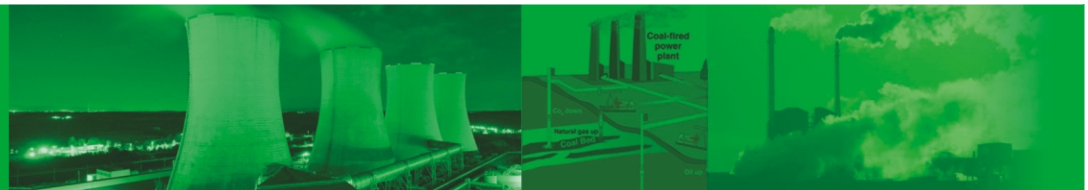
ACBCCS 2015

Carbon Capture, Storage and Utilization: Towards a Low Carbon Growth Strategy

27th - 31st July, 2015, IIC, New Delhi, India



3rd Workshop on Awareness and Capacity Building in Carbon Capture and Storage

27th - 31st July, 2015

India International Center
New Delhi, India

PROCEEDINGS

Organized by

Climate Change Research Institute

Supported by

सत्यमेव जयते

Ministry of Earth Sciences
Government of India

ONGC ENERGY CENTRE

ONGC Energy Centre,
SCOPE Minar

3rd Awareness and Capacity Building Workshop on

Carbon Capture, Storage & Utilization

Towards a Low Carbon Growth Strategy

(ACBCCS 2015)

PROCEEDINGS

Date	:	**July 27-31, 2015**
Organized By	:	**Climate Change Research Institute**
Venue	:	Seminar Hall-1, India International Centre, New Delhi

Climate Change Research Institute
Science & technology solutions for sustainable energy future

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Prof. D. P. Agrawal
Chairman, Governing Council
Former Chairman, UPSC

Message

I am pleased to give a message for the Proceedings of the national level Awareness and Capacity Building workshop on **Carbon Capture, Storage and Utilization (CCSU): Towards a Low Carbon Growth Strategy** organized from July 27-31, 2015 under the aegis of Climate Change Research Institute. I very much appreciate the workshop's objective to provide understanding of science & technology of carbon management and its growing importance in the energy industry.

Due to my brother demise in my home town I could not attend the workshop. But later I was updated about the proceedings of 5 days. In the energy Industry new processes for carbon dioxide removal and recycling are developing fast. It is in this context workshop has provided an opportunity to review the status and renew our efforts through participation of young research scholars & students, who could learn with experts engaged in this area from academia and industry across the country. I thank them all for their active participation.

Being Chairman, Governing Council of CCRI, I thank Ministry of Earth Sciences and ONGC Energy Centre for their kind support to the capacity building workshop. I am happy to note that Dr A. Bandyopadhyay from University of Calcutta has given a concept note to put forward a multi-sectoral project for consideration by the Government of India. It is recommended that there should be more investment in Research & Development (R&D) so that pilot scale facilities are developed through industry-academia collaborations in order to build indigenous capacity.

I am confident that sustained efforts put in by Dr. (Mrs) Malti Goel, founder Climate Change Research Institute on this subject for advancement of science & technology will go a long way in spreading awareness and building capacity in environment and climate change education among youth and society at large.

Prof. D. P. Agrawal

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FOREWORD

At the outset I convey my sincere thanks to all the eminent speakers, delegates and sponsors for their kind cooperation and for making recently concluded workshop on **Carbon Capture, Storage and Utilization: Towards a Low Carbon Growth Strategy (ACBCCS-2015)** a success. The national level awareness and capacity building organized under the aegis of Climate Change Research Institute got overwhelming response and was a big achievement both in terms of profile and content.

Global warming and climate change concerns have triggered efforts to reduce the concentration of atmospheric carbon dioxide. Carbon capture, storage & utilization is considered a crucial strategy for meeting CO_2 emission targets. I thank Dr. M. Sudhakar, Advisor, MoES for his advice and efforts to focus on importance of technology development in CO_2 removal processes in the energy intensive industries. It is a great honor that Dr. M. O. Garg, Director General, Council of Scientific & Industrial Research and Director, CSIR–Indian Institute of Petroleum Research has inaugurated and blessed the 5 day workshop. It is our privilege that Dr. M. P. Narayanan, Ex-CMD, Coal India Ltd., Dr. B. Bhargava, DG, ONGC Energy Centre, Dr. Jyoti Parikh, ED, IRADe, Prof. Javed Ahmed, Dean (Science) Jamia Hamdard and many other eminent personalities from industry and academia were present in the inauguration of the ACBCCS 2015 workshop. Dr. Anupam Agnihotri, Director JNARDDC Nagpur and Dr. Ajay Mathur, DG Bureau of Energy Efficiency (BEE) delivered keynote lectures. Speakers from Anna University Chennai; Manipur University, Imphal; ICRISAT Development Centre, Andhra Pradesh; University of Calcutta; NGRI Hyderabad; NTPC-NETRA, Noida; National Fertilizers Ltd, Vijaipur; Tata Steel, Jamshedpur; CIMFR Dhanbad; MNIT Bhopal; Delhi University and JNU besides other top organizations like CERC and ONGC have delivered lectures during the five day workshop.

ACBCCS 2015 proceedings have been brought out to put forth perspectives on carbon removal and utilization processes in the knowledge domain. Various problems and solutions in CO_2 sequestration - chemical, biochemical and biological options and terrestrial CO_2 storage processes are covered.

It is hoped that you find it interesting and contribute to take it forward. I take this opportunity to once again thank all the stakeholders for making this workshop result oriented and valuable for the nation.

Malti Goel

Dr. (Mrs.) Malti Goel
20.11.2015

Climate Change Research Institute

Awareness and Capacity Building Workshop on

Carbon Capture, Storage and Utilization

Towards a Low Carbon Growth Strategy

July 27-31, 2015 at IIC, New Delhi

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Climate Change Research Institute

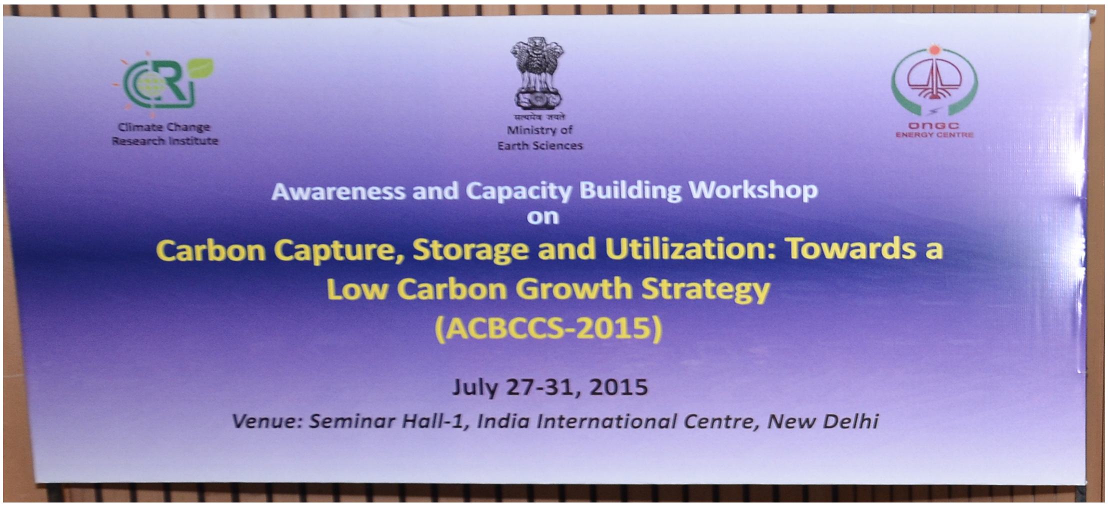
3th Awareness and Capacity Building Workshop on

Carbon Capture, Storage & Utilization

Towards a Low Carbon Growth Strategy

ACBCCS 2015

EXECUTIVE SUMMARY



ACBCCS 2015 Objectives:

- To provide understanding of science & technology of Carbon Capture, Storage and Utilization and its growing importance in the energy industry.
- To learn about CO_2 Capture-chemical, biochemical, biological options and identify terrestrial CO_2 storage processes in the context.
- To put forth perspectives on carbon removal and utilization processes in knowledge domain and submit recommendations to concerned agencies.

