# ACBCCS
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**Ministry of Earth Sciences**
Government of India
Prithvi Bhawan
Lodhi Road
New Delhi-110003

## CCRI

# 2nd Workshop on Awareness and Capacity Building in Carbon Capture and Storage

15th -19th January, 2013

India International Center
New Delhi

# PROCEEDINGS

## Carbon Capture and Storage: Earth Processes

# 2nd Workshop on

# Awareness and Capacity Building in Carbon Capture and Storage

## ACBCCS 2013

**India International Center, January 15-19, 2013**

# PROCEEDINGS

## Carbon Capture and Storage : Earth Processes

# NATIONAL ADVISORY BOARD

# Second Workshop on Awareness and Capacity Building in Carbon Capture and Storage


## PREFACE

According to the Intergovernmental Panel on Climate Change (IPCC) assessments, the carbon dioxide concentrations in the atmosphere have increased to 399 ppm at present from the pre-industrial value of 280 ppm. A safe limit of 450 ppm has been set for the year 2050 to save the Planet Earth. There is a growing concern of global warming and climate change impacts due to this, demanding vigorous and scientific action at global and national levels. Both mitigation and adaption approaches are being developed to respond to the complex dynamics of climate change predictions.

The energy sector has been in focus as highest contributor for carbon dioxide emissions. To tackle global climate change from energy generation and use carbon capture & storage technology has emerged as a game changing technology. It has been endorsed as a vital technology for abatement of carbon dioxide concentrations in the atmosphere. The capturing of excess carbon dioxide, its utilization and storage technologies are the ways towards its permanent fixation away from the atmosphere. The challenges are immense and need to be addressed by scientific & technological means.

The five day national level Workshop on **Awareness and Capacity Building in Carbon Capture and Storage (ACBCCS 2013)** was held from January 15-19, 2013 at India International Centre, New Delhi. The ACBCCS-2013 provided a platform for the young researchers to learn more and endeavored to enhance understanding and knowledge on carbon capture, utilization and storage related earth processes. The proceedings of this capacity building workshop are presented here.

We convey our sincere thanks to the National Advisory Board for ACBCCS 2013 for their support and encouragement. I feel indebted and motivated by the overwhelming response from the eminent experts and delegates from various institutions across the country. This would not have been possible but for the support from the Ministry of Earth Sciences, Government of India.

Dr. (Mrs.) Malti Goel
*Convener*
*Executive Director, CCRI*

## OBJECTIVES

- To provide an opportunity to create awareness and enhance understanding of CCS and earth processes in carbon recycling.
- To share experience and global knowledge in carbon capture, utilization and storage technologies and address research needs in the Indian context.
- To put forth perspectives on carbon sequestration and earth processes in knowledge domain and submit recommendations to concerned agencies.

### WORKSHOP THEMES AT A GLANCE

| | |
|---|---|
| **15.01.2013** | **CCS Overview and Status** |
| **16.01.2013** | **$CO_2$ Reduction in Power Sector** |
| **17.01.2013** | **Earth Processes in CCS** |
| **18.01.2013** | **$CO_2$ Utilization** |
| **19.01.2013** | **Guest Lecture and Panel Discussion** |

# SECOND WORKSHOP ON AWARENESS AND CAPACITY BUILDING IN CARBON CAPTURE AND STORAGE

## ACBCCS 2013 – CONTENTS

# ACBCCS 2013 - THE ROAD AHEAD

1. **There is an urgent need to establish** a **National Institute of Carbon Capture, Utilization and Storage in the country to coordinate national perspectives, give thrust to R&D in its various sub-components and enhance the contribution of the industry in joint collaborative research and technology development.**

2. India is geared to achieve energy independence. It is being increasingly realized by the coal dominated economies that technologies for all resources of energy need development to accelerate growth of electricity capacity addition in the country. Certainly, it is time to take action for development of clean energy in the context of climate change threats. Two main areas unavoidable for clean energy growth are solar energy and clean coal energy. Clean coal includes Carbon Capture and Storage.

3. According to latest inventory of geological resource of coal by Geological Survey of India, India has total resource of 293.5 Bt and proven resource of 118 Bt. The lignite total resources are 41.9 Bt and proven resources are 6.1 Bt. Adequate planning and infrastructure is needed to unlock the potential and develop technologies for use of coal in environmentally sustainable manner.

4. Due to increasing $CO_2$ emissions with increase in coal based capacity, more thrust is need to be given to coal based clean energy development. There is a plan to upgrade power plant technologies for increasing the efficiencies of generation from supercritical and ultra supercritical technologies. The 12$^{th}$ Five Year Plan an addition of 78,000 MW fossil fuel based generation. This is also visible from the fact that for the first time technology of carbon capture and storage is also receiving attention.

5. India is among the few developing countries, which had a CCS research programme beginning 2006. The research is funded by the government viz. MoS&T, MoES and industry viz. NTPC, ONGC, Reliance and others. A large number of projects on carbon capture and storage (CCS) technologies including $CO_2$ capture, terrestrial and biosequestration are under implementation. Internationally, India has been founder member of Carbon Sequestration Leadership Forum since 2003, a Ministerial level programme aimed at collaborative R&D. The Global Carbon Capture and Storage Institute (GCCSI) have been established in Australia. Currently 18 large scale CCS projects are being implemented across the world. From India NTPC has joined GCCSI as industry representative.

6. There is need to support and intensity research on Carbon Capture, Utilization and Storage (CCUS). Beyond just research, it is necessary to look at many other variables that continue to have a close bearing on strategic application of this technology. As India gears to achieve a global presence in this frontier it is right time to institutionalize the efforts as fresh institute totally dedicated to CCUS.

7. Objectives and goals of the Institution were outlined. A suggestion was made to the Organizers to initiate the proposal and take it up with the concerned Departments of Government of India and Planning Commission.

# EXECUTIVE SUMMARY AND IMPORTANT HIGHLIGHTS

## ACBCCS 2013

1. A National Level Workshop on Awareness and Capacity Building in Carbon Capture and Storage: Earth Processes (ACBCCS 2013) has been organized under the Chairmanship of Shri R.V. Shahi, Former Secretary, Ministry of Power, from January 15-19, 2013 in New Delhi attended by the participants from academia and industry. This awareness program was so conceived as to create understanding about the stabilization of carbon dioxide concentrations in the atmosphere through an emerging process of Carbon Capture, Utilization and Storage (CCUS).

2. Dr. Harsh K. Gupta, Member, National Disaster Management Authority and Former Secretary, Department of Ocean Development was the *Chief Guest*. In his Inaugural Address he said that the workshop is very timely and commended this initiative. Shri M. P. Narayanan, Ex-CMD Coal India in his brief address suggested involvement of coal sector in $CO_2$ sequestration research. Shri D.K. Agrawal, ED NTPC highlighted the NTPC's initiatives and action plan for reduction in the $CO_2$ footprints. The eminent faculty included Dr. M.A. Atmanand, Director, NIOT, Chennai, Dr D.M. Kale, Director General, ONGC Research Center and Prof P.S. Yadav who came all the way from Manipur University, Imphal among other distinguished experts (Annexure 2)

3. In the five days workshop we have covered different themes. On $15^{th}$ January beginning was made with '**Carbon Capture, Status, International and National Overview'**. There was an introductory lecture on carbon capture & storage by Dr. A.K. Ghoshal, IIT Guwahati. Current international and national status was deliberated by Dr. Malti Goel, CSIR Emeritus Scientist. Then CCS corporate sector initiatives in India were presented by Shri Prakash Hirani from NTPC. Dr. Agneev Mukherjee from TERI presented on the scoping study on CCS in the Indian context.

4. On the second day the theme was '**$CO_2$ Reduction in Power Sector'**. $CO_2$ recovery from power plants issues & challenges, and various approaches were described by Dr. Anshu Nanoti, Indian Institute of Petroleum. One can capture $CO_2$ by physical, chemical and biological techniques. Dr. Ghoshal described physical and chemical methods in detail. This was followed by a **Field Visit to Indian Oil R&D Centre, Faridabad**. The R&D centre has advanced research facilities in the energy sector and reduction of $CO_2$ footprints from petroleum sector.

5. On 17th January the focus was on '**Earth Processes for $CO_2$ Sequestration'**, whether it is surface or sub-surface storage or both or even ocean. This was directly linked to the peak of the workshop. 'Geological sequestration of $CO_2$ in Saline Aquifers and Indian Perspective' was delivered by Shri A.K. Bhandari. Shri A.K. Bhandari was earlier with Geological Survey of India, Ministry of Mines. '$CO_2$ Storage Options: Ocean Perspectives' was delivered by Dr. M.A. Atmanand, Director, NIOT Chennai. He conveyed the importance of Ocean Sequestration challenges and presented new research proposed. 'Options for $CO_2$ Storage and Role of Unconventional gas' was by Dr. Balesh Kumar from Gujarat Energy & Research and Management Institute.

6. In the afternoon session '$CO_2$ Sequestration Potential for the Forests of North Eastern State of India' was delivered by Prof. P.S. Yadava, Manipur University, 'Prospects in Biomimetic Carbon Sequestration' by Prof. Satyanarayana Tulasi, Delhi University and 'Bio-sequestration of Carbon Dioxide: Potential and Challenges', by Prof. Uma Devi, Andhra University.

7. On 18th January theme was **$CO_2$ Utilization,** it included '$CO_2$ Sequestration Potential to Indian Coal Fields' presented by Dr. D. Mohanty from CIMFR, Dhanbad. 'Real-term Implications $CO_2$ Sequestration in Coal fields' by Shri Vikram Vishal from IIT Bombay & Monash University Australia. 'Reservoirs of $CO_2$ Storage & Value Addition in EOR Process' linked to enhanced oil recovery delivered by Dr. D.M. Kale, Director General, ONGC Energy Centre, originator of the Ankleshwar project. Challenges in Carbon Dioxide Storage and Enhanced Oil Recovery with Emphasis on Monitoring Techniques were discussed by Mr. Gautam Sen, Ex- ONGC.

8. On 19th January Shri V.S. Verma, Member of the Central Electricity Regulatory Commission, an eminent speaker and well known technocrat delivered the **Guest Lecture on Policy and Regulatory Interventions in Abatement of $CO_2$ Footprints.** It was pointed out that the thrust is to be given to CCUS rather than CCS. The CCS meant capturing $CO_2$ and throwing it somewhere as a waste product. The CCUS considers it not as waste product but it can be industry good or energy good. This is followed by roundtable discussions and presentations by the delegates.

9. Support to the Awareness and Capacity Building Workshop from Ministry of Earth Sciences is thankfully acknowledged. We are extremely thankful to the leading experts and distinguished speakers in the field, who have shared their enriching experiences in the workshop, and exposed the delegates about real-time situation, issues and challenges.

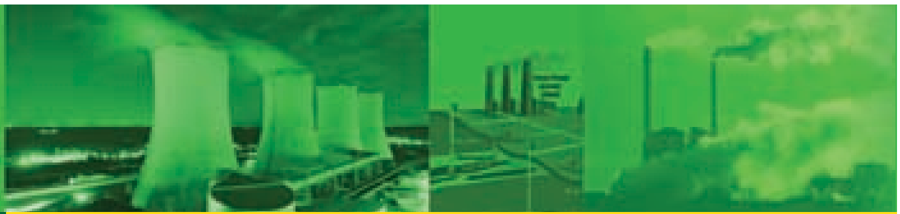
## IMPORTANT HIGHLIGHTS

**Some of the key highlights of the Workshop as 13 points to ponder about CCUS in 2013 as follows:**

- The largest power utility company, National Thermal Power Cooperation (NTPC) has been addressing the $CO_2$ issue by improving performance of running power plants and introducing technology for improving efficiency of generation. The NTPC has taken up CCUS as one of the research areas in its research wing NETRA (NTPC Energy Technology Research Alliance) and is in the process of pilot testing algae based $CO_2$ sequestration at Faridabad based power plant.
- India has Coal India, which is the single largest coal producing company in the world. The coal sector is major repository and is responsible for carbon dioxide emissions. Coal India should come forward to play a leading role in advancement of CCUS technologies.
- Large number of CCUS technologies including capture, utilization and recycling and transport are under development worldwide. In India research has begun. It should be directed research and pilot projects with industry collaboration are needed for confidence building.
- TERI has carried out scoping studies of CCS in India. It has highlighted need for mapping $CO_2$ footprints from power utilities and high energy industries. Source sink matching studies are needed to optimize the cost of implementation of CCUS.
- The bio sequestration approach is promising and has potential to become future viable technology. The algae based sequestration however needs mammoth data collation and standardization process for it to be effective.
- Efforts need to be accelerated to recover energy and materials from $CO_2$ recycling and extracting pure carbon from captured $CO_2$.
- As regards to $CO_2$ storage inside the earth, data for geochemical and geophysical information about potential reservoirs need to be generated for future simulation studies at probable sites and locations in the country.
- A disaster management plan and risk assessment should be the important components of the Integrated Plan of Action.
- Experimental techniques of monitoring, measurement and tracking of $CO_2$ migration in the oil fields for enhanced oil recovery are developing and there is need for more thrust in this direction in India.

- The potential of sequestration of $CO_2$ in the marine environment for phytoplankton growth by slag utilization of industry need to be assessed through a business model.
- Awareness about what one group is doing from the other is lacking, which leads to duplication as well as under utilization of the assets. The CCRI could take lead in information dissemination in the area of clean coal technology and CCUS research.
- Implementation of any new technology requires regulations. At present there are no regulations about $CO_2$. To tackle global warming related issues the environment regulations not only for industry but also for urban environment may include $CO_2$, for providing impetus to coal & power sectors, which are set to a robust growth in the current & next plans.
- There is an urgent need for a National Institute of CCUS to give thrust to R&D in various components and enhance the contribution of the industry in joint collaborative research and technology development and to coordinate national perspectives on climate change.

CCRI



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## INAUGURAL SESSION

15th January 2013

# INAUGURAL ADDRESS


**Dr. Harsh K. Gupta**
**Member, National Disaster Management Authority**

I am very happy to be with you in this morning. I will capture the central theme right away and I am in total agreement with Shri M. P. Narayanan ji, that carbon capture and storage needs more attention of policy makers. I very much appreciate the initiative of Climate Change Research Institute to organize this workshop to address the problem of climate change and CCS challenges. Important aspect is that what $CO_2$ storage does to the earth. Very often we say that first we inject a material and then see what will happen. Certainly, it has lot of implication to geological sciences. I sincerely hope that outcome of this meeting provides recommendations to take it forward and I urge Shri Narayanan to generate more interest in it from the coal sector and to help with a proposal to institutionalizing it.

It is certainly the right time because 12th five year plan is being launched. In my discussion Shri Narayanan he has also expressed similar sentiments. He said it is good to start as a fresh institute totally dedicated to CCS rather than as an appendix to some of the existing institution. I think it is a worthwhile that a core team is formed with Dr. Malti Goel, Former Adviser in the Department of Science & Technology (DST), who has been the driving force behind $CO_2$ sequestration research programme, for taking the lead. I suggest that we should start with the objectives and the global status, its importance in the Indian context and payoff in the next 4-5 years which could be many folds of the investment. These should form the basic elements. Once structure is planned we can approach the Planning Commission, Government of India. Industry involvement and support from the coal sector should be there because coal sector is mostly responsible for the production of the carbon dioxide and from the energy sector as well. I am really surprised that this has not yet happened. But better late than never!

The Indian industry has to come forward in a big way in technology development. I give an example of a simple technique used for a low temperature thermal desalination plant based on the concept of flash evaporation which is very simple. The pilot plant of 100 thousand liters a day was set up in 2005 at a cost of 8 crore rupees at National Institute of Ocean Technology, Chennai. The plant at Kavarathi is working for the last eight years. In this area water born diseases were very high. As a result of water purification, the reported cases in the hospitals have dropped to almost 30%. With a population of around 1000 people, all are collecting 10 liters water per day. The cost per liter was coming out 10-13 paisa per liter. Following this example two more plants have been set up on a demonstration scale. But Industry has not accepted it and has not come forward to replicate on a large scale.

There is another important aspect of it for industries, who produce a lot of industrial waste water. The temperature of the effluent is about 85°C. It has to undergo cooling cycle before letting it out. We can apply the flash evaporation method to produce power from it. An assessment should be made about how much waste water is with fertilizer plants alone which can be recycled or put to use in power production.

Coming to the specific topic of today, I think we really need to look for the places where we could possibly sequester carbon dioxide. Gas hydrates are emerging as a very-very potential area of storage. This storage has many challenges. The first time I was introduced to gas hydrates was in 1990s. When gas is transmitted in the undersea pipes they may go through 3-4 degree temperatures and pipes may get choked. In 1990s gas was to come from the Middle East through the Indian Ocean to India and there was a question that if gas is condensed and pipes are choked what will happen. As a solution it appeared that the Bottom Simulating Reflector should be used to detect and get the passage clear.

