignite is available at a relatively shallow depth and is non-transferable, its use for power generation at pithead stations is found to be attractive. The cost of mining lignite has to be controlled to be economical for power generation

Coal will continue to be major fuel source for power generation, till foreseeable future. In the economic analysis the additional costs of capturing and storing CO2 is to be considered for coal based power plant. The location issue is relevant since it has to be observed that optimum logistics and raw material issues are addressed. The options for new power plants will be where it will be installed are; (a) close to the fossil fuel reserves, (b) next to consumers/ load centers, (c) coast based generation units or (d) adjacent to potential storage sites. The quantity of coal availability might become relevant since CCS requires between 20 and 30% more coal for the same electricity output.

E.3. Coal Bed Methane

Under India's coal bed methane (CBM) policy, formulated by the Indian government in 1997, 26 virgin coal bed methane (VCBM) blocks have been allotted for commercial development to different operators through global bidding. Increase in demand of coal from power sector has resulted in the allotment of coal blocks within India's CBM blocks. This has caused an overlap in the allotment of coal and CBM blocks.

E.3.1. Indian Fuel Scenario for Thermal Power Generation unit

- Raw High Ash and Washed low ash Non coking Sub bituminous coals (85 %)
- Middlings of Caking Bituminous Coals (rest)
- Imported low ash ,high moisture ,high volatile coals
- Fresh Water origin Lignite (Neyveli)

- Marine water Origin Lignite (Gujarat & Rajasthan)
- Bio Mass (Agri. Wastes & Non carpentry wood wastes) & alternate Fuel Availability

E.4. Hydro Carbons--Petroleum and Natural Gas

India has total reserves of 775 million metric tonnes of crude oil and 1074 billion cubic metres of natural gas as on 1.4.2009. While CCS is thought appropriate for coal based power, it is hydro carbon industry which has considerable experience regarding CO_2 injection for enhanced recovery, transportation etc and also after storage sites.

The total number of exploratory and development wells and metreage drilled in onshore and offshore areas during 2008-09 was 381 and 888 thousand metres respectively. The Crude oil production during 2008-09 at 33.51 million metric tonnes is 1.79% lower than 34.12 million metric tonnes produced during 2007-08. Gross production of Natural Gas in the country at 32.85 billion cubic metres during 2008-09 is 1.33% higher than the production of 32.42 billion cubic metres during 2007-08.

The refining capacity in the country increased to 177.97 million tonnes per annum (MTPA) as on 1.4.2009 from 148.968 MTPA as on 1.4.2008. The total refinery crude throughput during 2008-09 at 160.77 million metric tonnes is 2.99% higher than 156.10 million metric tonnes crude processed in 2007-08 and the pro- rata capacity utilization in 2008-09 was 107.9% as compared to 104.8% in 2007-08.

The production of petroleum products during 2008-09 was 152.678 million metric tonnes (including 2.162 million metric tonnes of LPG production from natural gas) registering an increase of 3.87% over last year's production at 146.990 million metric tonnes (including 2.060 million metric tonnes of LPG production from natural gas).

The country exported 36.932 million metric tonnes of petroleum products against the imports of 18.285 million metric tonnes during 2008-09. The sales/consumption of petroleum products during 2008-09 were 133.400 million metric tonnes (including sales through private imports) which is 3.45% higher than the sales of 128.946 million metric tonnes during 2007-08.

F. Clean Coal Technologies

The future technology trends are being driven by three main criteria viz. efficiency, environment and economics. Green House Gas (GHG) emission from thermal power stations has been drawing greater attention in the recent past. Any improvement in efficiency would result in lesser fuel being burnt and in corresponding economic and environmental benefits. Therefore, the conversion efficiency which is a function of turbine and boiler efficiency needs to be improved to reduce the GHG emissions. The steam turbine efficiency has been increasing with the increase in unit size accompanied by increase in steam parameters.

Constant efforts have been made in the past to improve the technology and efficiency of thermal generation, and units with higher steam parameters have been progressively introduced. Increase of steam parameters i.e. temperature and pressure is one of the effective measures to increase efficiency of power generation.

In the 12^{th} Plan, based on the experience gained by NTPC, other generating companies should also adopt super critical technologies so as to reduce green house gases emissions.

However, the approach of efficiency improvement would yield environmental benefit only to a limited extent and there is a need to look beyond for larger quantum of environmental benefits which is possible only by adopting new clean coal technologies.

F.1. Clean Coal Technologies

This group of technologies basically focuses on conversion process which, by virtue of either improved efficiency or better amenability to pollution control measures result in reduced environmental degradation. These technologies include fluidized bed combustion, integrated gasification combined cycle etc.