ACBCCS-2015 Summary

- Pre-Conference Lecture Notes
- Inaugural Session
- Six Technical Sessions
- Special Session
- Open Round Table Discussion
- Participants Presentation
- Concluding Session

27.07.15

Inaugural Session

- Introduction to ACBCCS 2015 – Dr. (Mrs) Malti Goel, CEO, CCRI
- Inauguration Address - Dr. M. O. Garg, Director General, Council of Scientific & Industrial Research and Director, CSIR – Indian Institute of Petroleum Research

- Key Note Address – Carbon dioxide Management – Aluminium Industry Perspective, by Dr. Anupam Agnihotri, Director JNARDDC, Nagpur
- Guest Address - Dr. M. P. Narayanan, EX-CMD, Coal India Ltd.
- Special Address - Dr. Jyoti Parikh, ED, IRADe
- Brief Address - Dr. B. Bhargava, DG, ONGC Energy Center

Technical Sessions

Eminent Speakers

- Dr. Anupam Agnihotri, Director JNARDDC, Nagpur
- Shri V. S. Verma, Ex-Member, CERC
- Dr. Ajay Mathur, DG, Bureau of Energy Efficiency
- Prof. K. Palanivelu, Anna University
- Prof. Malti Goel, Jamia Hamdard & Former Adviser, DST
- Prof. Satyanarayana Tulasi, Delhi University, South Campus
- Mr. Gautam Sen, Ex-Ed ONGC, Oil & Gas Consultant
- Prof. P. S. Yadava, Manipur University
- Shri Rabi Mukhopadhyay, NTPC
- Dr. K. Sudhakar, NIT, Bhopal
- Dr. Amitava Bandyopadhyay, University of Calcutta
- Shri Nirmal Jit Singh, NFL, Vijaypur
- Dr. S. Sarkar, Tata Steel, Jamshedpur
- Dr. Vinod Mendhe, CIMFR, Dhanbad
- Mr. Thomas Weber, Jupiter Oxygen Corporation, USA
- Mr. Tamotia, Jupiter Oxygen Corporation, USA
- Prof. B. C. Tripathy, School of Environmental Science, JNU
- Dr. Tapas Bhattacharya, ICRISAT Development Centre, Telengana
- Dr. Pinnelli S.R. Prasad, CSIR –NGRI, Hyderabad
- Dr. Abhijit Mitra, University of Calcutta
- Dr. Balesh Kumar, Ex-NGRI, Hyderabad
- Dr. M. Govindraju, Bharathidasan University, Trichy

28.07.15

CO_2 Abatement & Utilization – 2 Sessions

- Overview of Carbon Dioxide Removal Processes and Capacity Building in CCSU
- Power Sector Development vis-a-via CO_2 Abatement
- Climate Change Mitigation via Utilization
- Industry Perspective Research at NTPC
- CO_2 Utilization in Coal-fired Power Plant: Industry Perspectives
- Long Term Microbial Carbon Sequestration Options For Enhanced CO_2 Utilization

29.07.15

CCS Perspectives in Industry – 2 Sessions

- Efficiency Improvement Strategies: Energy Industry
- Experience of operation of Carbon Dioxide Recovery Plant at NFL Vijaipur Unit

- Aqueous NH3 in CO_2 Capture from Coal Fired Thermal Power Plant Flue Gas: N-Fertilizer Production Potential & GHG Emission Mitigation

29.07.15

CCS Perspectives in Industry - Special Session

- Carbon Management – Steel Industry Perspective
- Low Carbon Growth Strategy for India Based on Oxy-Combustion Carbon Capture and CO_2 Utilization For Enhanced Coal Bed Methane [ECBM] Recovery
- Coal Bed Methane recovery Status and technological Issues in India
- Beauty Yoga & Immunity

30.07.15

CO_2 Bio Sequestration and Storage – 2 Sessions

- Soil carbon stock and CO_2 flux in different terrestrial ecosystems of North East India
- Soil as Source & Sink for Atmospheric CO_2
- Clathate hydrates: A powerful tool to mitigate greenhouse gas
- Seaweeds: A Potential Reservoir of Carbon
- Enhanced carbon dioxide utilization by plants grown in Free Air Carbon dioxide Enrichment (FACE) facility
- Challenges for CO_2 Storage: India's Perspective

31.07.15

ACBCCS 2015 - Concluding Session

- Open Round Table: **CCSU - Towards a Low Carbon Growth Strategy**
- Delegates Presentation
- Guest Lecture on CO_2 Storage & EOR

ACBCCS 2015 - Delegates' Nominating Institutions

(i) Jawaharlal Nehru Aluminium Research Development and Design Centre, Nagpur
(ii) CSIR-Central Institute of Mining and Fuel Research, Dhanbad
(iii) Oil & Natural Gas Corporation (ONGC), New Delhi
(iv) Oil & Natural Gas Corporation (ONGC) Energy Centre, Delhi
(v) Delhi University, South Campus
(vi) The Energy and Resources Institute (TERI) , New Delhi
(vii) Tamilnadu Agriculture University, Trichy
(viii) Dayal Singh College, Delhi
(ix) Department of Education, Delhi

Climate Change Research Institute

3th Awareness and Capacity Building Workshop on

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ACBCCS 2015

RECOMMENDATIONS

The recommendations of the ACBCCS 2015, summarized as Coal Energy Sector, Industry and Academia, Policy, and Center of Excellence, are given below

1. Coal Energy Sector

In the coal energy sector Carbon Capture, Storage and Utilization (CCSU) is being researched to stabilize concentrations of carbon dioxide and mitigate climate change. India should capture the progress made elsewhere to continue use of coal. Adoption of new technology such as high flame temperature oxy-fuel combustion can result in significantly more efficient, economical and environmentally-compliant operations for CCU. A plant, either new or retrofit, in the vicinity of a coal mine could become a source of enhanced CBM by using captured carbon dioxide. The gas recovery through desorption process can be enhanced by as much as 20%, for coal has greater affinity for carbon dioxide as compared to Methane. The technology is not merely suitable for high ash coal, but also saves on water use.

2. Industry and Academia

Carbon dioxide removal processes for Industry are developing fast. Possibilities of CO_2 utilization in biofuels and chemical synthesis are getting matured and can no longer be ignored. Towards a low carbon growth strategy, industry should participate in technology development and India's efforts in CCSU should also be documented. Recent developments in BECCS, - Carbon sequestration in Plants & Soil – Oceans Sea Weeds – Clathrates are to be recognized as an important component in the Policy

3. Policy

It was agreed that policy support is required for finding best solutions for indigenous CCSU technology development through Industry-academia participation. Carbon sequestration is to be acknowledged as an important component in climate change agenda requiring 'TECHNOLOGY SAUVY' approach in climate change negotiations.

4. Center of Excellence

During ACBCCS 2015 workshop deliberations a multi-sectoral programme has been suggested for development of NH_3 based and alternate absorbents for CO_2 capture. The programme needs to be anchored with the participation of Ministries of Power, Chemicals & Fertilizers, Agriculture, Earth Sciences and academic Institution - University of Calcutta. The recommendation note by Dr. Bandopadhyay, University of Calcutta on **Suitable CO_2 capture technology in Indian Coal fired Thermal Power Plants, Fertilizer Plants, Integrated Iron & Steel Industries, Petroleum Oil Refineries and Cement Industries having potential CO_2 emissions from point stationary sources** has been prepared.

The CCRI can play a role to anchor the project through creation of a CCSU Centre of Excellence aimed at knowledge networking among the various stakeholders. Such a Center could work for developing perspectives on carbon removal and utilization processes in the ongoing research projects in academic institutions and industry in knowledge domain for meaningfully application of research output to develop pilot projects. There is also need to establish a pilot scale facility to test all the CO_2 capture research results at one place.

ACBCCS 2015

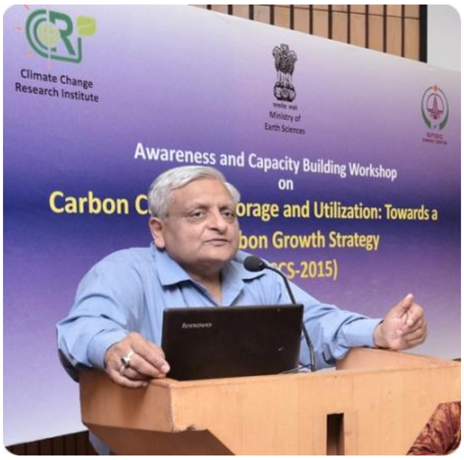
INAUGURAL SESSSION

27.07.15

INAUGURATION ADDRESS

Dr. M. O. Garg, Director General

Council of Scientific & Industrial Research and Director, Indian Institute of Petroleum, Dehradun



Very good afternoon and warm welcome to the five day workshop on Carbon Capture & Storage as well as Utilization! Carbon dioxide or carbon as you call it, comes out from all kind of sources, but two major sources are power and transportation sectors. The industry contribution may be 10-15%, but a bulk of it may be around 55% comes from the power sector at least in India, because our energy is mostly coal dominated. Transportation sector is also major contributor but being a distributed source actually makes it more difficult to capture CO_2 coming out from the tail pipe of vehicles.