The question of industry involvement is therefore very important. Although we may get some experts from abroad to find the solutions, but it is required to have confidence building in ourselves and believe in what is being done. At National Geophysical Research Institute, I will like to name two persons, Dr. Kalachand Sain who has developed several innovating techniques to meet the requirements, to really estimate the quantum of gas and to quantify them and see that these techniques have been very successfully applied. Dr. P.S.R. Prasad is also working on a laboratory experiment of sequestration of carbon dioxide. Because there appears to be a very good potential that you can use carbon dioxide to push the production of gas from gas hydrates. By displacing the $CH_4$ by $CO_2$ methane can be produced as fuel.

It was at very good time that these initiatives were taken in 2006 or 2007 in DST. Could we become the turning point to the future, how we look at energy, how we do in this emerging field? **It is the right time and it is very important that we come up with a doable plan. We can keep a budget of around 100 crore type of money which is possible to support and come up with a plan as early as possible. I am sure that with the enthusiasm and support this group has got, it is quite possible.**

15th January 2013

## BRIEF ADDRESS


**Shri. M.P. Narayanan**
**Former Chairman**
**Coal India Ltd.**

I am very happy to learn about the ACBCCS-2013 workshop on CCS, as this subject is close to my heart. My connection with carbon sequestration is that of long association with Coal India, a company which produces so much of coal. We are the third largest coal producer and the Coal India is the single largest coal producing company in the world. But they think that by producing coal, their responsibility ceases there. I personally believe that something beyond that must be pursued. On the research and development activities for carbon sequestration, Coal India's contribution till today is almost nil. There was a mention of industries like ONGC, NTPC etc. and their involvement. I think that Coal India has a role to play and to this extent I can assure Dr. Malti Goel that together we can directly take it forward and we can see to it as one of the cash rich companies like Coal India with around 42,000 crores cash liquidity gets involved.

Capacity building as Dr. Kasturirangan, Member, Planning Commission, has mentioned in his message is important. I think institutions like Indian School of Mines, Banaras Hindu University and other mining institutions and universities also should pay serious attention to it. Special courses like this have to be conducted and awareness has to be created. Dr. Malti Goel's involvement carbon sequestration is very much appreciated. At present about 600 million tonnes of coal is consumed and it should go to 1000 million tonnes very soon and then

1.6 billion tonnes. Once you capture carbon dioxide, variant is to store it. That is going to be a real challenge. As I see in the programme we have very interesting lectures on storage aspects including ocean sequestration. I would suggest that to $CO_2$ sequestration inside the mines need to be given a thrust as well. Dr. Harsh Gupta, Member NDMA has agreed to support this through Government. *I strongly suggest that more than NTPC and ONGC, Coal India ought to take interest. At appropriate level of the CMD, it should be taken up and I am sure that Coal India will come forward and involve themselves in these activities.*

We need to find implementable solutions through continuous R&D activity. I wish the workshop to become a success. Thank you very much!

# SPECIAL ADDRESS


**Shri D. K. Agrawal**
**ED & Head, NTPC-NETRA**
**Greater Noida**

I am pleased to address the delegates of the Workshop and agree that coal is definitely playing an important role in $CO_2$ factor. Coal is one of the biggest contributors of the GHG emissions and global warming. The NTPC has organized the Roundtable meetings along with Ministry of Power and one of the conclusions was that we should work towards capture and may not be to that extent towards storage. In one of the papers we are presenting in the afternoon there is more detailed view on that.

As far as $CO_2$ capture is concerned, even before it was being done in the present form by capturing from its point sources, NTPC was very actively involved since 1995, to identify how we can improve the performance of the existing power plants. The power plants had wide range of efficiency some were operating on the efficiency of using 6.65 kg coal for producing 1 unit of electricity, while some units were using 1 kg of coal for producing 1 unit of electricity. There was a very high potential and it was one of the very important areas to improve the performance of the power plants and reducing emissions.

Another initiative that the government has taken is to introduce PAT scheme – Perform, Achieve and Trade. Utilities will be benefitted through trading of certificates with those non performing. Another initiative is National Clean Energy Fund (NCEF). This fund is huge, presently having about 8000 crores. It is generated by 50 rupees per tonne of coal consumed and charged from utilities. Utilities can propose projects which are of their interest and if approved by Ministry of Finance 40% contribution from the government side can be met from NCEF. The NTPC has taken up two projects one is a Solar Hybrid Project – integrating solar with the conventional power plant and improving the deliverables of the power plant. The second project is utilization of heat of flue gas, which is at temperature of the order of 140-

150 degree centigrade. Heat can be extracted for use in air conditioning through aqua ammonia cycle.

Coming back to coal based thermal generation NTPC is consuming about 400 million tonnes of coal. By 2017 total coal consumption in the country is expected to become 840 million tonnes and about 240 million tonnes will have to be imported. It is very important that we should conserve the use of coal and NTPC utilities have taken initiatives to improve the efficiency. At the same time, we are also conscious that there should be capture of $CO_2$ which is going out in the atmosphere along with other pollutant gases. For that there are few projects at NETRA- NTPC Energy Technology Research Alliance – One of the Research wings of NTPC. More information about these will be shared in the afternoon session.

*I very much appreciate that a suggestion has been made that Coal India should also take the initiative on how coal use can be made more environment friendly. When we are transporting coal from the mines to the plant area, we are transporting ash also. Ash content is high and sometimes it can be of the order of 45%. Whatever best that can be done to refine the coal by Coal India, will be most welcome. It will be a win-win situation. In fact it is good for CIL, it is good for NTPC or any other power utilities and also for the environment.*

Thank you.

15th January 2013

# INTRODUCTION TO THE PROGRAMMME

**Dr. (Mrs) Malti Goel**
**Convener**
**ACBCCS 2013**

It is a great pleasure for me to extend a warm welcome to the Second Awareness Workshop on Carbon Capture and Storage. Today is a memorable day. We are honored by the presence of Dr. Harsh Gupta, Member, National Disaster Management Authority (NDMA) and Former Secretary, Department of Ocean Development as Chief Guest. Also we have presence of other eminent personalities on the dais and off the dais, Shri M.P. Narayanan, Ex-CMD, Coal India Ltd. and Shri D.K. Agrawal, Executive Director, NTPC have graced the occasion. I recall that in 2007, we had an International Conference on $CO_2$ Sequestration and R&D Challenges, where some of the dignitaries here were present. The International conference from my previous Department of Science & Technology was held at NGRI, Hyderabad and attended by delegates from many countries. In DST we have had Inter-sectoral Meets of Stakeholders in CCS technology as well.

The excess carbon dioxide in the atmosphere has become the key component of concern especially in the 21st century. For those who practice Yoga, would know that excess carbon dioxide in our body is a problem. We are always asked to breathe out to keep ourselves healthy. Similar way we can say that the planet Earth, which is according to Gaia hypothesis, is a living system getting perturbed by excess carbon dioxide. There is a continuous interaction between living organic matter and non-living inorganic matter in the earth system and earth behaves like a living body. Excess $CO_2$ is creating a problem of climate change and we need to handle it through Science and Technology.

As India is geared to achieve energy independence, technology of all energy sources need to be developed to accelerate the growth of electricity capacity. Coal consumption has been growing in India as well as in the world, more so in Asia Pacific countries. The development of CLEAN ENERGY in the context of climate change threats has given rise to innovations such as carbon capture & storage (CCS). *India is among a few developing countries which has a CCS research program beginning 2006 and the research has been funded by the Govt.; The Ministry of Science & Technology, Ministry of Earth Sciences, and Ministry of Environment & Forests and industries like; ONGC, NTPC, Reliance and others.*

To create awareness and for capacity building about $CO_2$ sequestration and to understand the processes this national level workshop has been organized. Proposal to this workshop began in discussions with Dr. A.K. Ghoshal from IIT Guwahati and took shape under the guidance of National Advisory Board chaired by Shri R.V. Shahi, Former Secretary, Power. We are extremely thankful to Shri Shahi ji and Members of the Advisory Board and CCRI. I am happy to see delegates from different institutes and research laboratories at a short notice and thank all eminent participants and particularly Dr. Ghoshal for their good wishes.

I present a brief outline of the five day ACBCCS-2013 workshop, which is structured to create awareness about the recent developments in carbon capture & storage and to throw light on its consequences and challenges. It starts with an introduction and then there are three lecture sessions on CCS including a scoping study for CCS in the Indian context from TERI. This is followed by lecture sessions on $CO_2$ capture using physical and chemical techniques and search for low cost materials for $CO_2$ capture. On the third day our focus changes to $CO_2$ storage processes. Dr. M.A. Atmananad, Director, NIOT, has kindly agreed to speak on the subject of Ocean sequestration. Sessions on saline aquifers, basalts, terrestrial and bio technique sequestration from eminent speakers are to be held.

On the fourth day i.e. 18$^{th}$, two sessions are dealing with enhanced gas recovery from the coal mines and role of monitoring for enhanced oil recovery, which can prove to be of immense value also. The program is compact and we hope that each of you get something to take back home. On the last day Shri V.S. Verma, Member, Central Regulatory Electricity Commission, has kindly consented to deliver a Guest Lecture on Policy Aspects of CCS. This is followed by an open roundtable discussion.

India has vast environmental policy framework which relies on the earlier policy acts and guidelines which began from 1974 onwards. The national action plan came in to being in 2008 to address the climate change issue. The CCS is not included in the climate change program. With the launch of Science & Technology Innovation policy in 100$^{th}$ Session of the Indian Science Congress held very recently (Jan 3-7, 2013, we feel that India should innovate on CCS and CCUS as well, so that technological feasibility and economic viability are also developed in view of India's energy independence on coal. We need to promote research in this area no doubt. We need to prove to the industrial community and also we need to prove to the world. With these remarks I once again convey my sincere thanks to all distinguished participants.

15th January 2013

# INTRODUCTORY LECTURE ON CARBON CAPTURE AND STORAGE


**Dr. A.K. Ghoshal**
**Professor, Department of Chemical Engineering & Head, Centre for Energy, IIT Guwahati, Assam**

In this lecture, I will be discussing mainly on the overall aspects of carbon capture and storage. From the experience I have gained I would share with you different areas of carbon capture & storage. Then I shall follow it up with a lecture on physical and chemical methods of $CO_2$ capture in detail tomorrow.

In the Inaugural Session it was mentioned that NTPC has already taken into consideration several super critical units and they are have better efficiency and reduce $CO_2$ emissions. But even if we go for super critical or ultra super critical units, we are not avoiding the carbon dioxide emissions in those places. Some $CO_2$ emissions would be there, may be less per unit when compared to per mega watt of electricity produced by normal sub critical units.

Therefore there is a need for CCS. Carbon capture can be done in two ways. One is pre combustion capture and another is the post combustion capture. There are other emerging technologies such as oxyfuel technology and micro fuel technology etc. In the pre combustion capture we know that $CO_2$ capture takes place before the combustion. In the post combustion capture, it takes place after the combustion.

Among the post combustion capture technologies amine based capture is well known but there is a problem of high cost. There are other capturing technologies like adsorption, chemical looping combustion which are in the research stages. I may add that cryogenic separation is not given much attention. Possibly the cryogenic will play some role so that we can store the $CO_2$ in liquid form for some time and later on it can be put to use.

Coming to the pre combustion capture, an example is hydrogen membrane reforming which is adopted for Natural gas. In case of Natural gas it is being heated through the steam reforming reaction and then carbon monoxide is converted into carbon dioxide in the water-gas shift reaction. This technique can be applied to coal syn gas and is suitable particularly for high sulfur coals and heavy petroleum residue. The efficiency is very high in case of IGCC. In this separation, membranes have an important role.

In oxy fuel technology the role of membrane comes into picture twice, first when oxygen is to be separated from the air and later for separation from flue gas. The oxygen is used to burn the fuel. Here we are producing mainly $CO_2$ rich fuel gas. The $CO_2$ can be separated from the flue gas and captured.

The captured $CO_2$ has to be utilized or it can be stored. There are number of usages for manufacturing urea, soda ash, and food and beverage industries etc. for $CO_2$. In $CO_2$ utilization, efforts should focus on the conversion to usable products and fuels that will reduce its emission.

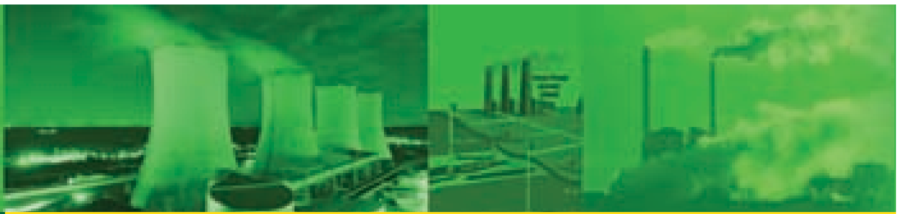
In the non geologic storage $CO_2$ is permanently immobilized to produce solid materials and useful products with economic value. In indirect storage photosynthesis is enhanced and $CO_2$ is stored. Use of $CO_2$ to react with metallic iron to form carbonate is another important area. We have to find out new reaction, new path ways to be developed that can help to utilize $CO_2$ in terms of products. The NTPC is doing work on bio sequestration by using the micro algae for value addition.

For geologic $CO_2$ storage there are three possibilities, one is the oil and gas reservoirs, second is unminable coal seams and third is deep saline reservoirs. We have to ensure that carbon storage will not affect the geologic integrity of an underground formation and that $CO_2$ storage is secure and environmentally acceptable.

Coal bed methane recovery at certain coal sites where the coal cannot be taken out and there are some amount of methane in absorbed condition. Its production can be enhanced by injecting the $CO_2$. In the saline formations under the seas and the deep saline formations on the earth, there is a scope of 120 billion tonnes of $CO_2$ that can be stored in US alone. We have to understand and optimize the process of underground storage to ensure the safe and permanent storage.

*Parallel investigations are required in different areas. New areas of carbon capture are needed so that we can improve the carbon capture technology. It has been suggested in the morning there should a dedicated institution for this kind of work. At present proper direction is lacking and there is a need for a national regulatory framework. With this I would like to thank you for your patient hearing.*

CCRI



# 2nd Workshop on Awareness and Capacity Building in Carbon Capture and Storage

15th -19th January, 2013

India International Center
New Delhi

# TECHNICAL SESSION

15th January 2013

# CURRENT STATUS OF CCS RESEARCH – NATIONAL & INTERNATIONAL

**Dr. Malti Goel, CSIR**
**Emeritus Scientist, Jawaharlal Nehru University, New Delhi**

Hearty welcome to all the dignitaries on the dais and off the dais! In 'Carbon Capture, Utilization and Storage – Current Status and Future Perspectives', I shall cover five topics; one is current energy scene in India, second is the drivers for CCS i.e. why should we pursue carbon capture & storage? Third is what the technologies are? Fourth, international status of CCS and finally, current status in India and the way forward.

**Current Energy Scene**

Looking back into the growth pattern in the past century it is seen that the world population grew 4 times, the urbanization grew more than 10 times and water use increased 9 times from what it was in 1900. At the same time energy use has increased more than 16 times and the carbon dioxide concentrations have increased by almost 30% (according to the Inter-governmental Panel on Climate Change). Coal combustion is a key source of energy as we all know. It is the main source of $CO_2$ also. The studies have indicated that in 2010 the energy sector was contributing of about 65% of all greenhouse gas emissions, while in 2030 it might go up to 75 to 79%. The contribution is going to increase with the energy consumption.

In India in the current electricity install capacity of 207.000 MW coal based from thermal power generation share is 57%. India is the third largest consumer and fourth largest producer of coal in the world and the contribution to energy is almost 80%. In the 12th five year plan an addition of 78,000 MW coal based power generation is planned. In 13th Plan 1,00,000 MW of coal based power generation is targeted. By 13th plan, all new plants should have super critical technology. No new plant will be based on lower efficiency of pulverized coal.

India is emerging in renewable energy sector no doubt and at present 12.5% installed capacity is from renewable. The Government has launched Jawaharlal Nehru National Solar Mission, which is addressing the upgradation of solar energy in the country. Options for solar upgradation viz., photovoltaic, solar, thermal and hybridization are taking place quickly, though costs remain high.

**Drivers for CCS**

The drivers for carbon capture are global climate change mitigation strategies, global treaties and protocols. India is part of these conventions and protocols. Secondly for India's energy security and sustainability, coal has to continue to be used as energy resource. This would mean need for taking measures for $CO_2$ reduction. According to International Energy Agency (IEA) study graph about the various options, CCS was considered as one of the option for reducing $CO_2$ footprints. By 2050, as much as 17% reduction is possible by CCS. This would be in addition to increase of efficiency of generation, which would contribute up to 20%. Third driver is national policies and programs such as National Climate Change Action Plan and policy directions that CCS research is to be pursued. I have been closely associated with CCS development in the country, both as driver (inception on national $CO_2$ sequestration research programme – India) and as expert (Pacific Northwest National Laboratory, USA). I feel happy to see young researchers taking interest in $CO_2$ sequestration research.