F.2. Fluidized Bed Combustion (FBC) technology

The quality of coal available in India is of low quality, high ash content and low calorific value. The traditional grate based fuel firing systems have got performance limitations and are techno-economically unviable to meet the rising demand and techno-economic challenges of future.

Fluidized bed combustion has emerged as a viable alternative and has significant advantages over conventional firing system and offers multiple benefits –

1) Compact boiler design
2) Fuel flexibility;
3) Higher combustion efficiency; and
4) Reduced emission of noxious pollutants such as SOx and NOx.

F.3. Fluidized Bed Combustion Systems:

These boilers operate at atmospheric pressure.

F.4. Pressurized Fluidized Bed Combustion Systems (PFBC):

These systems operate at elevated pressures and produce a high-pressure gas stream at temperatures that can drive a gas turbine. Steam generated from the heat in the fluidized bed is sent to a steam turbine, creating a highly efficient combined cycle system.

F.5. Integrated Gasification Combined Cycle (IGCC)

Integrated Gasification Combined Cycle (IGCC) System is one of the clean coal technologies in which coal is converted into gaseous fuel, which after cleaning is used in CCGT plants. The IGCC systems which are commercially available have shown higher efficiencies and exceptionally good environmental performance in SOx removal, NOx reduction and particulate removal. IGCC, if commercially proven, will be one of the most attractive power generation technologies for the 21st century.

The following essential properties of coal gasification process differentiate this process from coal combustion:

1) Process of coal gasification is conducted with low gasifying medium (oxidizer) number to obtain high chemical efficiency in the process and low content of NOx in the gas.

2) About **99%** of sulphur is converted into **H_2S** and **COS,** and only a little into **SO_2;** these gases are removed from the gas in the cleaning process.

2) Ash is efficiently removed from the gas in melted form.

3) High pressure of the process of coal gasification allows the construction of a combined gas-steam power plant with high efficiency.

4) Gas is cleaned of sulphur compounds and of ash before burning.

The process of coal gasification, as a part of the technology used in generation of electric energy, allows producing "clean” gas fuel from "dirty" coal.

F.6. Oxy –Fuel Technology:

Oxy-fuel technology refers to technology where pure oxygen is mixed with fuel instead of air for the purpose of combustion.

Atmospheric air contains 20.95% oxygen, 78.08% nitrogen and rest part is occupied by the inert gases like Neon, Helium Xenon etc.

Generally atmospheric air is used to form a mixture along with the fuel for combustion purposes but as the oxygen content in air is only 20.95%, higher temperature cannot be reached on account of energy used in diluting the inert gases.

Higher temperature can be reached if pure oxygen is mixed with the fuel and then that mixture is used for combustion. This negates any chance of energy being used for dilution of the inert gases.

Approximately the same total energy is produced when burning a fuel with oxygen as compared to with air; the difference is the lack of temperature diluting inert gases like nitrogen, Helium, Xenon etc.

Oxy-fuel combustion process is the process of burning a fuel by making fuel-pure oxygen mixture using pure oxygen instead of mixing the fuel with air where air acts as the primary oxidant. In oxy-fuel combustion process, since there is no nitrogen component and only pure oxygen is mixed with the fuel to make oxygen- fuel mixture, the fuel consumption is reduced, and higher flame temperatures are possible, thereby increasing the efficiency of the process.

F.6.1. Application of Oxy- Fuel Technology in Fossil Power Plants

Oxygen fired pulverized coal combustion (Oxy-Fuel), offers a low risk step development of existing power generation technology to enable carbon dioxide capture and storage. The justification for using oxy-fuel is to produce a CO_2 rich flue gas ready for sequestration.

F.6.2. Importance

Oxy-fuel technology is important for clean electricity generation using fossil fuel for the following reasons:

1. The potential for a medium- to long-term, lower cost and lower technology risk, option for achieving near zero emissions from coal-based electricity generation;
2. The potential to retrofit this technology to standard PF technology (sub-critical as well as super/ultra-super critical PF technology).
3. The prospect of applying the technology to new coal-fired plant with significant reductions in the capital and operating cost of flue gas cleaning equipment such as deNOx plant.
4. The mass and volume of the flue gas are reduced by approximately 75%.
5. Because the flue gas volume is reduced, less heat is lost in the flue gas.
6. The size of the flue gas treatment equipment can be reduced by 75%.
7. The flue gas is primarily CO_2, suitable for sequestration.

F.7. Integrated Solar Combined Cycle (ISCC)

Our country is gifted with vast potential of solar energy. which can be utilized to generate power. Direct solar insolation for over 10 months in a year are available in the Thar desert stretching over vast areas of Rajasthan and Gujarat. Even if 1% of it is used, it can generate about 6000 MW of electric power.