As you may know processing of transportation fuel in the refinery also adds to 8-10% of the crude oil CO_2 emissions. On one hand we have high sulphur, high heavy crude and on the other hand we have ever changing target in terms of fuel quality. Presently we are on Euro IV and proposing to leap frog to Euro VI. We would need to go for hydrogen because it is the only way one can upgrade a low quality feed stock to high quality fuel. It not only removes sulphur but also sequester carbon dioxide in the process of producing lighter fuels. When we produce hydrogen in a refinery, for every ton of hydrogen, 16 tons of CO_2 is produced. Refinery is therefore emerging as a great source of CO_2.

In the modern industrial world, Indian government has introduced Digital India, Gramin Vikas and many other programmes. All of these would need energy, and energy doesn't come without carbon as we are dependent on fossil fuels. On the other hand, we are looking for solar, wind & other renewable energy sources. Economics is important in them as the installation cost for solar power plant is almost above 10 crore per MW capacity and much higher compared to coal power plant. Even solar plant is not completely CO_2 free as making of silicon chip and cleaning etc. are CO_2 intensive.

I must congratulate Dr. Malti Goel for putting together this awareness workshop on Carbon Capture, Storage and Utilization (CCSU). We have a wide coverage of topics from industry perspectives such as Aluminum, Steel, Fertilizers, Carbon dioxide utilization, sequestration in gas hydrates and biofixation etc.

The CO_2 capture technology is pretty mature now and various options are becoming available. I would recommend that we do not need too much research now in terms of what method for CO_2 capture. At the Indian institute of Petroleum (IIP) Dehradun a number of processes;, for example using hindered amines, liquid ammonia process, membrane processes like Pressure Swing Adsorption are studied. We need to establish a pilot scale facility to test all the CO_2 capture research results at one place. Technology Centre at Mongstaad (TCM) is one such centre in Norway. The gas from power plants and gas based plants can be transported through a pipeline and CO_2 content from 8 to 14% can be tested. Various solvents can be tested for CO_2 capture. We should have a similar facility in India as it will help in upgrading our research results.

At IIP another area we worked on is CO_2 storage in Metal-Organic Frameworks (MOFs). Taken up in collaboration with SINTEF, Norway, exciting results were obtained. As far as CO_2 utilization is concerned the issue is how much CO_2 can be utilized. We need billions of tones to be sequestered. Various options such as Algae process also being studied for conversion of CO_2 into fuels & value added chemicals. Possible solution will emerge either as economics become acceptable or we are able to use CO_2 to produce fuel with the help of solar energy. I am sure science will one day lead to such solutions.

I inaugurate the workshop and wish successful deliberations for five days.

INTRODUCTION TO WORKSHOP

Dr. (Mrs.) Malti Goel
President CCRI & Convener ACBCCS 2015

Today is the memorable day for the Climate Change Research Institute!. We are honored by the presence of Dr. M. O. Garg, Director General, Council of Scientific & Industrial Research. Prof. Narayanan, Dr. Jyoti Parikh, Dr. Dr. A. Agnihotri, Dr. B. Bhargava are among other eminent personalities who have graced the occasion and are with us. It is sad that Prof. D. P. Agrawal could not attend due to tragedy in his hometown.

To give a background to the workshop, this series of awareness and capacity building was conceived in 2009 as the only one in India and this is the third Workshop in the series. I owe it to Ministries of Earth Sciences and Science & Technology. Our aim is to share the world view, experience in the Indian context and address research issues. Internationally, scientific researches in CCS as well as technology demonstrations are growing. At present out of total 74 projects in pipeline, 13 large scale projects are in operation, and 9 are under construction. First large scale project in power sector is Boundary Dam Integrated Project became operational in Oct. 2014. One year down the line in steel industry in a DRI plant, CO_2 capture of 0.8 mpta has begun in Abu Dhabi in 2013. Nearly 44 projects are in planning stage.

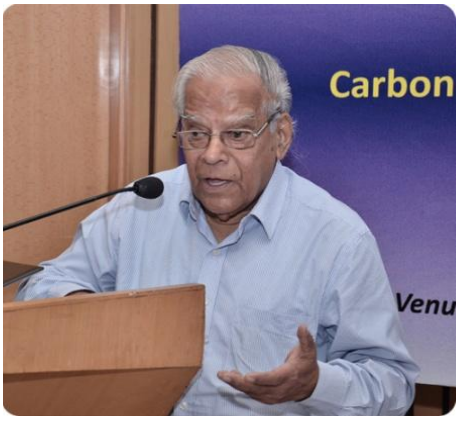
The present workshop theme is 'CO_2 removal processes in energy intensive industry'. Dr. Anupam Agnihotri, Director JNARDDC, Nagpur has kindly agreed to deliver Key Note address on Aluminum industry perspectives. An overview of power sector development followed by an overview on CO_2 sequestration and need for capacity building are covered. There are 3 lecture sessions on CO_2 utilization on 28th July. On the next day (29th July) focus changes to industry perspectives and there are lecture sessions from fertilizers and steel industry among others. In the special session we have a lecture from Dr. V. Mendhe, CIMFR and a spiritual lecture on Yoga has also been planned for those interested.

CO_2 when disposed in the earth is treated as waste product. This can lead to several problems in terms of safety. How it can become an industrial good and utilized or recycled? CO_2 chemistry is gaining importance? Microbes and enzymes are becoming important. On the fourth day i.e., 30th July the sessions are dealing with advancements and innovations taking place in CO_2 sequestration technology. The concluding session is on 31th July, and has an Open Roundtable discussion as well as a guest lecture on enhance oil recovery.

With India gearing to achieve energy independence, technologies for all resources of energy would need development to accelerate the growth of electricity capacity addition in the country. India should innovate on CCS or CCSU so that technological feasibility and economic viability is developed through demonstration and pilot projects in view of India's energy independence on coal. The Institute thankfully acknowledges support from Ministry of Earth Sciences and ONGC Energy Centre we are extremely thankful to all dignitaries on the Dais and off-the Dais for accepting our invitation.

GUEST ADDRESS

Dr. M. P. Narayanan
Ex-CMD, Coal India Ltd.



Distinguished delegates! I am here representing coal sector and what you can say is guilty of contributing to the carbon footprints. In coal we project the production rate as 10%, 12% or 14% growth as per Plan, without really considering how much it will affect environment adversely. I have been saying from the last conferences that power, oil and coal sector should devote to research & development (R & D) in ways to reducing CO_2 footprints. Although CMPDI is doing some study about CCS and some work has been done in NTPC in their own power stations, we should also have a comprehensive study on R&D spending on CCS from these sectors. Cleaner coal is always better, but beneficiation of coal has not received much attention so far. Emphasis is more on the 'quantity' than 'quality'. At present we are producing 574.80 million tones and the ambitious programme is to double it to 1 billion tones.

The programme in power sector having emphasis on efficiency improvement and setting up of super-critical power plants is worth mentioning. However, there is focus on zero emissions projects elsewhere say in European Commission. In India we do not have such effort and need to have total energy management. Our PSUs have not taken the responsibility in this direction, therefore I would once again emphasis that we should invest sufficient R&D funds to promote CCS and pilot scale facilities should come up.

I must compliment Dr. Malti Goel, as a significant contribution was made by her in the Ministry of Science & Technology as Adviser in launching a nationally coordinated CO_2 sequestration research programme within a short time. I am sure that these efforts would lead to setting up pilot projects in our country.

I am very much interested to participate in CCS deliberations and shall be attending the workshop on all days.

Thank you very much!

SPECIAL ADDRESS

Dr. Jyoti Parikh
ED, IRADe, New Delhi

Distinguished guests! I would also join with Shri M. P. Narayanan, about the perseverance of Dr. Malti Goel in support of R&D and joint technology projects with Ministries. Our institute had first project on CCS from DST and then we held a conference in 2008 with the support from DEFRA. A number of scientists involved in storing and capturing of carbon dioxide participated from across the world.