**CCS Technology Overview**

We can group CCS Technologies into five sub sets of technologies. Capturing excess $CO_2$ from power plants and compaction of separated $CO_2$ into liquid form is one. $CO_2$ capture technology or separation form the flue gas is an energy consuming process, whether chemical or physical. Chemical processes are absorption and chilled ammonia process. Solid absorbents are the porous materials and by pressure swing or temperature swing or vacuum swing they release $CO_2$. Membrane separation is another physical process. Any of capture technologies we adopt we have to economize and minimize energy consumption. In cost distribution curve of CCS, the capture cost has highest share, so maximum research is being pursued on capture.

The capture $CO_2$ needs to be transported to appropriate sites and injected if it is to be stored in geological for permanent fixation of carbon dioxide or utilization into value added products. The initial logic given for CCS adoption globally was that the existing oil pipelines could be used for the $CO_2$ transportation and the cost of transportation will be minimized. So pipeline is one way of doing it at a certain pressure. The marine transportation requires temporary storage facilities at the port. From land it can be transported in trucks or tankers to the coastal site. Source and sink matching which is 'Geostratiphic Acceptance' is also important. If the distance is more between source and sink the transportation cost will increase from 5 to 10% to about 15 to 20%.

The third technology sub set is on the surface sequestration. Terrestrial plantation, mining waste, metal industry slag, bio sequestration, marine algae sequestration all are different storage options. Each requires different challenges to be addressed. Our body has enzymes. If enzymes are less in our bodies toxicity increases. In a similar way the enzymatic capture of $CO_2$ is proposed on the earth. The metal industry slag and mining waste are other options. Absorption of $CO_2$ in soil is very high. If we can increase soil by 0.1% all $CO_2$ problem can go away.

The sub-surface storage occurs in saline aquifers, empty oil & gas, mineral rocks, coal fields, shale reservoirs. There is a thinking of using of $CO_2$ injection during hydraulic fracturing which is required for shale gas discovery. Exon has done some experiment on this. There are many challenges is $CO_2$ underground storage namely reliability of storage, safety, security and permanency. Even in the long-run leakage should not be there. Long-term site assessments from physical and geological conditions are required. Risk assessment, policy and public perception are important. In addition there can be ocean storage, which is of three kinds. One is phytoplankton growth that is on the surface, using iron fillings for enhanced growth of the marine plantation, second is storage under the sea at greater depths. Third option is storage in gas hydrates, which is again a frontline area of research.

The $CO_2$ utilization results into value added products. One can have short-term and long-term utilization products. In the short-term uses are in food processing in carbonated drinks, value added products, fuels and chemicals, fertilizers etc. $CO_2$ is a chemical reactor and with appropriate catalyst it can form methane, ethylene, formic acid, carbon monoxide, which is then converted into energy fuels. In the long-term enhanced oil recovery and enhanced gas recovery are value added products from $CO_2$ utilization. Enhanced mineralization on the surface, enhanced photosynthesis, enhanced forestation is the research topics for study.

**International Status of CCS Research**

What are the international perceptions about CCS? CCS is looked at as a future clean energy technology but an energy intensive initiative. There is a long-term strategic importance for CCS as part of the worldwide climate change mitigation efforts. Internationally, the interest in scientific research in this area has been growing quite rapidly. Some universities abroad have started formal M.Sc. Course in CCS like Edinburgh. There are short courses in carbon capture in many parts of the world which are held regularly on yearly basis. Up to 90% of the emissions can be captured. At present three major $CO_2$ capture efforts are dealing with pre-combustion, post-combustion and oxyfuel options. Two are post-combustion type, that is using conventional coal and oxyfuel and the third is pre-combustion type. Oxyfuel is having 90% of $CO_2$ in the flue gas, so there is less cost for separation. It was thought oxyfuel could be a better option. However, there is no clear winner as of now and the dilemma is whether to go for pre-combustion or post-combustion or oxyfuel combustion.

Then are several international initiatives viz., Carbon Sequestration Leadership Forum (CSLF) is an initiative of Department of Energy, USA that has focus on collaborative R&D in Carbon Capture and Storage. Began in 2003 it has 22 countries as member. Global Carbon Capture and Storage Institute (GCCSI) established in Australia in 2009 aims to accelerate commercial development of CCS. Then Euro Mission Fossil Fuel Platform that came in European Union as a technology platform for promotion of CCS technology. European Fossil Fuel Forum was set up as CCS project network for the stakeholders. All these activities are taking place simultaneously specially in America and European Union. According to US Department of Energy more than 250 projects are in different stages of planning, construction and abandonment etc. According to Global Carbon Capture & Storage Institute 74 large scale demonstration projects are in the pipeline. USA is the leader in carbon sequestration research having 113 CCS research projects in different stages of implementation, which include 24 large scale projects out of 74. Out of these 8 are operational and are sequestering about 20 million tonnes per annum. Another 6 or 7 are under construction and may come up by 2014 or 2015. China also has 10 CCS projects.

The first scientific report on research challenges in CCS came out in early 1990s from USA from Massachusetts Institute of Technology. The technology was introduced in the early 90s and global research output during 1990-2000 was not high. I recall submitting a paper in the Japan Conference on $CO_2$ reduction using polymeric substances, way back in 1993. Japan was then leader in $CO_2$ capture. Our study of research output under the CSIR Clean Energy R&D project at JNU has shown that during 1991-2005, there were a few (less than 20 in a year) research publications globally, but from 2006 onwards research output in CCS has been growing exponentially. A study of country wise research output suggests that America is leading and Australia and China are doing well. Both India and South Africa are in nascent stage in terms of research output. Technology wise i.e. pre-combustion, post-combustion and oxyfuel, the oxyfuel is getting the highest research publications and pre-combustion chemical capture is getting the lowest.

**Current Status in India and Way Forward**

India became a member of carbon sequestration leadership forum in 2003 and this led to launch of research programme under the Department of Science & Technology. Thrust areas were identified as (i) modeling of terrestrial agro forestry sequestration, geo modeling was not included but feasibility of geo modeling was also being done (ii) carbon capture materials & process development (iii) Biofixation through micro algae and terrestrial ways of $CO_2$ sequestration and (iv) CCS policy development studies. India is member of many other international co-operations that work for the development and dissemination of CCS technologies. These include International Partnership for Hydrogen Economy, joined US in Future gen Project, US Big Sky's CCS Partnership. Asia Pacific Partnership for Clean Development and Climate (AP6) to address sectoral priorities. India is also a member of Global Carbon Capture Research Institute and International Energy Agency.

Several institutions and universities like Delhi University, Andhra University, JNU, Manipur, Bharatidasan, Rajiv Gandhi Vidyalaya, Bhopal, IIT Guwahati, NGRI, the National Thermal Power Corporation, ONGC, National Environmental Engineering Research Institute, CIMFR, Indian Institute of Petroleum, NIOT and many others are engaged in research. Research output measured in terms of numbers of research publications, however suggested that papers published since 1991 from India are less than 25 out of total 1297. India's fertilizer industry has one CCS plant and that too was planned not for $CO_2$ sequestration, just like $CO_2$ for EOR was not being done for $CO_2$ sequestration or climate change.

*Way forward* **–**CCUS research in India has begun. It would be needed to give more thrust on both short term and long term applications and investment also needs to intensify. *The CCUS technology development requires joint collaborative and directed research with industry participation. India would need a policy regulation to address the concerns of global warming and to develop $CO_2$ mitigation technologies.*

In this context I recall following quotation from none other than Dr Albert Einstein;

"*Research is to see what everybody else has seen. But to think what nobody else has thought*".

# CCS - CORPORATE SECTOR INITIATIVES IN INDIA


**Shri Prakash D. Hirani**
**Addl. Gen. Manager**
**NETRA - NTPC Ltd.,**
**Greater Noida**

I thank the organizers for the invitation. I may point out that carbon dioxide has the lowest global warming potential among the greenhouse gases, but $CO_2$ is one gas which has contribution of about 77% in global warming. Global $CO_2$ emissions reached about 31.6 giga tonnes in 2011 and it is predicted that it will go up to 40 giga tonnes in 2020. Present $CO_2$ concentration level is 395 ppm. India is on the third place in terms of world $CO_2$ emissions after China and USA but per capita emissions are far low compared to other major countries. Even China's per capita emissions are three times higher than that of ours and USA is more than 17%.

There are a number of pathways available for carbon mitigation. NTPC is one of the premier power utilities, who are blamed for carbon dioxide, the greenhouse gas. Efficiency improvement in fossil fuel power generation by adopting super critical, ultra super critical and advanced turbines is being pursued. Renovation and modernization of the old power plants and increasing power plant efficiencies, through partnerships in excellence has been carried out. The NTPC is also venturing into renewables, solar, wind turbine, tidal and biomass as carbon mitigation options.

Carbon capture and storage involves capture from stationary bulk emitting sources like the power plants, its compression and transportation preferably in a liquid form, storage in a geological safe formation with a continuous measurement monitoring and verification of the stored $CO_2$. Taking an example of a 200 mega watt coal fired power plant, the $CO_2$ level is 12%, moisture 5-10%, soft smoke there are in SPM and then nitrogen are about 72-75% at a temperature of 140 to 150°C. Total flue gas quantity is 1000 tonnes per hour. Approximately, the carbon dioxide emission is about 180 tonnes per hour. In order to experiment with capture the NTPC is putting up one algae based $CO_2$ sequestration plant at Faridabad power station, which uses Natural gas instead of coal. The flu gas will be at 120-150°C to be transported to the algae pond. Total pipeline from plant to pond will be 200 meters. At the end of the pipeline, temperature falls to 35-40°C through efficient cooling process. We are working along with the Indian Oil Corporation and with Government of India support.

Another initiative is specific to Ramagundum plant. The plant produces ash at very high pH of 11 or 12. The flu gas is directly pumped into ash and smoke for $CO_2$ fixation. There is a reduction in the ash activity also. By reducing the diameter of the pipeline and the pumping cost can be reduced. We are in the process of putting up a pilot project at Ramagundum for testing this approach.

The amine absorption process has been adopted for the urea plants as already mentioned by Dr. Malti Goel. Indo Gulf Fertilizers, Lucknow has $CO_2$ utilization plant for many years. Three new companies plan to take it up.

As regards to storage many parts of India are in seismic zone 4 & 5. By storing $CO_2$ in a geologic formation effect on seismic activities is not known. Moreover, most of the area falls under the shield area. The shield area is supposed to be the area where the $CO_2$ storage is not advisable. In geological storage the technical requirement and scale of operation will vary from site to site. It cannot be one solution for all the sites.

The NTPC provides guidelines of CCS and has framed CCS guidelines in 2009. These were discussed again in the workshop at Hotel le Meriden in 2011 participated by 150 delegates from different institutes. The policy was adopted once again as follows

"India is going to support R&D technologies aimed for reducing $CO_2$ emissions from coal based industries. Definitely India is not going for any demonstration plant on CCS. Of course we can see demonstration plants outside India if other countries are willing to do that. But big demonstration plants are not going to be viable in India."

Besides the corporate initiatives as regards to CCS, NTPC has launched hydro power projects as they are carbon neutral. In collaboration with Nuclear Power Corporation of India nuclear energy is also targeted. We have a joint venture with 49% stake. NTPC is supporting implementation of 20,000 MW grid connected solar power targeted under the Jawaharlal Nehru Solar Mission.

*Environmental initiatives of NTPC avoided 1.96 million tonnes of $CO_2$ in 2011-12. Millions of trees have been planted besides the R&D initiatives for solar, thermal and PV, waste utilization and also on the use of biomass as fuel. Through corporate initiatives $CO_2$ reduction of 5 million tonnes have been done so far. New initiatives for $CO_2$ avoidance are being taken every year***.** Thank you very much.

# TERI'S SCOPING STUDY ON CCS IN AN INDIAN CONTEXT


**Dr. Agneev Mukherjee**
**The Energy and Resources Institute, New Delhi**

First of all I would like to thank the organizers to giving me this opportunity to present here at this gathering. We recently conducted a scoping study on carbon capture & sequestration in India in collaboration with Global CCS Institute.

This study was conducted with a view to identifying the potential role for CCS in India. The power sector accounts for almost half of the emissions in the country. Among the industries the cement and the iron & steel industries are major contributors, food processing and ammonia contribute to relatively smaller proportions. In the overall scheme, it is the power sector followed by the cement and steel industry which are the major emitters. Therefore I will be dealing with these three sectors.

In power sector, coal accounts for about 57.3% of the total installed electricity capacity in the country. Besides super critical power technologies it is planned to develop ultra mega watt power plants, which are 4000 gega watt in size. The second largest source of $CO_2$ emission is the cement sector. The cement sector has grown at a compounded annual growth rate of more than 8% over the last decade and today it is the second largest in the world. China is the number one, several times India's size. It is a matter of pride that Indian Cement Industry is one of the most energy efficient in the world. The clinker plants for processing into cement have the lowest final energy use. Dry process is generally held to be the most energy efficient process and its proportion has increased drastically over the last half a century. The energy intensified wet processes on the other hand almost seen a corresponding decline over this period. Therefore we have the average $CO_2$ emissions from the cement sector at 0.68 tonnes of $CO_2$ per tonne of cement instead of 0.84 which is the world average. Yet total emissions from cement industry have to be reduced significantly, and the CCS can be a good option. In the Indian cement sector about 88% of the total production comes from large size plants and this is again favorable factor for CCS because of the economies of scale.

Indian steel sector is marginally behind the cement sector in the total emissions profile of India. India is the fourth largest producer of crude steel in the world and largest producer of sponge iron. Just like the cement industry, this industry has also witnessed very rapid growth in the recent years. Finished steel production is about 61million tonnes. The growth trend is expected to continue because in the year 2016-17, the crude steel capacity is expected to reach 140 million tonnes and therefore the emissions from this sector will also continue to rise unless some steps are taken. Unlike in the cement sector, in the Indian steel sector, average emission intensity is much higher than the world average. It is at 2.4 tonnes of $CO_2$ per a tonne of finished steel as opposed to 1.8 tonnes which is the world average. CCS can be possibly one of the options for reducing emissions especially in the case of larger units in the country.

Economic analysis of CCS has been carried out for a 4000 MW power plant. For a plant of this size consisting of 6 units of 660 MWs each, the net power output of the base power plant was reduced to 3755 MWs. Obviously CCS is a very energy intensive process and there is a capture penalty which it entails. To remove this disadvantage, we installed an extra unit of 660 MWs. Cost of the extra unit has been included in the capture capital cost which comes about 335 billion US dollars. The gross power output without CCS becomes 4620 MWs and net power output becomes 3850 MWs. The net power output has not significantly changed even though the gross power was high. The efficiency of the plant is significantly affected by the installation of the capture equipment. Therefore the heat rate has risen from about 9200 in the base plant to 13220 in the CCS installed plant. We have done this study for both imported and Indian coal taking some assumptions. The levellised cost of electricity was seen to rise by around 47%.

As far as current CCS activities in the country are concerned, the DST has been the nodal agency for conducting R&D in the sector and to set up the National Program for Carbon Sequestration in 2007. There are the 4 major thrust areas which were also explained by Dr. Malti Goel. ONGC had planned a pilot experimental project in Gujarat which as of now has been shelved. NELCO have plans to set up a carbon capture unit at Angol and to use it for capture for algae cultivation.

As regards to regulations there are different legislations which might govern CCS activities in India. These are mainly related to oil and gas, mining, health and safety, property right, transport, ground water and environmental impact assessment. Rather than framing new laws for these, it might be better if existing laws are amended to facilitate demonstration projects. Some of the existing legislations may govern the CCS activities in India. For example Indian Petroleum Act, one of the oldest legislations in the country which regulated the production and transport of petroleum in the country. Others like the Oilfields Regulation & Development Act, the Petroleum Minerals Pipelines Act etc. In addition interstate coordination may be required to address $CO_2$ transport and storage because it is possible that the project site would be different from the storage.

Government initiatives are needed to be taken to increase the public confidence and acceptance of CCS technologies. There are legal issues associated with CCS. The long-term ownership of $CO_2$ and its liability is one of the major factor. Because it’s not just about 10-20 years $CO_2$ should be stored at least a few 100 years or disposed off. But what if it leaks? Who will take the responsibility which is not something which has been addressed so far? The legal issues, related to land acquisitions, related to water contamination, what happens if leakage is taken place etc. have to be addressed.

Main barrier affecting the CCS deployment in the country is primarily that there is no accurate geologic storage site data available. Increase in the electricity cost alongside reduction in the net power output is another barrier. There are some changes required in the project appraisal and approval norms for financing agencies for power plants. Environmental impact assessment will be different in case of a CCS approved power plant compared to normal power plant. In CCS deployment we also require specialized manpower and suitable infrastructure. A full proof monitoring of storage site for long time has to be put in place.

*The capacity building programme like this and knowledge sharing among different groups is also very important. Capacity building is also required in areas such as storage site assessment as well as monitoring and verification. Financial institutions can play an important part because CCS is a very capital intensive sector. Some public engagement may also be required if CCS is ever implemented in the country. The carbon capture & utilization aspect should also be looked at.* Thank you.

# $CO_2$ RECOVERY FROM POWER PLANTS BY ADSORPTION: ISSUES, CHALLENGES AND APPROACHES

**Dr. Anshu Nanoti**
**Scientist-E II**
**Indian Institute of Petroleum**

As we know that there are three generic methodologies that can be used for $CO_2$ capture from a power plant. These are Post Combustion $CO_2$ capture, Pre Combustion $CO_2$ capture and Oxy-fuel combustion capture. Each methodology has its own merits and demerits.