F.8. Fuel Cell Technology

Fuel cells are electro-chemical devices that convert energy from fuel directly into electricity through electro-chemical reactions. These cells normally use hydrogen directly as fuel or as derived from natural gas or other hydro carbons. About 4-5 major technologies for fuel cells are in various stages of development worldwide.

All the technologies mentioned above if applied can help to reduce the CO_2 emissions from the atmosphere sustainably. Oxy fuel technology and IGCC can be integrated with other technologies at various stages of development and can be used for CCS purpose which can reduce the CO_2 and other emissions from the atmosphere and reduce the level of harmful gases in the environment.

G. Carbon Capture and Transport

The CCS process chain commences with CO_2 being captured from the flue gas of the industrial combustion process (power plant) using fossil fuel. This process design is for post-combustion capture process. In pre-combustion capture process solid/ liquid/ gaseous fossil fuel is first converted to a synthetic gas, which is mixture of hydrogen, carbon mono-oxide and carbon dioxide using gasification process. The synthetic gas can be reformed to hydrogen, and carbon dioxide. The CO_2 of the synthetic gas stream is captured to obtain concentrated synthetic gas stream.

The capture process is designed to capture CO_2 by absorbing it in a suitable solvent from flue/ synthetic gas stream. The CO_2 rich solvent is subsequently processed to remove CO2 in a stripper reactor to recover solvent for reuse. The removed CO_2 is compressed to super-critical state for transport it to geological site for storage.

Various processes have been developed for separating CO_2 from gas stream. These can be categorized as Absorption, Adsorption, Membrane, Cryogenic, Microbial/ Algal process. For large industrial process absorption process is being used. Ammonia and urea industries are using amine solvent (chemical) for capture and separation.

The primary constraint of designing capture process are thermodynamic parameters of gas stream i.e. temperature, concentration, pressure. These parameters value in flue gas are inadequate to ensure efficient extraction. The parameter values in synthetic gas are somewhat favourable.

Another emerging capture technology is application of high pressure membrane. It is a single stage separation process. The type of membrane being studied are (a) inorganic membrane e.g. silica / alumina / zeolites / palladium (b) Organic Polymers- the research include liquid membrane supported ionic liquids. For sustaining long term use of membrane the strength of membrane have to be ensured, and gas stream should be free from fine particulates.

In order to enhance performance of capture technology at thermodynamic condition of gas stream, a series of R&D is needed. These include

(a) Technology selection absorption or membrane
(b) Development inhibitors, catalyst & contactor
(c) Optimum use of waste heat
(d) Recycling of capturing solvent

The new solvents development should also have low vapor pressure, highly resistant to degradation, display low corrosivity in the presence of oxygen. New solvents should comply with technical attributes of

(i) Higher equilibrium capacity for CO_2
(ii) High CO_2 reaction rates
(iii) Having low regeneration energy requirement
(iv) Having good capture efficiency at low partial pressure and
(v) Higher yield during regeneration process.

The high reaction rate will in turn reduce the size of the absorption towers that will reduce capital and operating costs.

The tangible cost incurred in capture process is the maximum. All the research and development processes are focused on reducing cost of capture cycle. The capture process as described with MEA solution processing accounts for 80% of the total cost of CCS process. This excludes cost of monitoring and verification. Within the complete capture process, capture by absorbent accounts for approximately 34% of the total capture process cost. The circulation of the solvent and gas through the columns by pumps and blowers, accounts for approximately 17% of the total operating cost. The maximum cost of CO2 capture cycle is in solvent regeneration process occurring due to the energy requirement, enhanced yield of solvent regeneration. This phase accounts for 49% of the total capture cost. Applied R&D and design of the packed bed to reduce pressure drop can facilitate the cost reduction in all reaction phases.

Carbon capture units have capacity to capture 85 to 95% of CO_2 emissions from the exhaust gases of coal- and gas-fired power plants, oil refineries and steel plants. The subsequent process after capture is it to transport carbon dioxide to appropriate geological site for storage.

NEERI, India team is doing R&D on biomimetics to stabilize and immobilize the enzymes or alternately use a combination of both these approaches to achieve sequestration reaction at a satisfactory level. There have been several exploratory studies of the use of the enzyme carbonic anhydrase, which is one the most efficient catalyst of CO2 reaction with water, to produce carbonate ions to promote CO2 scrubbing from flue gases. The aims to mimic the reaction for fixation of anthropogenic CO_2 into calcium carbonate using carbonic anhydrase (CA) as a biocatalyst.