Currently, IRADe is modeling energy scenario up to 2050. This is for the Paris meeting to determine what kind of INDCs commitments are to be made. We come to conclusion that more the 3 billion tonnes coal will be required. Taking a very extensive renewable energy push, it could at the most come down to 2 billion tonnes. Therefore coal is here to stay. In a study with IIASA, which also does climate modeling, we compared our results for 2100. IIASA scenario, looking at the climate change up to 2 degree centigrade temperature rise, suggests no region is in the world can do without CCS. Some kind of negative absorbing activity such as green biofuels, renewables & soon will be there, but it is simply not possible to continue to use coal without CCS as well as have 2 degree centigrade temperature stabilization. Power Ministry has felt that CO_2 storage has risk of leaking in future and take a decision that unless developed countries demonstrate it we will not go for it. Point of view has been that we should continue with R&D efforts.

I am happy that CO_2 utilization is being given importance in this workshop. In this context I may add that National Action Plan on Climate Change 2008, required science & technology for finding solutions for targets set under all missions, but CCS was not included. At present things are not much different, At one time it was felt that carbon pricing could have given the boost to CCS, but CDM goals are no longer discussed. Price of carbon keeps falling and the momentum has gone down.

I am glad that this workshop has made it possible to review the status and renew these efforts so that India is not left far behind. In Paris when COP meeting takes place, INDC will be considered. In INDCs whatever goals are committed, they will be monitoring and therefore delivery will be important. We should work towards detailing of these aspects of CCS in appropriate manner, so that they can contribute.

We have to also keep in view that portfolio of CO_2 mitigation options are increasing like continuously for example LEDs have captured market and new business models are emerging. I thank Dr. Malti Goel for organizing this very important conference. I wish her all the best.

BRIEF ADDRESS

Dr. B. Bhargava
Director General, ONGC Energy Centre, New Delhi

Good afternoon ladies and gentlemen! First of all I must compliment organizers for a series of workshops on awareness and capacity building. Carbon is directly linked to our progress. When civilization started pure carbon was the sources of energy. Over the decades and over the centuries carbon content is getting reduced and time has come that further reduction in carbon content either directly or indirectly has become necessary. There are two ways; one is to avoid use of carbon by utilization of other sources where carbon presence is not there or negligible. Second approach is where carbon dioxide is produced; it is captured and stored or utilized. Whichever technology we use, it is the net energy gain that is important and is key to sustainability.

As technology and economics are the two sides of the same coin, they drive each other. We have to see on opportunity in CO_2 mitigation. As Dr. M. O. Garg has said earlier, options for carbon capture are already there, reasonably mature but lots to be done to find cost - effective methods for storage and utilization. To support clean energy development, idea of polluters pay was accepted some time back. The cess on coal is the source of funding and a National Clean Fund has been created.

As far as ONGC Energy Centre is concerned we have a corpus of 500 crores that has been approved to pursue clean energy technology options. We are happy to support this workshop. Time has come to support more & more capacity building efforts in newer areas. We invited expression of interest for proposals into fuel conversion among others. We got as many as 25 proposals dealing with conversion of CO_2 from various institutions across the country. Looking at those we felt that we should focus on utilization aspects rather than storage.

At the same time we need to focus on ways & means on how to avoid CO_2 emissions which means look for other alternative options like solar energy, distributed power generation etc. One solar lantern saves 50 lit of kerosene and CO_2 emissions are avoided. Newer possibilities exist with the Govt of India vision to achieve 175 GW of capacity from renewable energy sources as well.

Thank you!

KEYNOTE ADDRESS

CO_2 MANAGEMENT - INDIAN ALUMINIUM INDUSTRY PERSPECTIVE

Dr. Anupam Agnihotri

Director, Jawaharlal Nehru Aluminium Research Development & Design Centre (JNARDDC), Nagpur

Dr. Anupam Agnihotri described GHG emissions in World & India, current and future projections, as well as GHGs in Aluminium Industry and efforts to reduce GHGs in Aluminium industry. He said we need to recognize following facts & figures;

- Climate change is more transformational & critical issue than domestic terrorism viz.,, IS group, HIV/AIDS, Greece financial system instability, which presents fundamental challenges to our economic and social structures
- Greenhouse gases (GHGs) are driving climate change & are to be reduced urgently. Existing government policies are not sufficient to solve problem
- CO_2 emissions to be cut by 85% below 2005 (25.36 Gt) levels by 2050 to limit global mean temperature increase to 2°C above pre-industrial era

Key data on climate change ranking, share of global GDP, share of populations, CO_2 emissions and primary energy supply was presented for 10 largest CO_2 Emitters. Dr. Agnihotri also presented profiles of CO_2 emissions and populations for selected countries.

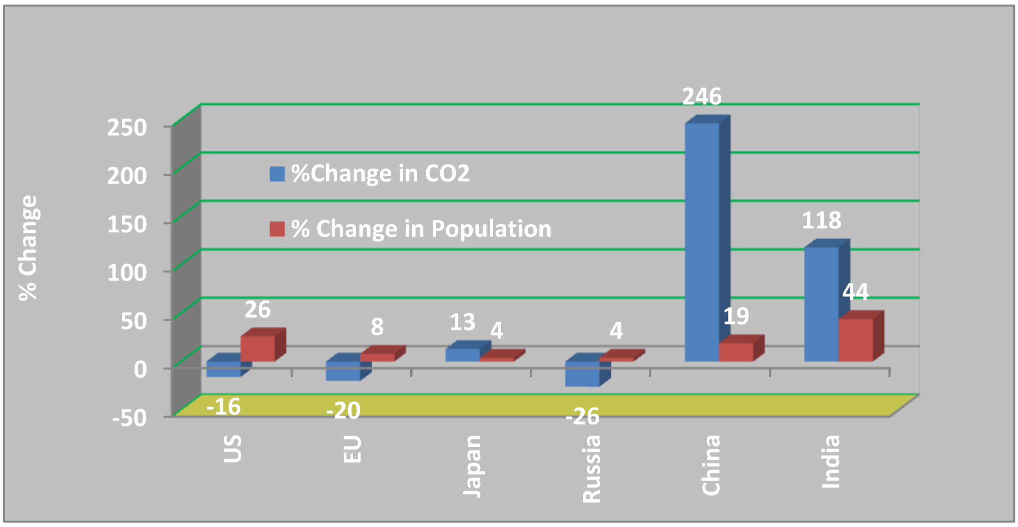
Key Climate Change Data for 10 selected countries

Country	CCPI Rank 2014	CCPI Rank 2013	Share of Global GDP	Share of World Population	Share of Global CO_2 Emissions*	Share of Global Primary Energy Supply
Germany	19	8	4.02%	1.18%	2.23%	2.38%
India	30	24	5.66%	17.84%	5.14%	5.72%
Indonesia	34	36	1.41%	3.48%	2.30%	1.59%
Brazil	36	34	2.87%	2.83%	4.12%	2.06%
United States	43	43	18.81%	4.48%	15.50%	16.71%
China	46	48	14.63%	19.42%	22.95%	20.91%
Japan	50	44	5.59%	1.84%	3.54%	3.52%
Korea	53	50	1.95%	0.72%	1.76%	1.99%
Russian Federation	56	55	2.99%	2.04%	4.90%	5.57%
Canada	58	58	1.75%	0.50%	1.58%	1.92%
Total			59.69%	54.32%	64.03%	62.37%