In pre-combustion approach, gasification of feed stock (Coal) produces a hot multi-component gas stream containing acidic gases like $H_2S$, $CO_2$ along with $H_2$. Conventional solvent based technology for removal of acid gases operates at low temperatures; hence the gas cleanup train requires cyclic heating and cooling steps to produce clean H. These temperature swings lead to over all thermal lower efficiency of the process. Developing an alternative adsorption based technologies using adsorbents which can work at high temperature for $CO_2$ and $H_2S$ removal will be a step change towards increasing the thermal efficiency of the process.

Post combustion is an end-of-pipe treatment of the flue gases for removal of the $CO_2$ present prior to discharge through the stack. The $CO_2$ levels are generally in the range of 5% to 15% depending on the type of fuel undergoing combustion and the $CO_2$ must be removed from the mixture of gases $N_2$, $O_2$, moisture and $SO_x/NO_x$ which are present.

In post combustion approach, solid adsorbents like zeolites and activated carbons can be used to recover $CO_2$ from flue gas mixtures by pressure swing adsorption (PSA) technique. Several adsorbent materials have been investigated for $CO_2$ recovery by PSA or volume swing adsorption (VSA). The general consensus appears to be that Zeolite 13X materials performs better than activated carbons or silica gels. Both capacities and selectivities for separation of $CO_2/N_2$ mixtures (representative of flue gases from power plants) are superior. However, power requirement during regeneration can be high and for this reason there is a large scope for developing new adsorbents which will show better selectivity and regenerability.

*Metal Organic Framework (MOF) is a new class of adsorbents attracting interest for selective $CO_2$ separation. These are materials in which metal ions or clusters are connected via organic links to form highly porous network structures.* Several MOF's have been proposed as adsorbents for $CO_2$ recovery. However, the several studies that have been reported so far on $CO_2$ adsorption on MOF's have been limited mostly to equilibrium isotherm and diffusion measurements with pure components. Not much data is available on adsorption processes such as (PVSA).

There are many R&D challenges in combined pressure and volume swing adsorption (VSA) during pre/post combustion $CO_2$ capture. Recent R&D developments are being made in adsorption based capture technologies to address these issues are enumerated. An experimental study is presented for the removal of $CO_2$ from two types of gas feeds representing pre-combustion and post-combustion process streams. Hydrotalcite and MOFs adsorbents for $CO_2$ recovery can be evaluated by measuring their equilibrium loading capacities in a gravimetric microbalance. Breakthrough, PVSA experiments performed in a single column micro-absorber unit are discussed. The results are compared with performance data generated with commercial adsorbent materials under comparable operating conditions. Thank you.

# CAPTURING $CO_2$ BY PHYSICAL AND CHEMICAL MEANS

**Dr. A.K. Ghoshal**
**Professor, IIT Guwahati**
**Assam**

Distinguished participants! I would like to begin with chemical absorption processes for $CO_2$ capture. These can be divided into two categories distinguished by the rate of reaction of solvent with $CO_2$. The first category, also termed as $CO_2$ treating processes in bulk, is applied when the partial pressure of $CO_2$ in the feed is relatively low and/or the product purity is high. $CO_2$ is removed to very low levels using faster reacting solvents such as primary and secondary alkanolamines and promoted hot carbonate salts.

The second category, termed as hybrid category, attains increased $CO_2$ removals by controlling the reaction rate of $CO_2$ with the suitably blended amine solvents. Improvement of efficiency of a contactor also demands investigation on the effects various operating parameters and materials characteristics. Monoethanolamine (MEA) is used for separation of $CO_2$ from flue gases from power plants due to its ability to absorb $CO_2$ under low partial pressure conditions. The flue gas usually contains $SO_2$, NOx, $O_2$, $N_2$, $H_2O$ and particulates apart from $CO_2$. Their presence affect $CO_2$ capture performance and hence additional measures are taken to remove $SO_2$, NOx, and particulates before the flue gas flow into the $CO_2$ capture system.

$CO_2$ removal/separation by adsorption has drawn renewed attention because of development of potential adsorbents such as zeolites, activated carbon, carbon molecular sieves, SBA 16 and metal organic frameworks as well as modification of the existing adsorptive separation technologies. However, successful commercialization of adsorptive separation technologies for $CO_2$ capture is yet to be in place. In pre-combustion capture, the fuel is not burnt directly but is converted at suitable temperature and pressure into synthesis gas (mixture of CO, $CO_2$ and $H_2$). Thereafter, CO is further converted to $CO_2$ and $H_2$ and then $CO_2$ is captured to get $H_2$ (the major constituent) as fuel. Membrane Reforming, Sorption-enhanced water-gas-shift (SEWGS) reaction and Integrated Gasification Combined Cycle (IGCC) are typical examples of pre-combustion capture technologies.

Hydrogen Membrane Reforming (HMR), a combination of steam reforming (SR) and water-gas shift (WGS) reaction modeled into a single unit, is also referred to as membrane water gas shift reaction (MWGSR). SEWGS is used to shift the equilibrium conversion of CO for its complete conversion and $H_2$ production maximization. IGCC turns high-sulphur coal, heavy petroleum residue, biomass or municipal waste into low heating value, high-hydrogen synthesis gas and then removes impurities before it is used as a primary fuel for a gas turbine.

*Growing concerns over climate change have led to a strong emphasis on the research and development of high-efficiency and economic $CO_2$ capture technologies. The R&D activities are focused on refinement of current capture technologies on one side and development of novel capture technologies that can deliver significant benefits on the other side*. Thank you.

# GEOLOGICAL SEQUESTRATION OF $CO_2$ IN SALINE AQUIFERS-AN INDIAN PERSPECTIVE

**Shri A.K. Bhandari**
**Sr. Advisor**
**Ministry of Mines, New Delhi**

I profusely thank the organizers especially Dr Malti Goel. My first introduction to $CO_2$ sequestration was in implementing the research project from Department of Science & Technology on pre feasibility study of carbon dioxide sequestration in saline aquifers in the NCR region. The $CO_2$ concentrations are increasing and economists warn that the increasing frequency of climate related events coupled with social trends may result in increased costs related to disaster relief, insurance costs and may burden the tax payers. There is an urgent need to contain or sequester the carbon dioxide.

In a little over a decade that geological storage of carbon dioxide has grown from a concept to a potentially important mitigation option. The geological structure and physical properties of most of the oil & gas fields have been extensively studied and characterized. They form a good option, but their storage capacity is not sufficient. Enhanced oil recovery is also a matured technology and offers potential economic gains from incremental oil production. The other option is use of deep unminable coal seams i.e., abandoned or uneconomic coal seams. Coal has a higher affinity to absorb carbon dioxide gas than methane and is a good option for sequestration of carbon dioxide. Coal permeability is one of the several determinant factors in selection of a storage site.

Deep saline formations are believed to have by far the largest capacity for carbon storage worldwide. It is relatively at less cost and much more wide spread than other options. Sediment rocks such as sand stone, lime stone have many small pores that can be filled with water, trapped by an overlying layer of known as cap rock.. There are a number of places were deep salt water reservoirs have been used as buffer stock for natural gas, giving confidence that carbon dioxide could also be stored safely, for thousands of years in carefully selected reservoirs. If carbon dioxide is injected into these deep reservoirs, some will dissolve into saline water and will become widely disbursed into the reservoir. Carbon dioxide can also react with the minerals within the reservoir and remain fixed there for eternity.

Why saline aquifers? Saline formations occur in almost all sedimentary basins throughout the world in almost all off-shores and on continental shelf. Saline formations lie in many parts of the world and are in the proximity of the stationary polluting sources thereby reducing the cost of the infrastructure. It can help in achieving near zero emissions for the existing power plants and industrial units. The fact that carbon dioxide has been naturally stored for geological time scales enhances the credibility of the storage options. Scenarios for negative impact and unintended damages are limited usually due to their high saline proportion and depth. They cannot be technically and economically exploited for surface use. The estimated storage capacity in depleted oil and gas fields is 675 giga tonnes with an upper estimate of 900 giga tonnes, whereas unminable coal seams have very limited to 3 to 15 or 20 giga tonnes.

For any storage site the depth of aquifer and hard rock is essential. Usually only aquifers at 800 meters or below sea level are considered for carbon dioxide storage as a temperature and pressure in the sub surface are favorable. Carbon dioxide can exist in dense phase as a liquid and occupies much less core volume than in the gaseous phase. A one tonne of liquid carbon dioxide occupies 509 cubic meters at surface conditions of zero degree and pressure of one bar. The same amount of carbon dioxide occupies only 1.39 cubic meters at 1000 meters sub surface conditions at a temperature of 35 degree and pressure of 102 bars. The cap rock provides the main trapping mechanism for the long-term security of the storage cap. Storage cap rocks are usually shale, limestone and basalt layers

The trapping mechanism varies according to site. There are multiple mechanisms of storage including physical trapping beneath low permeability cap rock, dissolution and mobilization. The physical trapping is structurally controlled. The other is unconfined trapping where there is no structural control, but it spreads all over the area when injected. The third one is the geo chemical trapping. Carbon dioxide in the sub surface can undergo a sequence of geo chemical interactions with the formation rock and water. Some of the carbon dioxide dissolves in formations water through solubility trapping. Some fraction may be converted into stable carbon and minerals that is the mineral trapping. The mineral trapping is the most prominent form of the long-term storage. Nevertheless the permanence of mineral storage combined with the potentially large storage capacity present in some geological settings makes saline aquifers a desirable option.

This does not mean that there are no risks of storage. The reservoir properties and modeling are more important here in contrast to storage in abandoned oil or gas fields, where geo physical data, pressure, measurements, both of the reservoir and the over burden and seismic data are available. All of this can help to characterize the reservoir. Saline aquifers are not of much economic significance otherwise and therefore not much data are available.

In hydrocarbon fields the existence of seal is demonstrated by the very existence of the field. In case of aquifers determination of properties by testing and modeling is required to know about cap rock integrity. If it is not well studied there are the chances of escaping of carbon dioxide through the cap rock. In saline aquifers an aqua flow modeling is required. Aqua flows are common from areas of high pressure to areas of low pressure. This effectively increases the potential for dissolution of carbon dioxide and might be considered a benefit. However if it is likely that flow towards the shallower parts of the aquifers occur and this could provide a route for effective leakage of carbon dioxide to the surface or to a position where a phase change to gases is likely.

The other factor is the risk of penetration in the ground water. In most water rock systems, carbon dioxide is the most abandoned gas, but fairly exceeds 2% by volume in solution. If there are fresh ground water aquifers with a lesser separation, there are chances of pollution of the ground water by them. Carbon dioxide solubility in water decreases sharply with decrease in salinity. This means that carbon dioxide in saline aquifers in sedimentary basin is less sufficient and implies that the low saline aquifers are better for carbon dioxide disposal.

There can be a reaction with the horse rock. Some formation damage may occur as a result of removal of carbonate from the aquifer sand stone when they react with the carbon dioxide and form the minerals. The stability of the ground may be affected if the minerals are dissolved or if pressure greater than geostatic are applied. Fracturing in this may increase permeability and porosity that may also damage the integrity of the sealing cover.

Finally we require a screening criteria for storage. Not all sedimentary basins are suitable for carbon dioxide storage. Some are too shallow and the others are dominated by rocks with low permeability or confining characteristics. Basins suitable for carbon dioxide storage have characteristics such as thick accumulation of sediments, permeable rock formations, saturated with saline water, extensive covers of low porosity which acts as seals and structural simplicity.

Reservoir prioritization on a regional scale has reasonably straight forward data interpretation requirements. In general the storage site should have adequate capacity and inductivity, satisfactory sealing cap rock and confining units, stable geological environment. Realistic and quantitative information of the characteristics of the sub surfaces are needed to assess the feasibility of the sites.

For specific site characteristics we need to have a 3D seismic coverage augmented by down hole samples as minimum pre requisite. If full cap rock sealing evaluation for which real core material from both reservoir and cap rock is needed, saline aquifers are generally unused. Therefore documentation of the properties of the sub surface is not compiled in an easy to access format. The geological considerations while assessing the feasibility of the storage site include safe and liable containment of carbon dioxide. The injection site must be selected to have the geological properties that will assume that the carbon dioxide will remain trapped. The size of the reservoir should be large enough to store the quantities of the carbon dioxide plants. Then the important characteristic is the porosity and permeability must be sufficiently high to provide sufficient volume for carbon dioxide and low injection of the carbon dioxide and it should have adequate separation for potable water.

Younger sedimentary basins are more suitable as high porosity tends to be present as shale rocks. In older basins porosity is lost due to cementation and compactness because of the depth of burial. Globally, there are several ongoing projects on carbon dioxide storage in deep saline aquifers. They are mainly in sedimentary basins which are of younger nature and are less than about 80 million years old. They are not in hard rock area.

In the distribution map of the sedimentary basins of world, sedimentary rocks occupy quite a large area and have good potential for storage. As regards the Indian scenario, from the geological map 2/3 of part of the country is occupied by Archian, igneous, metamorphic rocks those all in dark colors. They are all Pristine rocks. The potentiality of saline aquifer is very low. In the Himalayan area, there are a lot of sedimentary basins. But because of their tectonic activity and their fractured nature, the sites may not suitable for sequestrations. The prospective formations are mainly confined to the semi consolidated sedimentary rocks occurring in the Ganga basin and the Gondwana sand stone, Rajasthan basin etc.

Directorate General of Hydrocarbon has prepared prospective map of the hydro carbon in the sedimentary basins. This could be taken as a basis to assess the potential of sequestration in the area. In India the deep saline aquifers, the distribution of inland salinity and saline aquifer suggest that the maximum saline area falls in part of Rajasthan, Haryana, Punjab, Uttar Pradesh, Gujarat and Tamil Nadu. Incidentally our major thermal power plants are also located in these areas. In Gujarat an area of about 28,000 sq. kms is affected by salinity and escalation of deep saline aquifers has showed its presence up to a depth of 620 meters below ground level. The exploration indicted the presence of thick saline aquifers in the basalts and Pre Cambrian shale formations. The aquifers are under a free flowing condition. In the Kutch region, the aquifers are encountered at different depths and continue up to 458 meters below the ground. The exploration up to 600 meters depth indicated the presence of granular zone with high salinity in Bikaner, Jaisalmeer area. In Ganga basins, exploratory drilling and geophysical logging is shown the presence of deep saline aquifers. The saline aquifers are present in western extension almost running for 342 kms from Meerut in Uttar Pradesh to Rusalpur in Bihar. The highly saline aquifers at all depths are present in an area of 8,600 sq. kms in Meerut and Agra Districts.

Our study has indicated that saline zone present within the Alluvial sediments of Ganga basin are often discontinuous, thin and occur at shallow depths hence cannot be considered for sequestration of carbon dioxide. Then the occurrence of fracture zone in one of the areas within the Alwar quadrates recorded in the Pirthala, Thumpsana area, these zones lacked the depth, continuity and characteristics of a suitable reservoir. However we have one 6,200 sq. kms saline aquifers confined from Chidkara in the South to Chada in the North, which can be a potential storage site but has not been further studied.

Finally to conclude, the logical storage of carbon dioxide for reducing emission for mitigation of global warming is a new research area. There are gaps in our knowledge as to the regional storage capacity and potential of different sedimentary basin and the deep saline aquifer occurring within them. *Extensive further research is needed both regionally and globally to study their true potential. Despite the fact that there are some areas where additional work is clearly needed to improve technologies and to decrease uncertainties, there appears to be no insurmountable technical barriers for geological storage of carbon dioxide as an effective mitigation option.* A precondition for any CCS project should be its economic viability. Thank you.

17th January 2013

# $CO_2$ STORAGE OPTIONS: OCEAN PERSPECTIVES

**Dr. M.A. Atmanand**
**Director**
**National Institute of Ocean Technology, Chennai**

I would like to first compliment Dr. Malti Goel for taking such a topic which is a controversial one. While I am happy that she has taken such a task. I am also unhappy that we have a thin attendance. I will begin with an overall idea of what is National Institute of Ocean Technology (NIOT). NIOT is an Institute under the Ministry of Earth Sciences (MOES). We work in the various areas of ocean technology we are basically engineers with various backgrounds. We have 9 pilot plants for energy from the ocean current, waves etc. and a plant that converts sea water into fresh water in a technology called low temperature thermal desalination. At NIOT we do not stop with having an idea and publishing papers but we work towards a final full-fledged product or a plant.

We also work in the area of ocean observations. Today India Meteorological Department (IMD) predicted well that there is going to be rain and it is drizzling now. I am happy that the predictions are coming true. From NIOT we put up data buoys in the ocean for weather monitoring. The data buoys measure the various parameters on the ocean including temperature and that is utilized in the ocean model which is run by the IMD and other institutes for weather prediction. Such information about ocean, being on three sides of India greatly helps in predictions.