G.1. CO2Transportation

The separated CO_2 is further processed for transportation. The CO_2 transportation with pipelines is in practice in USA for enhanced oil recovery projects. The experiences indicate that CO_2 transportation in super-critical fluid state is highly economical in comparison to gaseous phase. The super-critical state has its own challenges such as leakages and associated cooling, fractures at joints and defects, purity norms. The necessary conditions for CO_2 supercritical fluid are (i) Critical Temperature in Kelvin, 304.2 degrees (ii) critical Pressure in bar (atmosphere) 73.8 for super-critical state (iii) CO_2 gas Density Kg/m3 (at 0 degree C) 1.9767 (iv) Super Critical fluid Density is 468 Kg/ m3. The 304 degree Kelvin is equivalent to 31 degrees centigrade, which is approximately room temperature.

There are purity norms of CO_2 for transportation. Captured CO_2 may contain impurities like water vapor, H_2S, N_2, methane (CH4), O_2, mercury, and hydrocarbons. A requirement exists for specific processing for removal of impurities. Before transport, the CO_2 is dehydrated to levels below 50 ppm of water. CO_2 reacts with water to form carbonic acid, which corrodes the pipeline, and changes super-critical conditions. H_2S is toxic gas. The pipeline and compressor design for CO_2 transport in super-critical state has its own design constraints.

The design of compressor is the primary applied research project as it will have to boost pressure from 1 bar to 110 bar (above 73.8 bar for safety factor). NETL, USA and South West Research Institute have developed multi-stage compressor for liquefying CO2 to super-critical fluid. The said compressor consumes less energy and occupies less space.

The pipeline lengths have to be computed in segments to align with booster pump, geographical profile, and design capacity of CO_2 mass flow. These will be used to compute pipe diameter. The pipeline is modeled as a series of pipe segments located between booster pumping stations. Based on the input information to the transport model, the required pipeline diameter for each segment is calculated. The pipeline segment diameter is calculated from a mechanical energy balance on the flowing CO_2. The energy balance is simplified by approximating supercritical CO_2as an incompressible fluid and the pipeline flow and pumping processes as isothermal. Booster pumping stations may be required for longer pipeline distances or for pipelines in mountainous or hilly regions. Additionally, the use of booster pumping stations may allow a smaller pipe diameter to be used, reducing the cost of CO_2 transport. The pumping station size is also developed from an energy balance on the flowing CO_2 in a manner similar to the calculation of the pipe segment diameter. Both the booster pumping station size and pipeline diameter are calculated on the basis of the design mass flow rate of CO_2.

Currently CO_2 storage in ocean is being explored actively. Carbon dioxide is continuously captured at the plant on land, but the cycle of ship transport is discrete. The marine transportation system includes temporary storage of CO_2 may be in liquefied state on land, and on shore loading facility in a tanker or pipeline transport to sea-shore, temporary storage at sea-shore , offshore reloading in the ship/ tanker and ship and injection in the sea. The total process is designed in semi-pressurized state at pressures near the triple point (6.5 bar,-52 degree Centigrade). The capacity, service speed, number of ships and shipping schedule will be planned, taking into consideration, the capture rate of CO_2, transport distance, and social and technical restrictions. This issue is, of course, not specific to the case of CO_2 transport; CO_2 transportation by ship has a number of similarities to liquefied petroleum gas (LPG) transportation by ship. The process competes with pipelines over large distances.

Costing is an important issue is deigning transportation scheme. It is cheaper to collect CO_2 from several sources into a single pipeline (hub) than to transport smaller amounts separately. Early and smaller projects will face relatively high transport costs, and therefore be sensitive to transport distance, whereas an evolution towards higher capacities (large and wide-spread application) may result in a decrease in transport costs. Implementation of a ‘backbone’ transport structure may facilitate access to large remote storage reservoirs, but infrastructure of this kind will require large initial upfront investment decisions. Further study is required to determine the possible advantages of such pipeline system. Similarly cost of marine transportation system should be estimated.

H. Carbon Storage

The carbon storage is the critical component of the CCS technology. At this stage CO_2 emission to the atmosphere are finally restricted by storing the captured gas in the selected geological site. For millions of years, crude oil and natural gas (in fluid form) have been stored naturally underground, where it is trapped in deep reservoirs or sedimentary basins protected by cap rock. CCS technology duplicates this process by safely storing CO_2 within similar geologic formations, such as depleted petroleum fields or deep natural gas reservoirs.

H.1. Sequestration of CO2

The carbon storage in geological sites has its logic from replacing carbon extracted from geological sites as fossil fuel and restoring them with CO_2 wherever feasible. The stored CO_2 in geological sites have to be protected from subsequent release to atmosphere with proper capping

The CO_2 is injected and stored into geological "storage reservoirs" using standard techniques that have been used in the oil and gas industry for many decades. During the storage process conceived in CCS, CO_2 is injected at least 1,000m (1km) deep into rock formations in the subsurface. For storing CO_2 the identification of secure storage site is essential. Each geological site must contain trapping mechanisms such as cap-rock (dense rock) that is impermeable to CO_2, which surrounds the storage area and acts as a seal to stop any upward movement of CO_2. It is also desired that CO_2 react with the porous surface of the rock to form stable compound, but in the process of reaction it should not weaken the rock structure. The storage site should have a stable geological environment to avoid disruption in storage on a long term. The basin characteristics such as tectonic activity, sediment type, previous drilling activity, geothermal and hydrology regimes of the storage site should be analyzed prior to site selection.