*energy-related emissions and emissions from deforestation

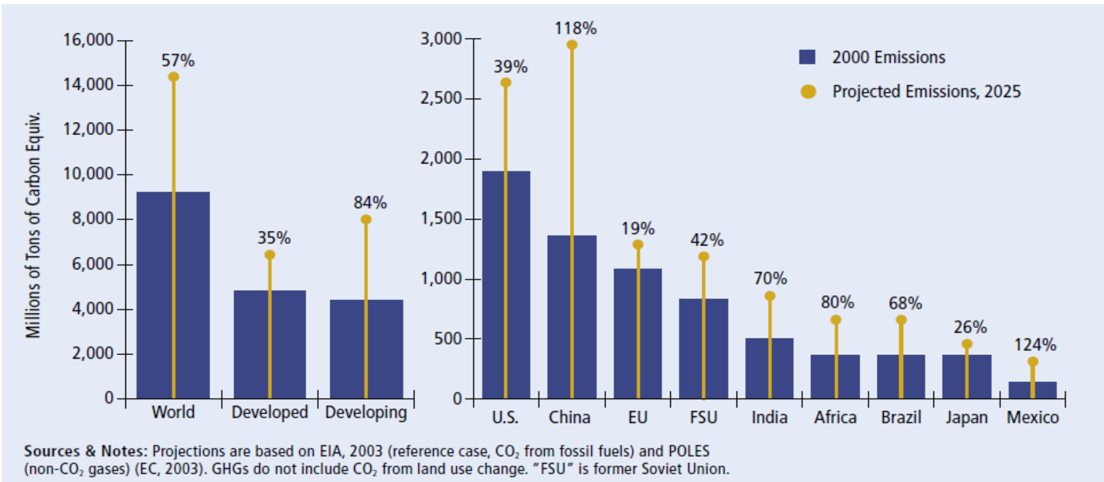
© Germanwatch 2013

Performance: Very good | Good | Moderate | Poor | Very poor



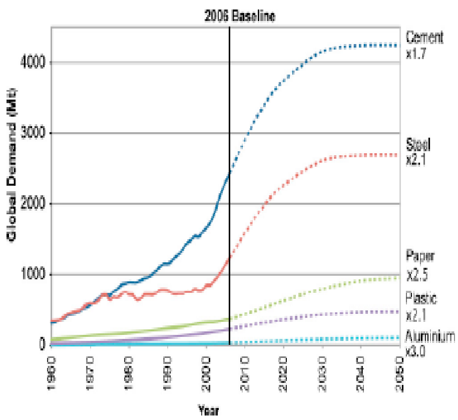
Percentage change in CO_2 and Polpulation from 1990-2012

Sectoral emission profiles for India and share of industrial emissions indicated that Aluminum production has 3% share.



Projected GHG emissions up to 2025

Indian Aluminium Industry comprises of 6 aluminum refineries and 7 smelters, which are one of world best. Global Demand Scenario of various metals was presented.



Source: Materials of Future, Material Science, 2014

Aluminum is a versatile material having vast scope in applications. A large amount of waste is generated from the industry. Total energy associated with primary aluminium production from bauxite ore to metal is approximately 22 kWh/kg of aluminum which is broken into 7.00 kWh/kg Al from Raw materials and 15.00 kWh/kg Al from Electrolytic Reduction. The GHG emissions are both Direct and Indirect. GHG Monitoring & Reporting Infrastructure in aluminium sector comprises of two major frameworks for measurement**:**

I. *Intergovernmental Panel on Climate Change (IPCC) guideline*: International body on climate change set up in 1988 by WMO & UNEP for regular assessments of scientific basis of climate change, its impacts, future risks & options for adaptation & mitigation
II. *Greenhouse Gas Protocol*: Developed by WRI & WBCSD, sets global standard for how to measure, manage, & report greenhouse gas emissions.

Three tier approach of Intergovernmental panel on Climate Change to computation of emissions is as follows.

- Tier 1: Technology specific emission factors for calculating CO_2
- Tier 2: Process specific equations with industry typical parameters for CO_2 emissions
- Tier 3: Process specific equations with facility specific parameters for CO_2 emissions

The protocol for measurement of PFC emissions which include Tetrafluoromethane (CF_4) and Hexafluoromethane (C_2F_6), from primary aluminum production are-

  – Tabereaux method
  – Overvoltage method
  – Slope method

Material carbon intensity of Aluminum is highest. The recycling of aluminum requires up to 95% less energy than that required for primary aluminum production. Recycling aluminum from used products saves an estimated 84 million tones of greenhouse gas emission per year. In cars one tonne of Aluminum can reduce 20 tonnes of CO_2 emissions whereas in sustainable trains the reduction by one tone of Aluminum can be as high as 40-60 tonnes of CO_2.

The approach to Carbon Neutrality for Aluminum industry can be summarized two folds.

a. Increasingly recycling of Alumnium is seen as a solution for reducing GHG emissions and continued industry improvement.
b. Global warming impact from aluminum production will be more than offset by the carbon dioxide reductions from its use in transportation.

Emissions savings from increased aluminum usage in transportation is so great that this industry will become "greenhouse gas neutral" in the next decade.

Dr. Agnihotri said that Jawaharlal Nehru Aluminium Research Development & Design Centre is for aluminum research and is currently engaged in following

- PFC measurements in aluminium smelters
- Use of spent pot lining as a fuel
- Projects for energy reduction
  – Equipment design for liquidus temperature

- Reduction in anode stud voltage drop
- Thermography studies for process efficiency enhancement
- Energy & mass balance of refineries

JNARDDC is Aluminium sector expert organization under NMEEE for implementation of PAT scheme.

ACBCCS 2015

Technical Session-I

CO_2 Abatement & Removal

28.07.15

Homage paid to Hon'ble Dr. A. P. J. Kalam

The morning news was about sad demise of former President Dr. A.P. J. Kalam, so shocking that we decided to pay homage to him before the start of first Technical Session.

Though I had the honor of meeting him during official work, I recalled one particular incidence. Do you believe in global warming? I was asked this question at a custom counter in Frankfurt Airport in 2005 while changing airplane to go to USA and it came as a surprise. The book I wrote on '*Energy Sources and Global Warming'* has just been published. Today we talk of global warming and climate change with almost certainty, but at that time, a decade ago, it looked more a political than a scientific question. A few months later I received a call from the Rashtrapati Bhawan. As the book was dealing with all aspects of energy generation from its various sources and their environmental implications, it caught attention of Hon'ble President of India Dr. A.P.J. Kalam. While releasing the book he said 'I have gone through the book and it is a fantastic book in its coverage'. He also said that he could not write any message as President of India but conveyed his Greetings! Anyhow I got highly motivated and inspired and it led me to contribute another book on *Clean Energy* in 2010.

To get his blessings I met him at 10, Rajaji Marg with the new book. He very much appreciated and also remembered his past remark. This time he wrote; "*Good effort! India has to graduate from energy security to energy independence by 2030. That means fossil fuel elimination, entering into the region of clean fuels; solar, wind, nuclear, hydro and bio-fuel"*. I was moved by his humility and concern.

Dr. A.P.J. Kalam was a visionary scientist, forever thinking ahead, keen to mentor youth in general and technocrats in particular. When I informed him about creation of CCRI he appreciated the idea very much and offered to help. Energy independence was coined by him as a solution to sustainable development as he stressed on futuristic areas for energy research such as; carbon nano-tubes (CNT) for increasing solar cells efficiency. In the lecture at Energy Technology Conclave in 2008 he had said "*Our scientists have to take up this challenge and come up with the development of a CNT based PV cell with an efficiency of at least 50% within the next three years so that it can go into the commercial production within five years"*.

Dr. Kalam was fond of making couplets to inspire youth to serve the nation. I quote one such couplet, which every family needs to imbibe;

'**Teach righteousness to your child, it brings peace of mind**
When there is peace of mind, there is beauty in the character.
When there is beauty in the character, there is harmony in the home.
When there is harmony in the home, there is order in the nation.
When there is order in the nation, the world becomes sustainable'

Alas! When there is likelihood of realization of his vision 2020 for the nation and as we are approaching 2020, he would not be there to see.
We pay homahe to our dynamic, chrismatic leader!
CCRI & ACBCCS 2015 Team

POWER SECTOR DEVELOPMENT VIS-A-VIA CO_2 ABATEMENT

Shri V. S. Verma
Former Member, CERC, New Delhi

Shri V. S. Verma, Former Member, CERC, described power sector planning in the country and difficulties faced in the process. When we have planning power sector, we have to do optimization of the cost of generation in the country. To minimize cost of generation transportation cost is to be taken into account. We transport fuel (coal) from the mines to power stations. Then we transport electricity through transmission lines. For example to transport electricity in some power stations in Arunachal Pradesh we have to see fuel combination we have. We have fossil fuel like coal, gas, nuclear fuel then we have hydro power stations. We have solar, wind and lot of other renewable sources are there. When we optimize we found that scarcity of fuel is main issue like nuclear fuel is not available in spite of several agreements & MOUs at high level and other attempts made. Uranium is not there in required quantity. If we want to do better in nuclear ability then we could not go ahead. Nuclear capacity is today 5300 MW. Imagine since independence we started from capacity of 1,367 MW and now we have total generation capacity of 272 GW (2,72,000 MW), this is as on 15th July, 2015. Out of which coal is around 1,65,000 MW. We have diesel 993 MW. We have gas 23,000 MW. Thus the total thermal consisting gas, diesel and coal is 1,89,313 MW of the thermal. Nuclear is 5,717 MW and hydro we have 41,632 MW. Renewable source of energy we have 35,776 MW.