NIOT works on the coastal environmental engineering wherein the coastal areas are studied. Wherever there are issues, we do a detailed study and some protection measures are being suggested. Also we work in the area of Deep Sea technologies. We are the first to put a Remotely Operable Vehicle (ROV) at a depth of 5289 meters successfully. That is a first of its kind in our country. We also developed an in-situ soil tester for measuring the sea bed properties. We are doing work in the poly metallic nodule mining, wherein the manganese nodules are to be taken out from the deep sea. We developed an underwater cruiser which has already been tested at 5000 meters and going to the next phase of 6000 meters.

autonomous coding system. The coding system will be used to core gas hydrates samples in-situ. Also we work in the area of marine biotechnology wherein special types of cage culturing, algae for bio fuel and also for deep sea microbes are under study. NIOT has a number of sea vessels, ships under their control to do the R&D in the ocean.

NIOT is engaged in several climate related studies. The climate being the average of the weather for about 30 years; global warming, deforestation and draughts and floods are the issues which have been attributed to the climate change. The atmospheric carbon dioxide has increased over a period of time and also the global average surface temperature has increased 0.6 + or - 0.2 degree. There are various prediction methods through which it has been said that definitely global mean sea level is going to increase. The main areas where India would be affected would be Sunderbans because it is almost near the sea level. In other countries Maldives is a country almost just on the mean sea level (MSL), slightly a meter or so above the mean sea level. There are other countries which can get affected. Finally, because of these, changes in the pattern of living resources in the ocean base can occur.

Coming to CCS options, in the power sector we know that $CO_2$ capture is not economically viable. The main industries which have to take up besides power plants are steel industries, oil and gas, cement industry etc. In Vizag Steel Plant we are trying to do some work in this direction. Before we talk about injection of $CO_2$ in the oceans, let us look at other methods which are available for mitigation. We can put some reflectors in the space to reflect sunlight and stop it from reaching earth. However, some of it is artistic expression and may not be practically feasible.

In ocean sequestration there are various options. One is iron fertilization which requires dumping iron pieces into the ocean. It can be tested on a smaller scale but may not be able to replicate exactly what is happening in the ocean. By dumping anything in the ocean other environmental aspects come into play. An experiments which was being performed by the International Consortium in which one of our senior scientist from the Institute of Oceanography was present, was prevented from doing by the Green Peace ship and they could not go ahead with the experiment.

Disposal of $CO_2$ in oceans can be from land based pipeline or even from the ship or by dropping dry ice in the ocean. We can test steel plant slag for sequestering the carbon dioxide and that can be used as a byproduct for putting up coral reefs. Gas hydrate research is another area that could be filled with carbon dioxide. Caron dioxide can be taken up to more than 2700 meters depth and because of the pressure there, it become liquid and it can be stored. We may plan to have such a l station which can be monitored by using remotely operable vehicle or in-situ using underwater vehicle. A networked ocean observatory would have to be planned.

In all these options challenges are there, which need to be addressed. Of course iron fertilization is a very slow process and direct deposition of carbon dioxide is a highly environmentally sensitive topic which needs to be assessed. The transportation to site is a technologically challenging area, because it is not a short distance to be pumped in a liquid form. In taking $CO_2$ to the gas hydrate locations, main issues are same. Using industrial slag or ash seems to be a viable proposition in this context. Sequestration process may ultimately give a value added product in a mineral carbonation process. Conceptually, the olivine and serpentine are mixed with carbon dioxide and finally the outcome could be used for reclamation, industrial waste utilization and production of construction material etc.

The marine algae *Chlorella Vulgaris* has got lot of lipids and lipids means you can get fuel, bio fuels and other nutracueticals can be extracted as it absorbs carbon dioxide. We have isolated it and we are in the process of doing it on larger scale. An experiment is currently in laboratory scale to assess how much of carbon dioxide is to be sequestered to get an optimum growth of algae. I am happy that my full team who are working on carbon dioxide sequestration are here. They all are working on various areas, in geology, in mechanical engineering, biotechnology, chemical engineering.

I would like to highlight here is that even though we can do these experimentally in the laboratory condition, the sea leasing policy is not in place in India for doing it on large scale. In order to have a large scale sequestration say for bio fuel production very large area is required. In the ocean up to 200 nautical miles it belongs to the State. It would necessary that it is taken up by an entrepreneur to develop a business model out of it by sequestering carbon dioxide on large scale. In the absence of a leasing policy business model can not be worked out. We are working on the concept of an experimental basis and are also in touch with the Planning Commission, Government of India. We have also set up an experimental facility in Andaman and in Lakshadweep.

Another important area in our opinion is Artificial Reef. We have a project by the Orissa Government as part of the UNDP project, when we put concrete structures in the sea near the coast. After a few months, it turned into an Artificial Reef and various fishes have started growing there. This is very advantageous for the fishermen because they don't have to go to longer distance in the sea. Our team in NIOT is trying to study the growth and its effectiveness.

A similar experiment is planned for a cement plant waste with respect to carbon dioxide sequestration. This would have twin advantages, the carbon dioxide is no longer present and the other advantage is that the biological growth takes place, flora and fauna comes there. It may not be an economic proposition to completely do it on a very large scale. It is to be tested first. Similarly the idea is to take flue gas from the power plant directly for $CO_2$ sequestration.

*In conclusion, I would like to say that, mitigating carbon dioxide is highly essential and capture, transportation and fixation are very much necessary. We have to find novel ways to do it. At NIOT we are engaged in laboratory scale studies. Our team is trying to do best possible ways in carbon dioxide sequestration using various methods. I hope that very soon we will be coming out with some results and our team should be able to present some of the results which ultimately could be useful for the country at large.*

Thank you.

17th January 2013

# $CO_2$ STORAGE AND ROLE OF UNCONVENTIONAL GAS IN REDUCING CARBON DIOXIDE EMISSIONS

**Dr. Balesh Kumar**
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**Gujarat Energy Research and Management Institute,**
**Gandhinagar, Gujarat**


First of all I thank Dr Malti Goel for inviting me to this Workshop. I will discuss R&D intiatives and viable & innovative options for carbon dioxide storage. The viable options are: $CO_2$-EOR (Enhanced Oil Recovery); $CO_2$-EGR (Enhanced Gas Recovery); geological $CO_2$ sequestration in basalt formations and saline aquifers. Oil & Natural Gas Corporation Ltd. have already initiated a project on $CO_2$-EOR in Ankleshwar oil field of Western India and $CO_2$-EGR is still in research and development stage. Indian basalts may not be attractive proposition for carbon storage, as areas having basaltic rocks are prone to increased seismicity. Further, these rocks are underlain by thick Mesozoic sediments, which are light gaseous hydrocarbon bearing. The reports on occurrence of deep saline aquifers away from the coastal zones are scanty and R&D efforts in this area need to be focused.

The innovative carbon storage advances are: Bio- Carbon Capture and Storage (Bio-CCS); Getting geothermal power with $CO_2$ instead of water in the arid areas where water is scarce; and Increasing the fertility of ocean and soil by carbon dioxide uptake. Growing role of unconventional gas, which is least carbon intensive, in the global energy scenario and initiatives towards carbon storage for mitigating the $CO_2$ emissions are the key challenges for sustainable energy future of World and even India (Global Energy Assessment, 2012). *The exploration and development of unconventional gas (coal bed methane, shale gas & gas hydrate) have gained or gaining importance in the country. The expanding role of carbon storage in reducing the impact of climate change will require reducing its cost and transformation towards integrated fossil fuel based energy efficient system.*

Coal bed methane production in India has not met the estimated production targets and the technology for exploitation of methane from gas hydrates is yet to be developed. Therefore, dioxide to the atmosphere, while coal adds to about 12%. The key technologies behind shale gas exploration & exploitation are horizontal drilling and multi-stage fracturing. India has taken initiatives towards shale gas development and the Government of India policy towards shale gas exploration and exploitation will be announced soon.

Potential shale gas bearing basins of India are: Assam-Arakan; Cambay; Cauvery; Krishna-Godavari; Gondwana & Vindhyan etc. The basins have shale horizons with suitable thickness, maturity, organic carbon content & porosity and geochemical, petrophysical and optical characteristics of these basins are similar to producing basins from other parts of world. The monitoring & modeling methodology for sequestered $CO_2$ are important for risk assessment. Thank you.

17th January 2013

# CARBON SEQUESTRATION POTENTIAL OF THE FORESTS OF NORTH-EASTERN INDIA

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Carbon management in forests is one of the important agenda in India to reduce emission of carbon dioxide ($CO_2$) and to mitigate global climate change. In the context North-Eastern region forest comprises of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura is 1,73,219 $km^2$ which is 66.07 percent of its geographical are in comparison to the national forest cover 21.5 percent. However, according to recent assessments there was a loss of 549 $km^2$ of forest cover during 2009-2011 in the North-Eastern states. Manipur and Nagaland have lost the highest forest cover of 190 $km^2$ and 146 $km^2$ respectively which is attributed to shifting cultivation and biotic disturbances. In the overall there is a decrease of 367 $km^2$ of forest cover in the country during the same period. The North-Eastern region constitutes only 7.98% the geographical area of the country but account for nearly 25% of the forest cover of the country.

The North-Eastern region is very rich biodiversity and has been identified as part of hot spots of world biodiversity. Therefore carbon sequestration potential of North-eastern forests is an important component of an overall carbon management strategy to reduce and to mitigate $CO_2$ emission mainly because of long grand growth period due to high rainfall area and high productivity of forest ecosystems.

Recently Indian Space Research organization – Geosphere Biosphere program (ISRO-GBP) under National Carbon Project has initiated to assess the carbon pools in the forest vegetation, soil and atmospheric carbon fluxes in the country to understand the role of forest in carbon capture and storage under anthropogenic change. There is limited information on carbon sequestration in the soil and forest vegetation of North-Eastern region.

Carbon stock in the aboveground biomass varied from 65.1 to 127.5 t C $ha^{-1}$ in sub-tropical forests, 86.7 to 295.5 t C $ha^{-1}$ in pine plantation and 93.5 to 105.8 t C $ha^{-1}$ in Montane wet temperate forest of Manipur. However carbon storage in the biomass of humid tropical forest of Meghalaya and Barak valley of Assam was reported to be 161.2 and 103.8 t C $ha^{-1}$ respectively. In bamboo forests of Assam and Manipur carbon stock in aboveground biomass was recorded to be 61.1 t C $ha^{-1}$ and 65.35 t C $ha^{-1}$ respectively. The rate for carbon sequestration in forest biomass is highly variable depending upon species composition, age of tree, nutrient status of soil and level of biotic disturbances.

The rate of carbon sequestration ranged from 13.7 to 15.9 t C $ha^{-1}$ $yr^{-1}$ in sub-tropical broad leaved hills forests and 6.3 to 13.7 t C $ha^{-1}$ $yr^{-1}$ in pine plantation in the state of Manipur. Soil carbon storage was estimated to be 27.73 to 48.03 t C $ha^{-1}$ in upper layer of soil (0-30cm) in the different type of forests of Manipur which is under estimated and forest soils may contain 2 to 3 time more carbon. In bamboo forests the soil carbon was reported to be 57.3 t C $ha^{-1}$ in 0-30 cm soil depth in Barak valley in Assam.

*There is an urgent need to quantity the carbon stock and rate of carbon sequestration in different types of forests at micro-level to assess potential of C-sequestration and sustainable managements of forests in North-East India. Estimation of carbon stock forests of North-East India may become operational to carbon trading future.*

Thus the forests of North-eastern region have a great potential to store carbon due to high rate of productivity as well as highest percentage of the forest cover in the country. The declining trend in forest cover in the region is matter of great concern and may be taken care in the future. Large tract of open forests in various North-Eastern states provide a great opportunity for carbon sequestration through mass scale afforestation and restoration programme in open forest, wasteland and shifting cultivation areas to reduce the carbon dioxide level in the atmosphere and to mitigate the climate change. Thank you.

# PROSPECTS IN BIOMIMETIC CARBON SEQUESTRATION

**Dr. Satyanarayana Tulasi**
**Professor**
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I will present prospects of bio-mimetic carbon sequestration which is a biological phenomenon for the use of non-biological problems. It is well known that thermal radiation from the Earth, in the form of long-wavelength infrared rays, lies in the absorption spectrum of carbon dioxide and other green house gases (GHGs). These GHGs absorb radiation primarily in a very narrow frequency band (7-13µm), while $CO_2$ absorbs over a much larger (13-19µm) spectral range. Thus $CO_2$ accounts for 21% of the greenhouse effect (after water vapour that accounts for 64%), which is higher than ozone (6%) and other trace gases (9%). Moreover, carbon dioxide makes up 68% of the total greenhouse gas emissions.

The atmospheric $CO_2$ concentration has increased from 280 ppm in 1800, the beginning of industrial age, to 396 ppm today. Without any mitigation, it could reach levels of 700-900 ppm by the end of the 21$^{st}$ century, which could bring about severe devastating impacts. This imbalance of $CO_2$ concentration has disturbed the Earth's carbon cycle that is naturally in balance maintained by the oceans, vegetation, soil and the forests.

Biological systems have solutions to the most dreaded problems of all times. The photosynthetic fixation of atmospheric $CO_2$ in plants and trees could be of great value in maintaining a $CO_2$ balance in the atmosphere. Algal systems, on the other hand, being more efficient in photosynthetic capabilities are the choice of research for solving global warming problem. The biomass thus produced could be used as fuel for various heating and power purposes.

Mankind is indebted to microbes for bringing and maintaining stable oxygenic conditions on Earth. A proper understanding of microbial systems and their processes will help in stabilizing atmospheric conditions in future too. Microbes such as fungi and bacteria have been found to be responsible for most of the carbon transformations and long-term storage of carbon in soils. The chances of persistent C storage are high in fungi due to their complex chemical composition and higher carbon utilization efficiency. In fact, increased fungal to bacterial activity has been shown to be associated with increased carbon stored in soil. The process of carbon assimilation by photosynthesis has made forests, trees and crops as the major biological scrubbers of $CO_2$. Terrestrial biomes are potential $CO_2$ sinks. The recent work on biomimetic approaches using immobilized carbonic anhydrase in bioreactors has a big hope for the safe future.

Photoautotropic organisms ranging from bacteria to higher plants have evolved unique carbon concentrating mechanism (CCM) in response to the declining levels of $CO_2$ in their surrounding environment. Photosynthesis is much more efficient in microalgae than in terrestrial $C_3$ and $C_4$ plants. This high efficiency is due to the presence of both intracellular and extracellular carbonic anhydrases and the $CO_2$ concentrating mechanism. The present focus is on exploiting the ability of microalgae to convert solar energy and $CO_2$ into $O_2$ and carbohydrates. Microalgal mass cultures can use $CO_2$ from power plant flue gases for the production of biomass. The algal biomass thus produced can directly be used as health food for human consumption, as animal feed or in aquaculture, for biodiesel production or as fertilizer for agriculture.

A fast growing marine green alga *Chlorococcum littorale* has been reported to tolerate high concentrations of $CO_2$. The wastewater containing phosphate (46 g $m^{-3}$) from a steel plant has been used to raise cultures of the photosynthetic microalgae *Chlorella vulgaris*. Flue gas containing 15% $CO_2$ was supplemented further to get a $CO_2$ fixation rate of 26 g $CO_2$ $m^{-3}$ $h^{-1}$. Research is in progress on the development of novel photobioreactors for enhanced $CO_2$ fixation and $CaCO_3$ formation. $CO_2$ fixation rate has increased from 80 to 260 mg $l^{-1}h^{-1}$ by using *Chlorella vulgaris* in a newly developed membrane-photobioreactor. A novel multidisciplinary process has recently been proposed that uses algal biomass in a photobioreator to produce $H_2$ besides sequestering $CO_2$.

Non-photosynthetic $CO_2$ fixation occurs widely in nature by the methanogenic archaebacteria. These are obligate anaerobes that grow in freshwater and marine sediments, peats, swamps and wetlands, rice paddies, landfills, sewage sludge, manure piles, and the gut of animals. Methanogens are responsible for more than half of the methane released to the atmosphere. These methanogenic bacteria grow optimally at temperatures between 20 and 95 °C. Carbon monoxide dehydrogenase and/or acetyl-CoA synthase aid them to use carbon monoxide or carbon dioxide along with hydrogen as their sole energy source. Waste gases from blast furnaces containing oxides of carbon were used for converting them into higher- Btu (more calorific value) methane using thermophilic methanogens. A column bioreactor operated at 55 °C and pH 7.4 was employed for the process. A mixture of three cultures of bacteria (*Rhodospirillum rubrum, Methanobacterium formidium* and *Methanosarcina barkeri*) was used for complete bioconversion of oxides of carbon to methane.

Heterotrophic bacteria having efficient carbonic anhydrase and phosphoenolpyruvate carboxylase and/or pyruvate carboxylase may be raised in fermentors, and these can be flushed with flue gases with $CO_2$ concentration to produce useful metabolites such as aspartate family of amino acids. Dual benefit of carbon sequestration along with useful product formation by employing microbes such as *Corynebacterium glutamicum* makes this approach very attractive.