Storage of CO_2 in deep saline formations with fluids having long residence times (millions of years) is conducive to hydrodynamic and mineral trapping.

H.2. Saline Aquifers

Global studies indicate that saline aquifers are present in onshore and offshore sedimentary basins. Saline aquifers have been identified as the inland storage site having maximum CO_2 storage capacity. In Indian context following study is needed.

- To estimate storage capacity of the saline formation to evaluate commercial viability;
- Proximity of thermal power stations to saline aquifer;
- Thickness of impervious (clay / sandstone) cap rock to ensure storage integrity;
- The reservoir pressure to estimate the storage capacity. Location of geological faults in the adjacent area; and
- Use of water of saline aquifers, in case they can be extracted from reservoir.

The saline aquifers content do not have any commercial value; it has not been adequately studied. In view of CCS the saline aquifers should be studied extensively. The study should include physical, chemical, and geological analysis. The analysis is needed to evaluate the nature and composition of the rock, porosity & permeability of the reservoir, and surrounding rock formation. The information obtained can be superimposed on GIS environment.

The saline aquifers are present in India different geological formations as revealed by exploratory drillings for the delineation of aquifer zones by Central Ground Water Board.

Maximum saline areas fall in parts of Rajasthan, Haryana , Punjab, Uttar Pradesh, Gujarat and Tamil Nadu. Some of the mega thermal power plants are also coming up in these areas. In India, the deep saline aquifers may prove out to be a very efficient option for carbon sequestration. There are insufficient public domain data available to estimate accurately the storage capacity of saline aquifers. In order to study deep saline aquifers, the sedimentary Basins have to be short-listed with adequate storage capacity estimates. Resistivity surveys for Deep aquifers are needed for delineating Rock type and the aquifers.

H.3. CO2 Storage potential in India

The CO_2 storage potential in India has been studied as a part of International Energy Agency (IEA) greenhouse gas programme (GHG), Holloway et. al. (2008). They carried out Regional Assessment of the potential geological CO_2 storage sites in Indian Sub-Continent. The CO_2 storage potential of India's sedimentary basin, and their classification of basin into good, fair and limited, is based on their expert judgment, and have to be established with field test using stratigraphic methodology. India has hydrocarbon fields in Barmer basin, Cambay basin, Mumbai Off-shore basin, Bombay High fields, off-shore Krishna Godavari basin, and oil fields in upper Assam.

The Basalt Formations are most viable options for environmentally safe and irreversible long time storage of CO_2. The basalts are attractive storage media as they provide solid cap rocks and have favourable chemical compositions for the geochemical reactions to take place between the CO_2 and the formation minerals, rendering high level of storage security. The Deccan trap has a vast basalt formation. The Intertrappeans between basalt flows also provide major porosity and permeability for injection. The largest lava flows of 1500 km across India from Deccan trap took place in the direction of Rajamundry and into the Gulf of Bengal. The basalts provide solid cap rocks and thus can ensure high level of integrity for CO_2 storage.

There are number of research opportunities in Carbon Storage which include;

- Mineral/ Physical Trapping of CO_2;
- Enhanced oil and Gas Recovery;
- Microbial – Biogeochemical Transformation of CO_2;
- Geophysical site selection and Monitoring;
- Chemical/ Kinetic behaviour in real time
- Well integrity- CO_2 resistant cement / steel;
- Numerical Simulation;
- Risk Assessment (FEP – Procedure);

- Hydrodynamic models of Aquifers; and
- Geo-mechanical rock behaviour etc.

H.4. Enhanced Coal Bed Methane Recovery (ECBM)

CO_2 sequestration in the un-mineable coal seams serves the dual purpose i.e. CO_2 storage and enhanced coal bed methane recovery. Coal beds typically contain large amounts of methane rich gas which is adsorbed onto the surface of the coal. The injected CO_2 efficiently displaces methane as it has greater affinity to the coal than methane in the proportion of 2:1 and is preferentially adsorbed displacing the methane absorbed in the internal surface of coal layers.

India has vast coal bed methane potential (1000 BCM.) The un-mineable coal seams in India occur in many Gondwana and Tertiary coal fields. The CO_2-ECBM can be advantageously used for exploiting the coal bed methane resources of India. The development and application of this technology is still at an early stage in the country. Directorate General of Hydrocarbons (DGH), New Delhi has planned to initiate CO_2-ECBM technology in some selected Gondwana coal fields.