In case we use Natural gas in place of coal again the price and quantity for a power station for 25 years is to be ensured. To establish gas power station there must be gas available for next 25 years. Gas agencies like ONGC and others are not able to assure about the gas availability. So the planning of power sector is affected by these shortages.

The subject of abatement of CO_2 emissions from the power sector specially has been a matter of concern for the sector personnel in general and the public at large in particular. Coal bases generation is major contributor of CO_2 emission. The research on the CCS technology i.e., carbon capture and storage has been an interesting subject among the researchers and academicians. Way back in early 2000s, after in-depth discussions and interactions with the sector professionals, the Govt. in the Ministry of Power took a conscious decision of not adopting or incorporating CCS in our power stations due to the following:

1. Adoption of this technology increases the cost of generation of electricity to double.
2. The efficiency of power generation comes down by 30% ie about 15% points.
3. The disaster management plan was not known.

However, the following viable alternatives were proposed by the Govt. to be implemented on the ground to reduce the CO_2 foot prints.

a. Retiring 15000MW old capacity to improve the average efficiency of power generation.

b. Renovation and modernization of old power stations to bring the efficiencies to near to design values.
c. Introduce new generation capacity with super critical parameters and ultra supercritical parameters.
d. Induct renewable sources of power generation like solar, wind etc

All the above measures will improve the CO_2 foot prints in the country. He said that besides this further research needs to be conducted on carbon sequestration and fixation in our various academic institutions and research laboratories.

Economics and costs of the new technologies is an important issue in Indian context. Introduction of renewable sources of power is also fraught with the dangers of disruption of grid discipline management as well as damages to the conventional coal fired power generation machines. Example of Germany should teach us good lessons in this regard.

CARBON DIOXIDE REMOVAL PROCESSES AND CAPACITY BUILDING IN CCSU

Prof. Malti Goel
Visiting Professor, Faculty of Science, Jamia Hamdard and Former Adviser, DST
New Delhi, India

Dr. Malti Goel, President CCRI in an overview presentation began by introducing genesis of anthropogenic climate change phenomena and 120 years of Science of Global Warming, Svante August Arrhenius, known for his electrolytic theory of dissociation hypothesized in 1896 that CO_2 is increasing in the atmosphere as a result of fossil fuel combustion and may be contributing to global warming if use of fossil fuels continues. This was followed by scientific evidence of Global Warming due to increasing CO_2 concentrations. Guy Stewart Calendar in 1938 produced scientific evidence for artificial production of CO_2 and its influence on climate. He predicted future CO_2 levels in the atmosphere.

In late 20th century the global carbon cycle started getting perturbations as a result of increasing concentration of CO_2, which was seen to increase as follows-

Year	Increasing CO_2
• 1980-1995	2.5-3.0 Pg/year
• 1995-2005	3.0-3.5 Pg/Year
• 2005-2015	3.5-3.8 Pg/year

Total CO_2 emission rate was in the range of 6 to 8 Pg/years. There has been global effort to develop Carbon Dioxide Removal Process, which can be grouped as

- Geo-Engineering
- Carbon Capture and Storage

Geo-engineering is the deliberate large-scale intervention in the Earth's natural atmosphere to counteract climate change. It involves use of mirrors in the atmosphere at a certain height for blocking solar radiations to reach the earth.

Carbon Capture, Storage and Utilization is end-of-solution for mitigation of CO_2 concentrations on earth. It has four major components, namely is-

I. CO_2 Capture from Power Plant Flue Gas
II. Absorption and Compression into Liquids
III. Transportation to Storage Sites in Geological and Terrestrial Storage
IV. CO_2 Utilization Chemistry

We can group CCS process in two categories; Engineering Processes and Biotic Processes. Engineering Processes involve Carbon Capture, Underground Injection, Geological storage, Enhanced Oil Recovery and Oceanic Storage

In Geological storage various options are

- Saline aquifers located below fresh water reservoirs separated by a permeable layer are porous sediments filled with water.
- CO_2 is sequestered hydro-dynamically and by reacting with other dissolved salt to form carbonates.
- It form gas like phase and also aqueous phase in dissolve from, creating multi-component environment
- CO_2 injection in oil & gas fields to extract more oils
- CO_2 can be injected into unmineable coal seams where it is absorbed to produce methane

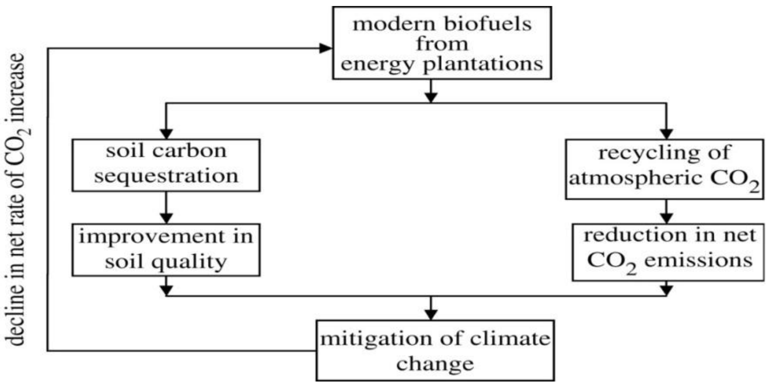
The Biotic Processes category has Terrestrial Sequestration, Carbonate Formation, Ocean Fertilization and Biofuels Production as options.

Biotic (Terrestrial) Processes

- Forests
  - Know rate of CO_2 sequestration in forests
  - how the C-pool is changing from year to year
  - Restoration of degraded forests can help

- Soil C-sequestration
  - Cultivated Soil due to leaching, nutrition depletion and contamination etc. has 50-75% original SOC pool.
  - SOC pools can be enhanced by restoration of degraded soil.
  - Soil rich in calcium and magnesium can sequester CO_2 by formation secondary carbonates in the soil depth.

- Biofuels



Production of Biofuels

(Source- production of biofuels using CO_2, Rattan Lal Phil. Trans. R. Soc. B 2008; 363: 815-830)

CCSU has been globally recognized energy technology and several International studies and global actions have been initiated.

- International Energy Agency future outlook study has predicted that CCS may have a share up to 17% by 2050 in reduction of CO_2 concentrations.
- According to Global CCS Institute 85 CCS demonstrations are currently in demonstrations, construction and planning states.
- In some of these CCS technologies are being demonstrated as promising business models. Carbon Sequestration Leadership Forum CSLF a collaborative R&D project has 23 countries as its member. Under CSLF umbellate a Series of Capacity building programmes have been held supported by World Bank, ADB and other multi-lateral organizations.

Among the Initiatives taken in other Developing Countries the following are worth mentioning

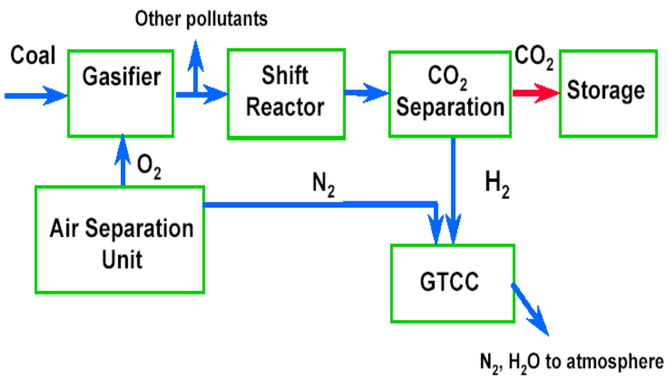
- **China**
    - Five projects are identified in early demonstration stages
    - CCS Roadmap identifies coal chemical sector as largest and lowest cost CO_2 capture opportunity
- **South Africa**
    - A Centre for CCS has come up in the South African National Energy Research Institute (SANERI) in 2009.
- **Maxico**
    - Pilot scale CO_2-EOR and 20 MW Capture projects

In India R&D Initiatives have been taken for developing Screening Criteria for Storage in Saline Aquifers

(i) adequate capacity and injectivity;
(ii) a satisfactory sealing cap rock and confirming unit
(iii) a stable geological environment and;
(iv) Realistic and quantitative information of the characteristics of the subsurface is needed to assess the feasibility of sites.