Biomimetic approach involves identification of a biological process or structure and its application to solve a non-biological problem. Carbonic anhydrases are the fastest enzymes known for their efficiency in converting carbon dioxide into bicarbonate. Efforts are underway for using carbonic anhydrase and other carboxylating enzymes from various microbial sources for $CO_2$ sequestration. The possibility of an on-site scrubber that would provide a plant-by-plant solution to $CO_2$ sequestration, apart from eliminating the concentration and transportation costs, is the potential advantage of the biomimetic approach. *The recent developments in immobilization of microbial carbonic anhydrases for its recycling and biological carbon sequestration are very encouraging. Microbes can be used leading to production of licems, melanin, hydrogen and calcium carbonate.*

This research is being carried out with the support from Department of Biotechnology, Ministry of Science & Technology. Thank you.

# BIO-SEQUESTRATION OF CARBON DIOXIDE-POTENTIAL AND CHALLENGES

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In this paper, the prospects of biological carbon fixation for remediation of $CO_2$ are explored. Plants are $CO_2$ sinks – they fix $CO_2$ during daytime. Tiny (microscopic) aquatic plants – the microalgae have even more efficient $CO_2$ fixing ability than large plants and trees. They have a very quick growth rate. Some of these species are rich in oil suitable for converting to diesel (fuel) and with nutrient properties (with omega fatty acids). Some species have carotenes and other pigments; some are rich in proteins. They can be mass cultured in lands not suitable for agriculture and their biomass can be beneficially used in production of biodiesel, nutracueticals for humans and as animal feed. Flue gas (a mixture of $CO_2$ and the other green house gas $NO_X$ ) released from Industries can be used to ferrigate the mass culture units of micro-algae thus effectively sequester them.

The proof of concept experiments of this biosequestration option has been demonstrated in 2005. Large scale industries based on this principle are yet to take off – despite the lure of biodiesel. *The challenges in this technology are many— both technical and fiscal. Technical issues relate to mode of transfer of flue gases to the algal culture medium and means of harvest of microalgae. Fiscal concerns are with regard to the cost of set up of the facility and the running costs.* The international experiments, studies carried out in a project sponsored by the Department of Science & Technology in association with Vizag Steel Plant and various options to meet the challenges are deliberated.

18th January 2013

# $CO_2$ SEQUESTRATION POTENTIAL OF INDIAN COALFIELDS

**Dr. D. Mohanty, Scientist**
**Central Institute of Mining**
**and Fuel Research, Dhanbad**

As Dr. A. K. Singh, Head Methane Emission Division could not attend, so I am presenting this paper. Coal Basin's criteria are geological, geothermal conditions, hydrodynamic conditions and carbon potential dependence on basin's maturity. Coal seam methane is methane formed during qualifications and trapped and stored in coal seams. The coal is the source rock as well as the trapped rock for methane. Methane occurs in absorbed form and free gas. By origin it may a biogenic origin or may be a thermogenic origin. Most of the researches have identified it of thermogenic origin as they are formed above 50 degree centigrade during coalification process and most of the methane occurs in absorbed form.

A high volatile bituminous coal is a very open structure and on further compaction become a large polymeric structure with functional groups at really different stages of coalification. Coal bed methane exploration model is given by Scot in 1999. In this we are dependent on hydrodynamic conditions. The flow of water guides the flow of methane. When we depressurize the coal seam, what we do basically is we pump out water. Again there is a difference between oil well and CBM well. In oil well the oil comes in the main pipe, but in the CBM well the water comes in the main pipe and the CBM comes through the analogue space. In the oil well the gas comes through the analogue space. Once the coal seam gets dried out one cannot really recover methane.

Coal has a dual porosity unlike other rocks, which have only matrix porosity. Coal also has induced porosity, imported by fracture system. $CO_2$ sequestration studies conducted so far support strong affinity of $CO_2$ to the coal molecule. The carbon dioxide being smaller molecule than methane is a preferentially absorbed on to the coal structure over methane. This however, gets more complicated due to shrinkage - swelling phenomena during absorption and desorption. Tectonic settings are also different for different regions.

India has abundant coal reserves, including the Gondwana and Tertiary coals and lignite deposits. These can serve as storage sites for $CO_2$ limited by permeability and other controlling parameters such as sorption capacity and porosity. We have measured actually the methane content and kept $CO_2$ storage capacity to 50% of methane absorption. It is very conservative estimate. Estimates for almost all the Indian coals have been carried out. Indian coal beds are classified into grey, concealed and unminable, based on its depth of occurrence and beds characteristics. $CO_2$ storage potential is estimated to be 44 -59 million tonnes. *The scientific assessment of $CO_2$ storage potential in coal bearing sedimentary basins may serve as a basis for research, planning and policy to enable carbon capture and storage technology deployment in Indian coalfields.* Thank you.

18th January 2013

# REAL TERM IMPLICATIONS OF CARBON SEQUESTRATION IN COAL SEAMS

**Shri Vikram Vishal**
**Research Scholar**
**IIT Bombay, Mumbai**

I am doing my PhD on coal bed sequestration from IIT Mumbai and Monash University both. I thank the organizers for giving me this opportunity. In the previous talk we learnt about coal seams. I will focus more on enhanced coal bed recovery. Coal is the source and reservoir of methane gas; the volume of methane stored is each coal is dependent on many factors. Methane is retained in coals as: adsorbed molecules on the organic micropores, free gas in pores, cleats and fractures, dissolved in solution within the coal bed. $CO_2$ has an additional effect compared to other gases that it is preferentially adsorbed onto coal surfaces, displacing methane from adsorption sites. $CO_2$-ECBM sequestration is a value addition project in management of increasing atmospheric concentration of GHGs as it recovers the cost of capture, processing, transportation and storage of $CO_2$ by production of methane.

The challenges in coal seam sequestration are many folds and research on field and laboratory scale is being carried out at various institutions across the globe to understand the reservoir behaviour. Several pilot scale studies for injection of $CO_2$ are under operation in different fields like Ishikari Basin, Japan and North Dakota, USA. Most of these basins have experienced loss in injectivity due to reduction in coal permeability with time. The decline may be attributed to the $CO_2$ adsorption induced swelling in coal mass which leads to closure of macroporosity (i.e. cleats) since $CO_2$ in supercritical form induces maximum volumetric deformation in coal.

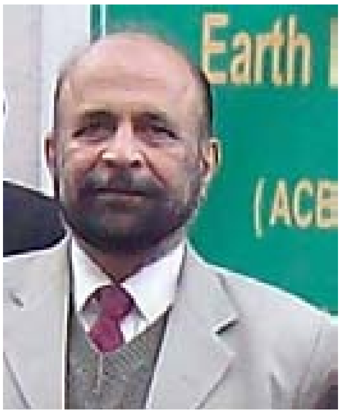
It is important to understand the response of coal in detail before implementation of the sequestration process on a field scale. Not many studies have been carried out on investigating the behaviour of Indian coal with $CO_2$ in terms of the real term coal-$CO_2$ interactions. The role of effective stresses, confining stresses, coal matrix deformation etc. on $CO_2$ permeability of Indian bituminous coal was discussed in a recent article. The results reveal that coal undergoes swelling and at higher depths, permeability reduces significantly, thereby altering the complete process of sequestration. Phase transformation of injected $CO_2$ at such depths may also lead to changes in coal-$CO_2$ interactions, finally influencing the injectivity of gases. Further, the influence of gas injection on the strength characteristics of coal as well as surrounding rock must be investigated for overall stability and safety of the system. Cap rock integrity is one of the most important parameters for sequestration of greenhouse gases and must be understood in greater details before actual implementation.

However, applications of carbon capture and storage (CCS) in coal seams have its own advantages and thus, focus on coal research for sequestration has gained attention over time. The mechanism of storage in coal being adsorption is safer as compared to the compressional mechanism in conventional hydrocarbon reservoirs. Simulation works have indicated that injection of $CO_2$ may be used to recover more than 90% of coalbed methane which during primary recovery only enable up to 40-50% of gas extraction. We have worked out the $CO_2$-ECBM recovery for a block of coal seam in Raniganj coalfield for a preliminary investigation of the process using numerical simulation. The results indicate a positive connotation for the feasibility of the process, with keeping in mind the assumptions and the constraints.

Therefore, to meet the growing energy needs, CCS in coal not only provides opportunity for capturing low carbon fuel, i.e. methane but also partly meets with the commitment of reduction of greenhouse gases (GHG) emission into the atmosphere. *The process of ECBMR shall also partly offset the cost of carbon capture, transportation and storage in coal and hence, CCS in coal may be a value-addition process as compared to other storage methods in saline aquifers or basaltic formations. Understanding the behaviour of coal in underground scenarios is the key to successful operations and if established, coal seam sequestration would lead its way to GHG release mitigation in future.* Thank you.

18th January 2013

# RESERVOIRS FOR $CO_2$ STORAGE & VALUE ADDITION- EOR PROCESSES




**Dr. D.M. Kale**
**Director General**
**ONGC Energy Centre, New Delhi**

Today I will be covering the topic of carbon sequestration mainly. One thing I would like to stress in the beginning that in any area of research not only ideas are enough, one should also have very good grip on numbers. Throughout this workshop make yourself capable as quantitative as possible.

Prof. Charles Keeling right from 1959 till he died, and after that his son every morning as he got up, took sample of air, go back in the basement, where they have a very delicate and very good equipment, spectroscope to measure the amount of $CO_2$ in the atmosphere. Global warming is the result of that. Every day's reading is recorded there from 1959 onwards. When there is a harvest in the Northern Hemisphere, a lot of carbon dioxide is absorbed. As a result the $CO_2$ in the atmosphere decreases. The $CO_2$ concentration measures 397 ppm now. An increase of one ppm in atmosphere corresponds to 8.08 billion tonnes of carbon dioxide that has to be injected in the atmosphere. Currently according to these assumptions we emit something like 30 billion tonnes in a year. If all this is retained in the atmosphere, every year concentration will increase 3.7 ppm. Fortunately that doesn't happen. What happens is that a large part of it is absorbed by the sea and land and small part is retained in the atmosphere. In last 160 years we have observed an increase of more than almost 100 ppm in $CO_2$.

There is a global economic down turn at present Tens of thousands of trees in Greece are being cut because they can't afford the fuel oil or Natural gas. Electricity is out of question. Cutting trees is very common but it is bad because it affects in two ways. One is straight away you burn, that is the worst fuel as far as the global warming is concerned. Another is that it also emits soot on burning. That is particulate carbon and this particulate carbon also adds to global warming.

The $CO_2$ emissions are increasing and if we continue business as usual, the emission will increase to 62 giga tonnes in the year 2050. International Energy Agency has suggested two plans to reduce this. One required reduction by 35 giga tonnes and the other by 48 giga tonnes in 2050. It is expected that about 20% of it should come from CCS by 2050. This amount comes to about 7 to 10 giga tonnes of $CO_2$ to be sequestered every year.

As you already know there are various possibilities of $CO_2$ storage. In a depleting oil field enhanced oil recovery can be done in two different ways. In a normal course large part of oil has to be left behind in the oil reservoirs as all the oil that we discover cannot be produced. We can recover more oil, by injecting $CO_2$. This can be done in two different ways. One is miscible displacement by $CO_2$ when injected in the reservoir at a certain pressure and temperature $CO_2$ is in super fluid state and as a result it doesn't form any interface with the oil. It has the viscosity and density of liquid while other properties are of gas. It is as good as displacing oil with the oil. When we are sequestering carbon dioxide in the reservoir it is never in gas form. It is always this super critical fluid because all reservoirs are at pressure of more than 70 atmospheres. Miscible displacement happens only at a pressure beyond a critical pressure and the pressure at which this miscibility is achieved is called minimum miscibility pressure. This is different for different reservoirs and depends on temperatures also.

For enhanced oil recovery the process is like this. First $CO_2$ is injected then water, then $CO_2$, then water, then $CO_2$. Now what happens is that $CO_2$ is miscible with oil so it displaces oil and then oil is produced from the production well. The reservoir has pores like sponge, a rock with a lot of connected pores. When this displacement is miscible, practically all of the oil ahead of this front is displaced. This is actually done to produce more oil and not to sequester $CO_2$ from the atmosphere. Usually the amount of $CO_2$ by burning of this produced oil will be much more than what is sequestered.

In world over, there are something like 134 different EOR projects based on injection of gas. Of that 134, 71 are based on $CO_2$ injections. Most of these are in USA and two are in Canada. There is no project in India as yet. There are certain reservoirs, which are having Natural gas and $CO_2$ in it. When Natural gas is produced $CO_2$ also produced. This $CO_2$, which is already sequestered and resting there peacefully, we bring it to the surface take it by pipeline to the oil field if necessary and then inject it and produce more oil. This in fact contributes to CO2 emissions because $CO_2$ is dissolved in oil and when oil is produced $CO_2$ would come out with it.

The second is immiscible displacement in which $CO_2$ is partially sequestered. In that reservoir the volume occupied by oil would now be occupied by $CO_2$ which is in critical phase. Only 0.3% of the total oil produced out of the enhanced oil recovery is through $CO_2$ injection. That is of 1000 barrels, every 3 barrels are today produced from $CO_2$. By $CO_2$ injection there is scope for something like 200 billion barrels of produced extra oil and that will lead to storage of about 70-100 giga tonnes of $CO_2$.

$CO_2$ is also present in Natural gas and on an average the content of $CO_2$ is about 2%. This is equal to around 200 million tonnes. Currently $CO_2$ from Natural gas production is separated and utilized in these sequestration projects in the world. The advantage is that $CO_2$ is available right there in the oil and gas fields, where all the required infrastructure and capacity for sequestering exists. It is easily separated as it is neither mixed with nitrogen (as in case of flue gas from a power plant) and nor it is at a high temperature as in the exhaust of thermal power plants.

The largest sequestration plant in the world is at a place called Sleipner. It sequesters 1 million tonnes of $CO_2$ per annum. It sources $CO_2$ from a Natural gas operation in the offshore and just below the gas field, there is a water bearing rock and in that rock $CO_2$ after separation is injected. Another project is in Algeria. This gas field has 5 to 10% of $CO_2$. Third major project uses $CO_2$ from a coal gasification plant. $CO_2$ is separated and transported across the international border between USA and Canada to a place called Weyburn. This oil field uses $CO_2$ for enhanced oil recovery. About 5000 tonnes of $CO_2$ is injected per day. That will amount to something like 2 million tonnes per annum. $CO_2$ here is of 95% purity. 26% of that $CO_2$ is recycled as it comes out with oil on the surface. The $CO_2$ is separated here i.e. recycled and reinjected. Its quantity goes on increasing as the process advances. More and more $CO_2$ needs to be recycled and ultimately it will come to something like 100% recycling.

The other option is sequestration of $CO_2$ in a depleted gas field. When all the gas is produced, pressure depletes in the abandoned gas field. $CO_2$ injected and pressurizes the field again. These kind of sequestration is less complex and less harmful, there is no question of any recycling and there is no long-term risk that is some day it may come out again in the atmosphere. Similar thing can also happen in depleted oil field. As pressure goes down when oil is taken out there is space available. When $CO_2$ is injected in the empty reservoir, one fluid is replaced by another fluid and $CO_2$ can be stored.

Saline aquifers are other type of reservoir where $CO_2$ can be injected as super critical fluid. Physical interaction taking place there is not very well understood about what would really happen after 5000 years. We can say that the earth has certain capacity to take in $CO_2$. That could be very large. Coal bed reservoirs and basalts are other options. Basalt is a type of rock, a basic rock as against an acidic rock and there have been several flows. There are places in Maharashtra where they have counted 600 different flows of basalts at different times. Between the flows there are formations. It is conjuncture that some of them would be having pores and then may be they are saturated with water and then it would be possible to drill and inject $CO_2$ in that store. However, this is a big question mark in terms of technology. ONGC has done only one well in Gujarat drilled through basalt and up to 600 meters could only be reached. It has taken considerable effort and heavy investment.

Looking at the map of India, it is seen that most coal based power plants or sources of $CO_2$ are far from the places where one can sequester $CO_2$. This would necessitate laying pipelines to carry $CO_2$ from the source to sink. Then only we can use that in our reservoirs. The total potential of India has been calculated by the experts to be 500 to 1000 giga tonnes which is really huge. India's total carbon dioxide emissions are only about 1 giga tonnes per annum. All of these cannot be captured and all of these cannot be sequestered. There is no way to capture or sequester $CO_2$ emissions from mobile sources. Only from stationary sources and mainly these are power plants, Natural gas, cement plants, steel plants.

*On a thumb rule for a 500 mega watt (MW) power plant one can calculate the amount of $CO_2$ that would be generated every hour and then amount of $CO_2$ emitted in 30 years. A reservoir should have that much as minimum capacity for storage. In addition the proximity of large coal based power plants to sink is desirable.*

We need to take an integrated view of $CO_2$ storage. When we talk of carbon in place of carbon dioxide we should remember that the ration is 1:3.6. A carbon molecular atomic weight is 12. $CO_2$ molecular weight is 44. On the lighter side there is place called Tawaloo, an island. This is the world's smallest country and for last forty years their landing strip is under the sea. I think this is the urgency!  Thank you.