I. Economics of CCS

CCS is in relatively early phase of development in respect of its costs, timings and relative attractiveness versus other low carbon opportunities. There is high degree of uncertainty in estimating the cost of CCS because of significant variations between project's technical characteristics, scale and application. There is also uncertainty over how costs will develop with time and variability of input costs such as steel, engineering and fuel development.

The cost of CCS is defined as additional full cost i.e. initial investments (capital costs) and ongoing operational expenditure of a CCS ready power plant compared to cost of state of the art non- CCS power plants with the same net electricity output and using the same fuel. The cost to include all components of value chain: CO2 capture at the power plant, its transport and permanent storage. The cost of CCS is expressed in expenditure incurred for per tonne of net CO2 emission reduction, to allow comparison with other abatement technologies

- The capture costs also includes the initial compression of CO_2 to a level that would not require additional compression or pumping if the storage site were closer than 300 km;
- Transport cost to include any boosting requirements beyond 300 km;
- For storage only geographical storage options such as depleted oil or gas fields and saline aquifers.

The estimation of CCS costs is based on the following parameters:

1. Demonstration phase: Sub commercial scale to validate CCS as an integrated technology at scale and start learning curve- 300 MW capacity coal fired plant- by 2015 in Europe.($ 80-120 per ton CO_2 abated),
2. Early commercial phase: first full scale projects to start ramp up of CO_2 abatement potential 900 MW coal fired thermal unit – by 2020; (US $ 50-70 per ton CO_2 abated) and
3. Mature commercial phase: wide spread roll out of full scale projects: significant abatement is realised – by 2030(US$ 40-65 per ton of CO_2 abated)

Beyond early commercial development, the cost of CCS is expected to evolve differently at each stage of value chain and according to different driving factors, and effective cost reductions in capital expenditure of capture equipment, combustion technology efficiencies, source sink matching i.e. onshore and offshore mix etc. The overall impact of these factors on CCS costs would depend on the roll out scenario after the early commercial phase. The introduction of new 'breakthrough' technologies, currently in the early stages of development phase such as chemical looping or membranes, could potentially lead to a step like reduction in cost of CO_2 capture. The estimates of long term CCS costs are structurally more uncertain and are highly dependent on the assumptions such as:

- Learning rates on currently non operational processes;
- Possible new technologies;
- Storage locations and availability;

- Rule out hypothesis; and
- Costs may come down faster with broader roll out, so global introduction of CCS would increase the overall cost efficiency.

The costs will be higher in case of retrofitting of Carbon Capture equipments/ facilities in the existing thermal power plants or other industrial installations due to availability of space and also shutting down of plant for carrying out modifications.

I.1. Stakeholders Survey

The survey of stakeholders' perception on Carbon Capture and Storage technology was undertaken by IRADe to support the research project. The questionnaire was designed to conduct the survey in June-July 2008 and restructured in February 2009, to seek elaborate answers on some issues, needed to analyze the CCS technology in the context of Indian power sector. A total of 54 interviews were collected from the respondents who are the key players from the target groups at various venues and locations. The team also tried to gather the information from the experts in the fields throughout the country. It was intended to elicit viewpoints from the top-level experts and stakeholders related to Indian Energy and Power sector, their perception on the following matters:-

i. Their understanding about the importance of CCS technology in restricting the concentration of CO_2 (as a GHG) in the atmosphere.
ii. Importance of the CO_2 emissions from Power Plants as a threat to global warming.
iii. Chances of developing efficient CO_2 capture technologies with low marginal energy consumption after R&D.
iv. Difficulties in reaching energy efficient and safety technology components of CCS.
v. Whether India can benefit due to the business opportunities offered by R&D needed to develop energy efficient CCS technology.
vi. Time horizon perceived for use of CCS technology in view of high-energy consumption in developing world.
vii. Key barriers affecting progress in R&D in developing CCS technology.

viii. The barrier to use CCS which can be overcome by undertaking R&D

ix. Specific ideas on the necessity of utilizing CCS technology in the context of Indian Power sector to arrest climate change.

The key stakeholders and decision makers were identified on the basis of their occupation and influential capabilities. The respondents were then divided into five broad categories namely:

i) Industry,

ii) Academic + Research + Modeller,

iii) Government + Bank + Regulators,

iv) Consultant + Project' and

v) Media + NGO + Environment.

The survey covered 54 individuals' professionals/ experts covering the whole spectrum of stakeholders without depending on the industry associations such as FICCI, ASSOCHAM, and CII. There are a number of respondents who are involved from various stakeholders in CCS R&D projects. These respondents are working on development of clean technologies, carbon capture technologies and carbon storage technologies.