R&D Studies on Carbon Capture in CSIR laboratories have been conducted with focus on require materials at high temperature and high pressure

- Studies on Carbon Capture started 2006 onwards in CSIR Laboratories, NTPC R&D and Academic institutions
- Thrust has been given to Pre-combustion Carbon Capture in view of cost benefits



In capacity building, Initiatives taken by the Indian Industry to organize Workshops and programmes as follows

- BHEL - DST Workshop on Clean Coal Technology in 2006.
- National Thermal Power Corporation workshop on Carbon Capture and Storage was held in 2011.
- NTPC Round Table on CCS was held at Power Management Institute Noida, in 2012.
- The Bharat Heavy Electricals Ltd., Trichy training workshops on CCT and CCS in 2011 & 2012.
- The BHEL hosts an EU TREC– STEP CCT-CCS cluster for advancement of technologies, in 2012.
- National Fertilizer Ltd (NFL) has adopted Japanese MHI carbon capture technology.
- India's first biotechnology process based carbon sequestration plant has been successfully commissioned on a pilot-cum-demonstration basis in Odisha by leading public sector Navaratna company NALCO in 2015.

The Climate Change Research Institute has been instrumental in organizing a series of Workshops on Awareness and Capacity Building in CCSU with multi-stakeholders participation as follows.

- Awareness and Capacity Building in Carbon Capture and Storage – 27-31 July 2009.
- Awareness and Capacity Building in Carbon Capture and Storage: Earth Processes – 15-19 Jan 2013.
- Awareness and Capacity Building in Carbon Capture, Storage and Utilization: Towards a low Carbon Growth Strategy – 27-31 July 2015.

The Institute is working with a mission to become a Centre for Excellence in developing human resources and technical capacity building in the area of climate change adaptation and mitigation. The current activities include

- To inform youth in schools and colleges about the ecosystem changes and consequences of climate change and through awareness and capacity building on topics of scientific & societal interest such as Energy, Health, Air and water.
- To work with industry, undertake trainings for helping them to meet their Corporate and Social Responsibility (CSR) targets while reducing CO_2 footprints through imparting national and international knowledge.
- To initiate studies/research on scientific & technological measures for stabilizing the greenhouse gas concentrations in the atmosphere.

CO_2 MITIGATION EFFORTS IN NTPC

Sh. Rabi Mukhopadhyay
Additional General Manager
NETRA, NTPC Limited

Sh. Rabi Mukhopadhyay, AGM, NETRA introduced NTPC's efforts towards CO_2 mitigation. He began by introducing Research & Development (R&D) and process development at NETRA, an R&D unit of NTPC. He said waste heat recovery from flue gas is utilized for air conditioning and desalination of sea water helps in reduction of CO_2 footprints.

The work is going on in Solar PV & solar thermal applications. At thermal power plant level, the efforts are being made towards setting up of super critical power plant with lower heat rate & specific coal consumption. The CO_2 emissions are lowered as we go from subcritical to supercritical boilers. In addition efficiency improvement of existing plants and stringent O&M procedures are adopted.

Typical Flue Gas Composition for a 500 MW coal fired power plant is as follows

- CO_2 : 11-12 %
- Moisture : 5-10 %
- Oxygen : 3-4 %
- SOx : 800-1400 ppm
- NOx : 600-800 ppm
- Nitrogen : Balance amount
- Fly ash : 100-150 mg/Nm3
- Temp. : 140-150 °C
- Pressure : Atmosphere

In the area of CO_2 separation & utilization
(i) Pressure swing adsorption process development
(ii) Micro-algae based pilot plant and
(iii) Modified amine based process development are being pursued.

In Pressure Swing Adsorption (PSA) Process Development CO_2 is selectively adsorbed in CO_2 selective adsorbent at 2-3 atmosphere pressure and is recovered at lower pressure. The PSA process & adsorption materials have been developed in collaboration with CSIR labs & IIT Bombay. Typically 85% recovery with 95% purity of CO_2 has been achieved from synthetic flue gas containing 12% CO_2. Shri Mukhopadhyay explained various steps involved in PSA process.

Micro - Algae process for utilization of CO_2, a Joint research project with IOCL R&D has been undertaken. An open pond pilot plant having 50 sq m and 20 sq m pond set at

NTPC power station has been set up. Flue gas was transported from chimney to pond using blower and bubbled through media, in which pH is maintained using flue gas. In this process maximum lipid content obtained was 24%. The findings are that extraction of bio-oil from algae does not appear to be economically viable. Maintenance of open algae pond is difficult – contamination and separation of algae from media is an issue.

PSA Test unit at NETRA

Microalgae Pilot Plant

Some work has also been initiated on modified amine based process development at IIT Guwahati. It requires separation of CO_2 from flue gas.

Major challenges for CO_2 separation from flue gas were summarized as

- Large quantity of flue gas
- Temperature of flue gas - to be cooled below 40-45 ˚C for any separation process
- SOx to be removed as per process requirement
- Particulate matter to be removed
- Additional machineries for desulphurization, gas cooling, gas handling etc. to be installed, which is otherwise not required for Indian power plants

ACBCCS 2015

Technical Session-II

CO_2 Utilization

28.07.15

CLIMATE CHANGE MITIGATION VIA UTILIZATION OF CARBON DIOXIDE

Dr. K. Palanivelu
Director, Centre for Climate Change & Adaptation Research
Anna University, Chennai

Dr. K. Palanivelu, Director CCCAR, Anna University presented world CO_2 emissions scenario from industrial activity worldwide. The Carbon dioxide emission has to be efficiently controlled due to environmental, economic and social demands. Among the various technology, gas absorption technology is of great importance for the capture of CO_2 and to prevent global warming. The results of CO_2 capture process using Gas Permeation technology having ceramic supported polymer-amine blend membrane were discussed. With the membrane comprising of polyvinyl alcohol and Triethylene tetramine [TETA], maximum CO_2/ N_2 selectivity of 50 could be achieved.

Table 1: Worldwide large stationary CO_2 sources from industrial activity with emissions of more than 0.1 Mt CO_2 per year

Process	Number of sources	Emissions ($MtCO_2$ yr^{-1})
Fossil fuels		
Power	4,942	10,539
Cement production	1,175	932
Refineries	638	798
Iron and steel industry	269	646
Petrochemical industry	470	379
Oil and gas processing	N/A	50
Other sources	90	33
Biomass		
Bioethanol and bioenergy	303	91
Total	7,887	13,466

Talking on future emissions Dr. Palanivelu said that Global CO_2 emissions would range from 29 to 44 $GtCO_2$ (8-12 GtC) per year in 2020 and 23 to 84 $GtCO_2$ (6-23 GtC) per year in 2050. Existing coal-fired power plants emit about 2 million tons of CO_2 per year. He said CCS refers to the sequestration of CO_2 from the other components in the flue gas or process stream of a power plant or an industrial facility. For separation of CO_2 from mixture of gases in the flue gas, Membrane Separator, CO_2 Absorption Reactor and Electro Chemical Reactor have been designed.

CO_2 Absorption Reactor and Electro Chemical Reactor in the laboratory are depicted below.

CO_2 Absorption Reactor **Electro Chemical Reactor**

Dr. Palanivelu said that CO_2 Utilization is an answer to economic and environmental challenges being faced due to global warming. It is environmentally friendly, as it eliminates "Storage" issues. The opportunities in existing and emerging application areas of CO_2 conversion and utilization were discussed. He described vast scope of CHEMICAL PROCESSES for CO_2 conversion and presented technical approaches to CO_2 utilization. Conversion required concentrated CO_2 sources for CO_2 capture and/or utilization; aim for on-site/nearby uses. If possible CO_2 is utilized to replace hazardous or less-effective substances in existing chemical processes for making products with significant volumes.
Research directions on CO_2 conversion & utilization were summarized as below.

(i) For applications that do not require pure CO_2, develop effective processes for using the CO_2-concentrated flue gas from industrial plants or CO_2-rich resources such as CO_2-rich natural gases without CO_2 separation.
(ii) For applications that need pure CO_2, develop more efficient and less-energy intensive processes for separation of CO_2 selectively without the negative impacts of co-existing gases such as H_2O, O_2, and N_2.
(iii) Hazardous or less-effective substance in existing processes with CO_2 conversion can be replaced by an alternate medium or solvent or co reactant or a combination of them.
(iv) CO_2 based on its unique physical properties as supercritical fluid can be utilized as either solvent or anti-solvent.
(v) CO_2 based on its unique chemical properties can be incorporated with high 'atom efficiency' such as carboxylation and carbonate synthesis.
(vi) Useful chemicals and materials using CO_2 as a reactant or feedstock can be produced.