18th January 2013

# CARBON DIOXIDE STORAGE AND ENHANCED OIL RECOVERY

**Dr. Gautam Sen**
**Ex-Oil & Gas Consultant**
**New Delhi**

I would like to thank the National Advisory Board especially Dr. Kale for my participation. Today carbon dioxide sequestration has become a necessity. The advantage of enhanced oil recovery is that it may give a business model. In an oil well nearly 70% plus the oil is normally left and by using miscible $CO_2$ injection, one could probably increase recovery by 20-45% of it. Besides oil fields, the depleted gas fields, coal seams and saline aquifer provides for storage of carbon dioxide in the sub surface. The volume of carbon dioxide that can be injected in saline aquifer is at least 20 times more than what can be done in oil & gas fields. Although saline aquifer would be ideally suited for sequestration of carbon dioxide there can be no business model.

The sedimentary basins exist all over the world, wherever the oil and gas fields are formed. A basin can be a depo centre of earth crust. The sediments from the high land such as mountains and other high places could be transported by water and get deposited in that basin. Because of gravity, subsidence continues and there is continuation of the tectonic forces. This happens over millions of years. Oil and gas is found with this sedimentary basin and these offer the best storage for carbon dioxide too, apart from the oceans.

A reservoir is a rock which is pores and permeable. Pores means it has a capacity to hold some more liquid or gas. Permeability means connectivity of pores. It is the basic petro physical property which is very important for carbon dioxide. The tectonic activity during sedimentation is important. There are three basic types of tectonics that happen in the world. One is the external tectonics, second is the converging tectonics and the third is the strike tectonics. Globally tectonics happens because of plate motions in the earth crust.

We can take three epochs Cenozoic, Mesozoic era and Pelusiac. Cenozoic era roughly you can say up to 70 million years. Mesozoic up to around 200 million years plus and Pelusiac era more than 450 million years. In a basin there has to be a regional cap rock to prevent any upward migration of hydrocarbon or carbon dioxide. The sedimentary rocks either have carbonates or basalts. Three carbon storage case studies I will discuss. One is Sleipner, other is Permian basin, and third is Weyburn. The Sleipner was the first field experiment in Norway where it was operated by STAT oil. The carbon dioxide enhanced oil recovery has been commercially deployed in Texas from Permian basin. Permian is basically carbonate reservoir where carbon dioxide injection has started. This has been happening for the last 30 years. The huge amount of oil per day (29 billion barrels) is produced in Permian basin in Texas from a carbonate reservoir. Weyburn is already discussed.

The seismic velocity is determined by the bulk model escape plus regional model escape. In water and gas it is basically bulk model escape. When carbon dioxide is injected there is a sizeable velocity at one point in time but it is different at the second point in time. That different has to be captured for monitoring methods. Primarily velocities or arrival times change and a picture emerges on the surface. This is the monitoring basic principle. The acoustic impedance contrast between the different layers is measured when seismic waves goes up and comes down through reflections. Properties of acoustic impedance contrast as well elastic impedance contrast are different. The longitudinal waves called ‘P’ wave and are basically longitudinal in nature, while the ‘S’ waves are transverse in nature. ‘S’ waves depend primarily on rigidity and longitudinal waves depend on both bulk model as well as regional model. The ‘S’ waves do not pass through liquid and gas. There have been certain advances in monitoring and in the way carbon dioxide is injected. The entire plan for infield drilling has to be made. Each case would be very different.

There are two kinds of reservoirs. One is in the areas where oil and gas need to be pushed, another is called the bypass oil fields. Bypass oil fields are those, where in some areas there is no permeability and in others permeability is better. These could be areas where the oil has been left behind and that particular area has to be monitored in terms of enhanced oil recovery. In big fields geometry of oil pool is entirely different and in some of the areas get drained faster whereas some are not depending on the heterogeneity within the reservoir. They are the bypassed oil source and they also need to be targeted.

About rock physics where we need to measure velocity of P wave and S wave as $V_P$ and $V_S$. Each area is reacting very differently depending upon the way $CO_2$ is interacting with the rock. Seismic is an interface property. The interface property is that it is a reflector tool. Seismic observations do not give information about geology but only give information about what is the difference between the top layer and the next layer. Seismic inversions are done to understand the actual geology of the area. It gives an idea of the volume but there are limitations. Vertical Seismic Profiling (VSP) is done to establish better resolution. The source is kept on the surface and receiver in the well or vice versa.

The seismic data is acquired in such a way that there is one source around 24 reservoirs. Today one can have up to 96 reservoirs on one side and 96 on other side. So it becomes 192 channels. The idea is that each point or product may be 192 times or 96 times surveyed. To get a better picture called ‘static’, either a post track inversion or pre track inversion is done. When the data is not static it is ‘pre static’. In the pre track inversion there are certain advantages. Once carbon dioxide is injected, the P wave is converted into S wave. That difference is to be captured. The analysis of the change is the crux of monitoring and interpretation.

There are the basic challenges to identify and quantify the injected carbon dioxide, leakage, seismic prospecting in time lapse mode etc. The 3D are done over the different points in time. Monitoring, verification and accounting of carbon dioxide remain a big challenge.

Repeatability of a survey is very-very important. In a given reservoir, 3D survey at different points in time above the reservoir and below the reservoir should not change. Repeatability is a prime thing and noise is the amount of non repeatability. Quantitative interpretation and analysis of detected changes are the major problems. Saline aquifers are better candidates in this respect as the amount of change in seismic because of the injected carbon dioxide is more. Normally the unconsolidated sediments, which are not cemented, reacts maximum with the presence of $CO_2$ gas. I happened to have seen the entire seismic of the East coast of India in my stay with Reliance.

There is something called Flag spot. Flag spot occurs in oil water contact. In seismic, the gas and water work differently at a flag spot, which cuts across different reflectors. The flag spot movement occurs because whatever hydrocarbon was there initially has been shrunk, while oil was taken out. The flag spot movement happens when carbon dioxide is injected and movement is tracked. Rocks with large porosity have high compressibility and are good. At the same time, carbonates are not so well cemented are not good candidates.

Gassmann fluid is another term used in monitoring. It is an equation and tells about the relationship about how an elastic property has changed with the injection of fluid. A model is worked out for expected change after injection. The Gasmann equation actually is a measure to know the deviation. It is used for relating the bulk models of dry rock when $CO_2$ is not injected, vis-à-vis an injected rock. Rocks porosity is defined in different ways. Homogeneous porosity would be when the entire rock will have a uniform porosity. Patchy porosity will be in between areas, not good petro physical properties. The behavior of the injected carbon dioxide in the two cases, homogeneous as well as patchy, for P wave is entirely different. Everything depends on the size of the patches also. In the homogeneous porosity there is a major reduction in velocity while in patchy, the reductions are much less with same volume of carbon dioxide injected.

There is also effective porosity and total porosity. Seismic measures the total porosity. Effective porosity means the pores are connected. Isolated pores also get affected by some kind of fluid movements. There is no way for them to get connected with the other pores. But seismic because of its low frequency, will see the total porosity. How much of a total porosity is part of the effective porosity? Some kind of empirical studies have to be done based on analogue data. That also becomes an important aspect of analysis. Analogue data means scanned information about actual well. Basically the whole aspect of monitoring and verifying is understanding, doing the timeline seismic, doing the inversion, studying the rock properties, getting into core, seeing how they are deviating from the seismic equations and building it up. It can help testing the model and validating it with subsequent timelines.

In conclusion, capturing and storing carbon dioxide from atmosphere is necessary in view of the anthropogenic effects. Saline aquifers, coal seams, old oil fields, depleted gas fields, sub surface with a sedimentary basin provide ideal storage spaces. *We may not have oil and gas fields where we can do this, but we do have saline aquifers. This need to be pondered as USGS estimate suggest that about the 140 million metric tonnes carbon dioxide can be stored. Petro physics modeling, monitoring movement of the injected carbon dioxide with time is essential to ensure permanent storage. Timeline seismic with all its constraints is still the best way to monitor.* Thank you very much!

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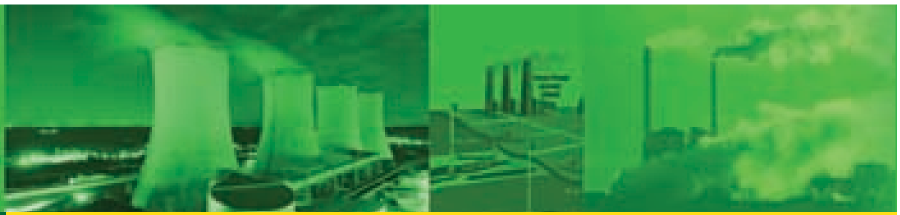


# 2nd Workshop on Awareness and Capacity Building in Carbon Capture and Storage

15th -19th January, 2013

India International Center
New Delhi

## CONCLUDING SESSION

19th January 2013

# POLICY AND REGULATORY INTERVENTIONS IN ABATEMENT OF $CO_2$ FOOTPRINTS

## GUEST LECTURE


**Shri VS Verma, Member, Central Electricity Regulatory Commission, New Delhi**

At the outset, I wish to thank the Organizers, especially Dr. Malti Goel, for inviting me to interact with all the eminent participants on the issue of Policy and Regulatory Intervention in Abetment of $CO_2$ Footprints. I am honored to be here amongst you. I have always been wondering that could the chemical scientists in the country explore the possibilities of finding out a technology to recover and reclaim carbon from carbon dioxide on a commercial scale. I feel the chemical scientist should be constantly working on this area rather than burying $CO_2$ underground.

2. While the planners in the country plan capacity addition in the power sector, they need to minimize the costs by optimizing the consumption of various fuels for power generation. But there is very strange situation in their front. All of us know that Nuclear fuel (Uranium) is in short supply and we cannot plan massive capacity addition based on Uranium as fuel. We have thorium reserves in the country and trying to develop the thorium based reactors for power generation. If this becomes commercially successful, we might not need any other fuel for power generation. Indigenous research in this area is already on with the Bhabha Atomic Research Centre (BARC) and the Nuclear Power Corporation (NPCIL).

3. The subject of availability of gas and its price, for power generation is quite an uncertain area. Accordingly, at present, we are not generally planning any power generation capacity addition based on gas or Nuclear fuel. We have about 11,000 MW gas based capacity of power stations and most of these are running at around 50% of PLF because of non availability of adequate quantity of gas. Fertilizer plants get priority in gas allocation.

4. As far as Hydro Power generation is concerned, as per information available in Central Electricity Authority (CEA), total potential of Hydro Generation in the country is about 1,85,000 MW but so far about 40,000MW capacity has been harnessed. 'Water' and 'water power' being the State subject as per the constitutional provisions, co-ordination and acceptance of the state becomes a pre condition to build Hydro Power stations in the country. The Hydro potential is mainly located in North and North Eastern States such as Arunachal Pradesh, Assam, Himachal Pradesh, Jammu & Kashmir, Uttrakhand. The maximum potential lies in the Arunachal Pradesh. As far as the Hydro sector is concerned, we are proceeding in the right direction but with the slow speed due to many other problems like availability and construction of approach roads, difficult terrain, as well as attitudinal problems in the state and settling all the displaced people. Environmental issues are the biggest hurdle in the setting up of Hydro Power in the country.

5. In view of the foregoing and ultimately, the planners have no alternatives except to base our power generation mainly on coal. Sufficient coal reserves are available in the country. But the indigenous coal companies, mainly the Coal India Ltd., a Govt. monolith, had not increased the coal production commensurate with the requirement of the power generating stations in the country and consequently we fell short of indigenous coal availability. Today we are consuming around 550 Million tonnes of coal per annum and we will have to import somewhere around 50 to 80 Million tonnes of coal. Coal and Railways need to develop ahead of the power sector commensurate with the expansion as planned in the power sector.

6. Environmental aspects play their own part not only in Indian context but internationally. At one point of time there was too much pressure on us to adopt Carbon Capture and Storage (CCS) Technology in our thermal generating stations for abatement of the $CO_2$. However, at the national level, we consciously opposed to adopt this technology because of the following reasons.

- i) It brings down the efficiency of generation by about 12-15% points.
- ii) Cost of power generation almost doubles
- iii) The foot print of equipment in the overall layout becomes very large. More land is required.
- iv) The technology is not proven commercially and there are uncertainties.
- v) The disaster Management Plan is not drawn out.

In view of the above we decided to accept the R&D in this area with a change in objective from CCS (Carbon Capture & Storage) to Carbon Capture and fixation (CCF). We could convert $CO_2$ into some useful building material etc.

7. To reduce the $CO_2$ emissions from the power sector, there is a National Programme on climate change. We adopted the following strategy to cater to the $CO_2$ reduction in the power sector.

- a) Retire the inefficient and old units of coal fired thermal plants where there is no possibility of improvement in their efficiency of operation. About 15000 MW capacity in the country is to be retired and our average efficiency of generation would appear to be better. This would improve from the present level of about 34%. About 5000 MW capacity is already retired. CEA takes the lead in this respect.

b) Carry out R&M (Renovation & Modernization) on the older units of 200/210 and 500 MW ratings. This will bring back the efficiency of operation to near to rated ones and in some cases could be better than the rated ones because of design change and/or adoption of new technologies like improved blade profiles etc. for steam turbines, could be affected on case to case basis.
c) The new units to be adopted in the upcoming plants shall have supercritical parameters to give us marginally better efficiency (by 1.5-2%) as compared to those of the existing subcritical 500/600/210/300 MW units. All our capacity to be added in XIII plan shall be through supercritical units of larger ratings of 500/660/800/1000 MW. The XII plan capacity addition shall also see the majority of thermal units with supercritical parameters.

The country also has a plan to introduce Ultra Supercritical Parameters on the future units to give an added advantage of further increase in efficiency.

8. The nation also laid sufficient stress on capacity addition through Renewable Sources of Energy. This will include Wind, Solar, Biomass etc. There are issues in regard to these technologies which are briefly mentioned as below;

(i) Cost of Wind & Solar power is exorbitantly on higher side and the monopolistic nature of supply of this technology is mainly responsible for such a scenario. Major Research needs to be sponsored by the scientific research Institutes/IITs and educational institutions and the scientific community at large to bring down the costs of these technologies for adoption in India. Indigenization of design and manufacture of all components of these technologies would definitely bring down the costs. These have to compete on commercial basis with the conventional technology as far as the cost of generation are concerned.

(ii) Another issue which is bothering the power sector in regard to the renewable sources of energy is grid connectivity and grid operation standards. The renewable energy generators must follow the grid connectivity standards and the grid code for operation and maintenance. The prediction of the generation from Wind and Solar plants one day in advance at time intervals of 15 minutes during the day (96 time intervals). We have allowed to the Wind Generators specially, a variation of ± 30% on the predicted values. But this is not generally acceptable to the wind generators. They are somehow not willing to invest in the prediction models to accurately predict and quote for each 15 minutes interval to the load dispatch centers to draw up the schedule of generation and drawls. A lot need to be done in this regard.

(iii) The renewable energy sources by and large are not able to support us on peak load management which normally occurs when these sources may not be available.

(iv) CERC have come out with attractive tariff structures for renewable sources of power generation and the renewable energy certificate (REC) schemes to promote the renewable energy in the country. The RECs can be traded in the power market. Two power markets namely IEX and PXIL are operating in the country today, one in Delhi and another in Mumbai. The third one might also come in due course of time. The

Renewable Energy Purchase Obligation (RPO) is an important tool to promote the renewable energy in the country. The cooperation the State Electricity Regulatory Commissions and State Govts. would be required to enforce the RPOs in the State. This is too vast subject to be discussed in this meeting and could be covered separately perhaps in greater details.

(v) Finally the cost of the Solar and Wind Plants must come down. These costs about 6-7 Cr./MW to about 8-9 Cr./MW as compared to conventional coal fired plant costing around 3.5 – 4 cr./MW.

9. Ms. Malti Goel took lead in organizing discussions and interactions in regard to Carbon Capture & Storage Technology. There is a need to arrive at some conclusion with regard to the utility to this technology in our context. The Carbon dioxide finally could be converted into useful building materials, we can perhaps adopt this in all our power stations at the same time reduce the carbon dioxide footprint of the power sector in the country.

10. The demand of power is outstripping the capacity addition in the country. We have an installed capacity of 2,15,000MW out of which about 25,000 MW is renewable energy and the demand is about 1,30,000 MW. We are able to generate only about 1,20,000 MW. We are thus short of peak power by about 10,000 MW. This does not speak well of the power sector. It only means that greater attention is required towards operation, maintenance and efficiency of operation of all the existing power stations. The state sector would need to pay more attention in this regard. The capacity of about 86,000 MW is under execution for the 12th plan period and about the same capacity would be added in the 13th plan period as well. Therefore, it may not be practical to imagine that the overall $CO_2$ emission would go down in the time to come. However, per unit of electricity or per MW hr of electricity production, the specific amount of $CO_2$ could be reduced by adoption of new and efficient technologies. Increasing the share of renewable energy like wind, solar, biomass etc. would also help in this regard. We should also encourage for indigenous production of these technologies. Further the cost of generation of this type of electricity would need to be brought down drastically through research and development.