The group 3 and 5 among the respondents were of the view that developed countries should lead by example by establishing successful demonstration CCS. Projects ongoing R&D work to make CCS technologies techno-economic viable was indicated by the survey. Few respondents suggested that global R&D center on CCS be established in India. There could be business opportunities for India because we are in a position to establish manufacturing base. Referring to regulatory issues, the emerging suggestion appears that a body in India may compile development in regulatory aspect in developed countries and its tuning to Indian scenario may be worked out. Responding to funding issue respondent referred to the need of specific financial support. The CDM may be applicable only after demonstration projects have reached cost effective deployment. Except for international support for the project no other suggestion emerged from the survey.

J. Roadmap of CCS Technology in India

Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Without decisive action, energy-related emissions of CO2 will more than double by 2050 and increased oil demand will heighten concerns over the security of supplies. Energy efficiency, many types of renewable power, hydro power,, nuclear power and new transport technologies will all require widespread deployment if we are to reach our greenhouse gas mission goals. Every major country and sector of the economy must be involved. Many other cheaper and simpler options need to be pursued prior to CCS which may be needed even after all is exhausted. They are:

- end use fuel efficiency by all economic sector;
- end use electricity efficiency – by using energy efficient equipments, and cut down on consumption ;
- end use fuel switching with focus on renewable and clean energy ;
- Power generation efficiency and fuel switching – super-critical, ultra super-critical, IGCC, oxy-fuel etc;
- Renewable as replacement of fossil fuel, waste heat deployment;
- Nuclear as alternate source of energy and resolving issues connected with nuclear energy application;
- CCS in power generation; and
- CCS in Industry and process transformation.

The current developments in India connected with CO_2 emissions mitigation in practice are as follows;

- Preparation of CO_2 and GHG Emissions Inventory at the national level (Central Electricity Authority)
- Improvement in efficiency of existing (old, inefficient plants) thermal plant by Renovation and Modernization. Mapping of thermal power station for higher energy

efficiency is being carried by Central Electricity Authority, Bureau of Energy Efficiency in collaboration with GTZ. Use of automation, communication, and IT are being applied for enhancing process, logistics and management efficiency.

- The new Greenfield plants having the state of art technology ensuring higher efficiency technologies (Super/ Ultra super critical) are being incorporated in UMPP). Most of these units are pit head power plant with captive mines and will be using best mining practices. The UMPP at Krishnapatnam, Mundra, Tadri, Girye, Cheyyur are coastal power plants and they plan to use of imported coal.
- R&D on Oxyfuel, ultra-super critical (steam temperature above 700 degree centigrade and 300 ata) and IGCC pilot plant are being developed by BHEL and NTPC
- Use of renewable energy, biomass, carbonaceous waste in the existing heating scheme of the boilers.
- The research and academic institutions are working on development of Carbon Capture and Storage technology (CCS) and its components need to set up a network to exchange information and for co-ordination.

Indigenous developments of the mitigation process require active participation of the government bodies, scientific community (academics & research institutions), design bureaus and consultants, manufacturing technologists. Each has a defined role. These design development leading to successful execution of demonstration project have to be established with:

(a) Basic and applied research on each component of CCS technology;
(b) Gap analysis between indigenous capability and off the shelf-technology availability in developed countries will guide scope of technology transfer;
(c) Analysis of technology of each component for their maturity for pilot project;
(d) Planning for capture ready plant. Define profile of capture ready plant;
(e) Project design for an integrated CCS pilot /demonstration project;
(f) Approval and permission of competent authority for regulatory checks and land use;

(g) Execution of demonstration projects; and

(h) Lessons learnt for subsequent project up-gradation, and scalability.

India is the member of Carbon Sequestration Leadership Forum (CSLF), and FutureGen project. The state owned leading Indian exploration company 'Oil and Natural Gas Corporation' (ONGC,) is establishing a carbon sequestration pilot project for EOR at Ankleshwar. Clearance of MoEF is essential for Environment Impact assessment (EIA). The state governments and the states sharing boundaries with the plant location where project will be implemented have permit issuance authority on the project, in context of state and national regulatory framework, health & safety, and land use. Without resolving risk factors associated with geological storage & transport, and pollution at capture stage, it will be difficult to obtain EIA approval.

Analyzing the current scenario of power sector development, it appears that earliest testing of CCS demonstration project can be feasible in the thirteenth five year plan i.e. 2017-2022. The eleventh five year plan is nearing its end. The large numbers of power plants to be commissioned during 12th plan are under construction or are in the process of placing orders for equipment and starting construction. The innovative concept for capture ready units can be thought of for thermal power plants to be commissioned in 13^{th} plan and beyond.