11. As regards the research in the area of CCS technology, the research needs to be directed in the specific areas by breaking the problem into smaller components e.g. one group has to take up availability of geological space, other groups have to function on availability of construction materials of the technology, disaster management, economic and other commercial aspects. *The scientific institutions will have a major role to play in this regard. Dissemination of information should be given utmost priority and importance. The outcome of this conference needs to be compiled in the form of recommendations and guidelines for the policy and decision makers. Conversion of $CO_2$ into useful products or back into the carbon through reversible cycle could also form an important research area.*

I am happy that the various dignitaries, eminent scientists and students have invited me to participate in the brain storming session and I am confident that sector is going to be benefited by these discussions. Thank you.

# PRESENTATION BY DELEGATES

**Mr. Abhijit Sarma Roy, Senior Research Fellow**
**Centre for Energy, IIT Guwahati, Assam**

Thank you madam for giving me an opportunity! It is wonderful opportunity to listening to distinguished personalities some of the top scientists and members from corporate sector. Basically I am coming from the biotechnology field and am micro biologist. I am from Assam and I did my Ph. D study in CSIR Jorhat, it was formerly known as IIT Jorhat. My Ph. D work was mainly in the field of petroleum hydrocarbons. I studied petroleum hydrocarbon dividing bacteria. There are many sites in Assam in Dispur district where ONGC has been doing drilling and exploration. There are many crude oil sites of course they are not in the news as other sites from around the world. There is a garden called Lakua tea Estate. This is a big tea estate. There are a hundred drilling sites in that tea garden. I did my research in that area and we are proud to say that ONGC has developed one technology and they are doing deliberations in that site. We got a patent also. After completing that I joined IIT Guwahati under Prof. A.K. Ghoshal.

I am a beginner in the field of algae bio-sequestration of $CO_2$ so this workshop came in a right time. I really learned a lot of things about what are the geological, physical and engineering aspects of $CO_2$ sequestration and what could be the real impact in the geological bodies all these. If we can utilize the $CO_2$ then some of the costs we are putting in it can be recovered. I learnt from Dr. Satyanarayana and Dr. Uma Devi who have vast experience in this field. I did some work for getting some value added products when we use the $CO_2$ with algae. After the workshop I would like to do incorporate some pharmaceutical networks into my research. I also learnt about the equipment which I would be requiring. I also feel bacteria can utilize $CO_2$ even faster. Apart from that the other lectures Prof. P.S. Yadava lecture from Manipur University was also very important because in the North Eastern states you can see that there is vast potential for $CO_2$ sequestration and plants which can be adopted to $CO_2$ should be screened. Thank you Madam!

**Mr. N. Thulasi Prasad, Project Scientist-I**
**National Institute of Ocean Technology, Chennai**

Good afternoon everybody! I would like to thank Dr. Malti Goel & her team for conducting this program and giving this opportunity to speak. For the past five days I have learnt that from the capturing technologies and how to transport the $CO_2$ from the industry to the required place and how to sequestration of the $CO_2$. I would add some other points regarding the sequestration of the $CO_2$. We can sequestrate $CO_2$ in the form of gas hydrates. That means in the form of $CO_2$ hydrates. A lot of research is going on in this area. In the Indian perspective we have 2000 trillion cubic feet of methyl hydrate. That means if methyl is replaced with the $CO_2$, we can get the $CH_4$ as well as store the $CO_2$ in the form of hydrates. This is one of the options of pumping the $CO_2$ into the reservoirs and is an area of research.

At NIOT, we started a climate study regarding how to store $CO_2$ in the oceans as told by our Director in detail. Basically, it is the storage of $CO_2$ in the form of reef. We are planning to have an MOU with the industry Ambuja Steel Plant for collecting the waste material, which is coming from the steel plants. It has 50% calcium oxide and by using $CO_2$ at certain pressure and temperature we can convert that into calcium carbonate. We have an inter-disciplinary team of engineers who are working to achieve the goal of carbon sequestration in the marine environment and are moving forward. Thanks to everybody!

19th January 2013

**Mr. Gaurav Kumar, Engineer Trainee**
**Coal Research HPBP, Bharat Heavy Electricals Ltd., Tiruchy**

First of all I would to like thank Dr. Malti Goel madam, for giving us an opportunity to speak. I don't have words to thank her. The workshop I am greatly impressed by Shri V.S. Verma sir, because whatever he told, that is extremely implementable and practical. I am doing something and you are doing something but we are not aware of each other's work. About myself, I am Gaurav Kumar from BHEL Tiruchy. Even we have a Coal Research Centre (CRC) that is biggest laboratory in Asia for research of coal and we have invested more than 150 crore on that laboratory. I am told that this laboratory was set up as part of the recommendations of the DST-BHEL workshop on clean coal technology concluded in 2006. We have every equipment there that can give information about coal activity, coal characteristics, chemical content and pollutants etc. Each and every thing we need can be found there. But most of industry, most of scientists, don't know about it.

Apart from that in BHEL we have IGCC 6.2 MW unit already in operation condition. We have restarted another project for IGCC in 2000, but it is yet to come into shape. For each MW in IGCC plant we have to invest 8 crore where as in conventional plant, it is 3.5 to 4 crore per MW. For this reason Government support is awaited for the project. Till now no coal based IGCC plant is operating anywhere in India. At BHEL there is one Circulating Fluidized Bed Combustion (CFBC) unit that will also reduce the content of $CO_2$. We have one Liquid Fluid Solid Fluid Combustion (LFBTF) unit and are working on advanced ultra super critical test facility. In super critical technology $CO_2$ content is reduced per MW as the efficiency is higher. In super critical we can get 40 to 42% of efficiency but in general conventional it is around 35 to 36%. Another ultra super critical project is a combined project with NTPC, BHEL and IGCAR, Kalpakkam. Advanced ultra super critical technology requires 700 degree Celsius and 70 bar pressure. And for that material itself is a very big challenge that can sustain such high pressure.

Apart from these we have focused on solar and nuclear energy also. BHEL in its Tiruchy complex completed a 50 MW Solar Plant. That is for our own purpose only. Another 5 MW plant is put up in Chennai. We are working for biomass cofiring also in collaboration with Jindal Steel. The rice husk and coal are to be combusted together, however it is not proving economical because husk is not easily available. Thank you!

**Ms. Rosy Yenn, Research Scholar**
**North East Institute of Science & Technology, Jorhat, Assam**

I am extremely grateful to the ACBCCS organizing committee specially Dr. Malti Goel Mam for giving me this opportunity to participate in the workshop on "Awareness and Capacity Building in Carbon Capture and Storage: Earth processes". I have been exposed to a spectrum of developments and challenges in the field of Carbon storage and capture over the last few days of the workshop. Being a research scholar in the field of biotechnology and having limited information about geological and physical aspects of carbon capture and storage (CCS), I was particularly enlightened by the deliberation of eminent geologists and engineers from top institutes across the nation. Apart from this, the field trip to IOCL, R & D centre in Faridabad was an excellent addition to my learning curve from the workshop.

During the field trip to IOCL R&D we were taken around to various research facilities and had a glimpse of operational units like Gasification Pilot Plant, Fluid Catalytic Cracking (FCC) etc. It was a new experience to see the miniature working models of full-fledged oil refining operations. It was heartening that one of the primary energy sector is putting efforts to harness non-conventional energy resources which is very important in the view of the fast dwindling of our fossil fuel reserves. The use of these non-conventional energy resources has a potential to have a drastic positive impact on our changing climatic conditions and lessen its harmful effect. Lastly I would like to congratulate the organizer for organizing this excellent workshop and thank for allowing me to be a part of it.

**Ms. Shikha Garg, Senior Research Fellow**
**India Meteorological Department, New Delhi**

I am Shikha Garg, I am currently working on different projects in the India Meteorological Department. Though I am not working on carbon sequestration or carbon capture at present, but I want to say that this Workshop is really helpful for me so I can take this topic for my Ph. D thesis. During my M.Sc. curriculum, I did my Research Internship in 2009 under Dr. Malti Goel madam at INSA on the Role of Energy Efficiency of Thermal Power Plants in $CO_2$ Reduction. I learnt a lot about the necessity of increased efficiency in thermal power plants so that we can reduce the amount of carbon emissions. I cherish these memories. Thank you!

**Mr. Aamir Hanif, Junior Research Fellow**
**Indian Institute of Petroleum, Dehradun**

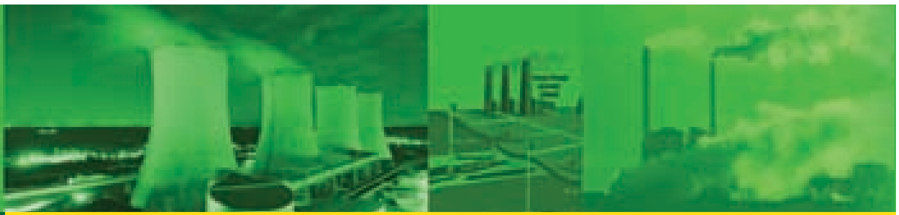
I am Aamir Hanif. I joined in the Indian Institute of Petroleum a year back. My research topic is on material synthesis for carbon dioxide capture. In this workshop, we learnt about many CCS technologies and the need for further research. The need is to make them more affordable so that the cost gets come down. There is a wide spectrum of technologies and there are diverse fields of bio-sequestration and chemical capture of carbon dioxide. First we need to identify whether we go for one option or should we go for multiple options for carbon dioxide capture.

Second is as pointed out by Shri V.S. Verma ji, there is no coordination between R&D institutes and the industry. That is the need of the hour. I am doing research in my laboratory. I really don't know what is the challenges in a power plant are. What are the real challenges? We at IIP are trying to bridge this gap. Our Director, Dr. M.O. Garg had signed an MOU with Indian Oil Corporation Ltd. R&D for sharing the research experiences and taking some of our students for R&D training, there so that they can see the industrial atmosphere and understand what are the real challenges faced in the industry. We already have R&D collaborations with IOCL for extracting biojet fuel from Jatropha. That is in the pilot plant scheme. Maybe we can see the day when biojet is used as a jet fuel at a commercial stage. Thanks!

**Mr. Rupak Kishore, Research Scholar**
**Centre for Energy, IIT Guwahati, Assam**

Please arrange this type of CCUS programme every year and connect to as many industrial persons as possible with the application part.

CCRI



# 2nd Workshop on Awareness and Capacity Building in Carbon Capture and Storage

15th -19th January, 2013

India International Center
New Delhi

# ANNEXURES

**Annexure 1**

# PROGRAMME OF THE WORKSHOP ON AWARENESS AND CAPACITY BUILDING WORKSHOP ON CARBON CAPTURE AND STORAGE: EARTH PROCESSES :Jan 15-19, 2013, India International Centre, New Delhi

**Day 1: 15.01.2013 (CCS Status & Overview)**

Forenoon Session: INAUGURATION

Afternoon Session

| | |
|---|---|
| 2:00 PM | Current Status of CCS Research - National & International<br>- Dr. (Mrs.) Malti Goel, CSIR Emeritus Scientist |
| 3:00 PM | CCS Corporate Sector Initiatives in India<br>- Shri D. K. Agarawal, ED, NTPC |
| 4:00 PM | CCS Scoping Study in Indian Context<br>- Dr. Agneev Mukherjee, TERI |

**Day 2: 16.01.2013 ($CO_2$ Reduction in Power Sector)**

Forenoon Session

| | |
|---|---|
| 10:00 AM | $CO_2$ Recovery from Power Plants by Adsorption<br>- Dr. Anshu Nanoti, IIP, Dehradun |
| 11:30 AM | Capturing $CO_2$ by Physical and Chemical Means<br>- Prof. A.K. Ghoshal, IIT Guwahati |

Afternoon Session: Field Visit to Indian Oil R&D Center Faridabad

**Day 3: 17.01.2013 (Earth Processes in $CO_2$ Storage & Recycling)**

Forenoon Session

| | |
|---|---|
| 10:00 AM | Geological Sequestration of $CO_2$ in Saline Aquifers- An Indian Perspective<br>- Dr. A.K. Bhandari, Ministry of Mines |
| 11:30 AM | Options for $CO_2$ Storage and Role of Unconventional Gas in Reducing Carbon Dioxide Emissions<br>- Dr. Balesh Kumar, GERMI & Ex-NGRI |

Afternoon Session

| | |
|---|---|
| 2:00 PM | Carbon Sequestration Potential of the Forests of North- Eastern India<br>- Prof. P.S. Yadava, Manipur University |
| 3:30 PM | Prospects in Biomimetic Carbon Sequestration<br>- Prof. Satyanarayana Tulasi, Delhi University<br>Bio-sequestration of Carbon Dioxide— Potential and Challenges<br>- Prof. K. Uma Devi, Andhra University |

**Day 4: 18.01.2013 ($CO_2$ in Industry & Value addition)**

Forenoon Session

| | |
|---|---|
| 10:00 AM | Opportunity of $CO_2$ Storage in Coal Beds<br>- Dr. A. K. Singh, CIMFR |
| 11:30 AM | Real Term Implications of Carbon Sequestration in Coal Seams<br>- Mr. Vikram Vishal, IIT Bombay |

Afternoon Session

| | |
|---|---|
| 2:00 PM | Reservoirs for $CO_2$ Storage & Value Addition – EOR process<br>- Dr. D.M. Kale, ONGC Energy Centre |
| 3:30 PM | Carbon Dioxide Storage and Enhanced Oil Recovery<br>- Mr. Gautam Sen, Ex- Oil & Gas Consultant, ONGC |

**Day 5: 19.01.2013 (Panel Discussion and Summing Up)**

10:30 AM Guest Lecture: Policy and Regulatory Interventions in Abatement of $CO_2$ Footprints

**Shri. V. S. Verma, Member, Central Electricity Regulatory, Commission**

**Panel Discussion**

12:15 PM Presentation by delegates and Awarding Certificates of Participation

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**Annexure 3**

# DELEGATES – ACBCCS 2013

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|---|---|
| Mr. Abhijit Sarma Roy, Senior Research Fellow,<br>Centre for Energy, IIT Guwahati, Assam |  |
| Mr. Gaurav Kumar, Engineer Trainee,<br>Coal Research HPBP, Bharat Heavy Electricals Ltd.,<br>Tiruchy |  |
| Ms. Shikha Garg, Senior Research Fellow,<br>India Meteorological Department, New Delhi |  |
| Mr. Aamir Hanif, Junior Research Fellow,<br>Indian Institute of Petroleum, Dehradun |  |

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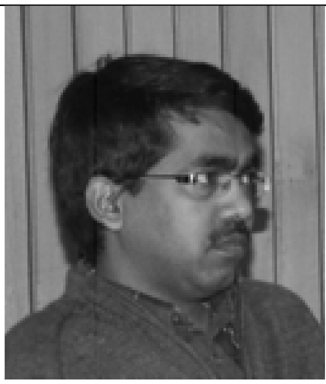
|---|---|
| Mr. N. Thulasi Prasad, Project Scientist-I,<br>National Institute of Ocean Technology, Chennai |  |
| Ms. Rosy Yenn, Research Scholar,<br>North East Institute of Science & Technology, Jorhat, Assam |  |
| Mr. Rupak Kisor, Research Scholar,<br>Centre for Energy, IIT Guwahati, Assam |  |
| Dr. S. Ramesh, Scientist-E,<br>National Institute of Ocean Technology, Chennai |  |

| | |
|---|---|
| Dr. D.P. Gond, Project Scientist,<br>Central Institute of Mining and Fuel Research,<br>Dhanbad |  |
| Mr. Rabi Mukhopadhyay,<br>NTPC-NETRA, Greater Noida |  |
| Ms. Shazia Faridi, Junior Research Fellow,<br>University of Delhi South Campus, New Delhi |  |
| Dr. G. Dharani, Scientist-D,<br>National Institute of Ocean Technology, Chennai |  |

| | |
|---|---|
| Dr. Phanikumar V Sistla, Scientist-E,<br>National Institute of Ocean Technology, Chennai |  |
| Mr. Vaibhav Johri, Project Scientist,<br>Centre for Studies in Science Policy, Jawaharlal Nehru University, New Delhi |  |
| Dr. Debadutta Mohanty, Scientist,<br>Central Institute of Mining and Fuel Research, Dhanbad |  |

## Vision

## Mission

To innovate and become a center of excellence for capacity building in climate change mitigation and adaptation technology.

# CCRI

Climate Change Research Institute is a unit of Climate Change Research Society, founded with a mission to promote environment education, innovation and teachings. It aims to address wide strata of society about the consequences of climate change on our lives and taking control measures. Institute is taking initiative to create awareness on energy security and sustainability through lectures in schools and college, workshops and internet reach. Its future work plan would include development of educational tools on topics of scientific and societal interest; such as energy, health and water in the climate change context. Research and studies would be undertaken on science & technology measures aimed at climate change mitigation and ways of $CO_2$ recycling.

For further information: Executive Director, Climate Change Research Institute, a unit of Climate Change Research Society, C-85 Shivalik, New Delhi-110017, Tel.: 011-41034450, (M): 9810287736, E-mail: info.acbccs@gmail.com