IEA has made an elaborate study on the role of CCS technology in mitigation of global carbon dioxide emission and documented a roadmap for development and implementation of the CCS scheme in power sector. Each developed country has a road-map for implementation of CCS technology. Key actions needed as recommended by IEA are as following

- Develop and enable legal and regulatory frameworks for CCS at the national and international levels, including long-term liability regimes and classification of CO_2 for storage.
- Incorporate CCS into emission trading schemes and in post-Kyoto instruments.

- RD&D to reduce carbon capture cost including development of innovative technology, and improve overall system efficiencies in power generation, also including innovative technologies such as IGCC, oxy-fuel, chemical looping to enhance CO_2 concentration in flue gas to enhance efficiency of carbon capture process.
- RD&D for storage integrity and monitoring, Validation of major storage sites, Monitor and valuation methods for site review, injection & closure periods. Define ownership issues of storage site for defining short term responsibilities.
- Raise public awareness and education on CCS.
- Assessment of storage capacity using Carbon Sequestration Leadership Forum methodology at the national, basin, and field levels.
- Governments and private sector should address the financial gaps for early CCS projects to enable widespread deployment of CCS for 2020.
- New power plants to include capture/storage readiness considerations within design by 2015.

The Key areas for international collaboration are summarised as following:

- Development and sharing of national and global legal and regulatory frameworks.
- Develop international, regional and national instruments for CO_2 pricing, including CDM and ETS.
- Global participation in development and execution of demonstration projects similar to schemes proposed by Organizations: CSLF, IEA GHG, IEA CCC, IPCC.
- Sharing best practices and lessons learnt from demonstration projects (pilot and large-scale).
- Joint funding of large-scale plants in developing countries by multi-lateral lending institutions, industry and governments.
- Route identification for CO_2 pipelines.
- Development of standards for national and basin storage estimates and their application.

K. Basic Research Work in field of CCS in India

The government institutions are pursuing basic research on CCS technology independently. The Government is supporting basic research on carbon sequestration, carbon capture through department of science and technology and clean coal technologies, IGCC, underground coal gasification, enhanced oil recovery and enhance energy efficiency etc are being pursued with participation of public sector units BHEL, NTPC, ONGC etc. The R&D on CCS being capital intensive, the private sector participation will be needed. For transition to applied research stage few research groups have to come together to form collaboration for pilot projects. The government will have to approve few pilot projects separately for carbon capture, carbon storage, and monitoring verification for validation of conceptual technology emerging from basic research. The transportation process design may be according to the existing standards of ASTM. The governments in principal approval will be needed for demonstration of CCS technology by integrating technology component at a future date. They are aware of the administrative issues such as

(a) Regulatory framework on health, safety, protection scheme,

(b) Financing of the project

(c) Environment impact assessment clearance

(d) Technology transfer,

(e) Land use and

(f) Compliance with existing legal provisions.

The important institutions and researchers working on CCS scheme in India are as follows:

a. The Government Organizations – such as Ministries of Power, Coal, Water resources and Mines, Department of Science and Technology, Geological Survey of India, CSIR institutions (NEERI, NIO, NGRI, CMRI, CMMS etc.)
b. Public Sector Units – BHEL, NTPC, GAIL, CIL

c. Private sector units – Tata Power, Reliance Power, L&T, PunjLloyd, Tata Bluescope, Shiv Vani oil etc.
d. Others such as Iron and steel Units, Instrumentation and Control system manufacturer for monitoring and safety
e. Regulators and government authorities and advisors.

CCS Being a complex process will require efforts of experts from multiple discipline and organizations. The progresses made in developed countries are very significant. The challenge is in integrating different indigenous engineering modules, technology transfer, and subsequent analysis of operation data. The formation of multi-disciplinary taskforce is needed to kick-start the project at pilot and then at demonstration. One of the options of initiating integrated effort is to have at least one Indian institution as knowledge center of CCS. The expected function of knowledge center could be:

- Develop a global network with international stakeholders associated with development of the technology for commercial application, and compile information on scientific, technological, regulatory developments;
- To bring together Indian stakeholders, especially business investors, and government, academic and others also who are interested in this area;
- To identify key questions & concerns with regard to CCS technology;
- To develop study projects to address the questions and issues, particularly which are of relevance to India;
- To study the cost of CCS and to suggest financing and cost-reduction measures;
- To study technology gaps in CCS and to suggest ways of bridging the technology gap;
- To make policy recommendations;
- To propose projects, including pilot and demonstration projects, to stakeholders;
- To interact with similar institutions and bodies overseas and to make available the latest information and insights to Indian stakeholders;

- To disseminate reliable and usable information ; and
- To promote study and research in this area & facilitate capacity building.