(vii) CO_2 can be used for energy fuels recovery while reducing its emissions to the atmosphere by sequestration.

(viii) CO_2 as C-source for chemicals and fuels can be recycled using renewable sources of energy.

(ix) CO_2 under either bio-chemical or geologic-formation conditions can be converted into ‘‘new fossil’’ energies.

Related CO_2 mitigation processes such as Carbon dioxide (CO_2) Fertilization and Sea weed production were highlighted. Enhanced photosynthesis occurs with increased atmospheric *carbon dioxide* concentration, in plants that produce a three-carbon compound (C3) during photosynthesis—including most trees and agricultural crops such as rice, wheat, soybeans, potatoes, and vegetables. These generally show a larger response than plants that produce a four-carbon compound (C4) during photosynthesis, mainly of tropical origin, including grasses and the agriculturally important crops maize, sugar cane, millet, and sorghum.

Utilization of CO_2 as an industrial by-product for seaweed production holds great promise not only in acting as a significant atmospheric sink for CO_2, but also in meeting to some extent global food, fodder, fuel and pharmaceutical requirements, particularly in the tropics. A number of Biological products can be derived from them, such as agars, alginates, have and will continue to have diverse applications in the food, chemical, pharmaceutical and other industries. The utilization of seaweed colloids in the industry remains to be one of the more exciting aspects of the world seaweed production.

The following Conclusions were made.

- ❖ CO_2 utilization can significantly help with our climate problems.
- ❖ The separation and conversion of CO_2 into fuels and chemicals have been assessed in terms of its chemical stability.
- ❖ Since CO_2 is a thermodynamically a very stable molecule in a high oxidation state its reuse often requires the input of energy and/or the use of hydrogen for chemical conversion
- ❖ Current industrial use of CO_2 is 2-3 orders of magnitude lower than the net anthropogenic CO_2 emissions
- ❖ Carbon dioxide can be a valuable precursor to a number of commercially valuable compounds. Commercially valuable chemical compounds can be synthesized (with catalyst) from CO_2 to aid in the deferment of the expense of carbon capture and sequestration.
- ❖ CO_2 utilization is an integral part of carbon management

Nature makes, Sustainable approach re-shapes !

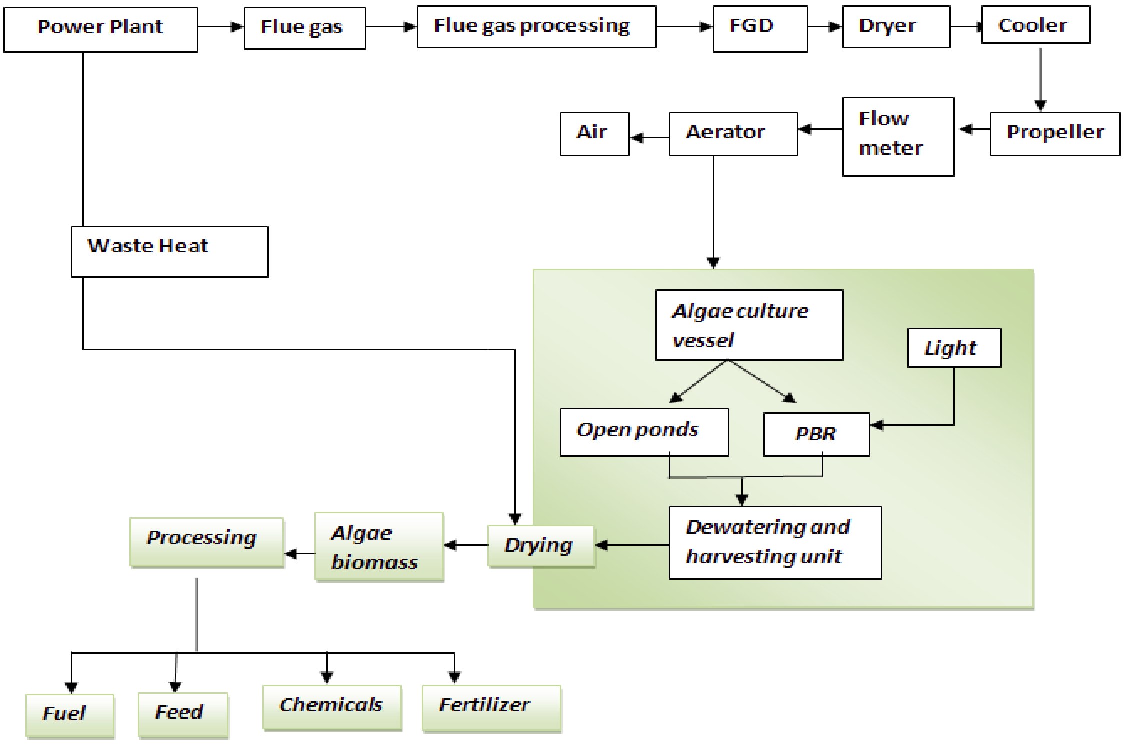
MICRO ALGAL CARBON SEQUESTRATION FOR CARBON DIOXIDE FIXATION IN INDUSTRIES

Dr. K. Sudhakar
Assistant professor /Department of Energy
Maulana Azad National Insitute of Technology, Bhopal, India

Dr. K. Sudhakar, MANIT Bhopal presented an overview of carbon capture and storage techniques. He described the work being done at in this area at MANIT and informed that subsequent to his participation in ACBCCS 2009, he completed his doctorate at NIT, Trichy and joined MANIT, Bhopal. He said that inspired by ACBCCS 2009 a new course on Green Technology has been started at MNIT, in which CCS has been included. The Proceedings of ACBCCS 2009 published as a Book on CO_2 Sequestration for Clean Energy came handy.. In fact MANIT is first to initiate a formal course on CCS technologies in the country.

Dr. Sudhakar explained proposed CO_2 sequestration system through an Algal farm.

Micro Algal Farm



Micro algae biomass production: can be computed using the equation

$$BM_{production} = \frac{\eta_{Transmission} \times \eta_{Capture} \times H_s}{E_{Micro\ algae}}$$

Where
$BM_{production}$ = Micro algae productivity in kg/m^2/year
$\eta_{transmission}$ = Efficiency of light transmission to micro algae
$\eta_{capture}$ = Efficiency of conversion of Incident sunlight to biomass in micro algae
H_s = Solar Irradiance falling on a horizontal surface (kWh/m^2/day)
$E_{micro\ algae}$

For computing Micro algae Lipid production, the following formulae is used

$$MO_{production} = \frac{f_L \times BM_{production}}{\rho_L}$$

Where
$MO_{production}$ = lipid productivity from micro algae (l/m^2/year)
f_l = micro algae lipid fraction usable for biodiesel
$BM_{production}$ = micro algae productivity in kg/m^2/year
ρ_l = density of lipids usable for conversion to biodiesel (g/l)

He described computations for energy stored in biomass; Transmission efficiency of sunlight to micro algae, Solar energy capture efficiency and Photon utilisation efficiency (Bush equation). The optimum values of parameter used in these equations were taken from literature or some assumptions were made. The biomass and oil yield are presented in Table.

Table: Biomass and oil yield

Variable	Site 1 (Chennai)	Site 2 (UNA)
Hs (kWh/m^2/day)	5.157	5.321
$\eta_{transmission}$	0.432	0.432
$\eta_{capture}$	0.216	0.216
$E_{Micro\ algae}$ (kJ/g)	23.62	23.62
$BM_{production}$ (g/m^2/day)	73.3	75.7
$MO_{production}$ (ml/m^2/day)	34.5	35.6

Results of the present model suggest that maximum algal biomass productivity is to be expected at a level of 345 T/ha/yr. He summarized the results of the model as follows.

I. The daily biomass productivity predicted by the model varied between 53 – 115 g/m^2/day. Highest productivity can be expected in parts of Rajasthan and lowest in parts of North eastern states. However average productivity of 80g/m^2/day may be possible in most parts of India.
II. The annual oil yield predicted by the model varied between 59000 – 162000 L/ha/yr. The results show an average potential of 60 g/m^2/day in most parts of India

III. Assuming oil content of 20 % of the algal biomass and for the consequent lower biomass productivity, a considerable potential of 80,000 L/ha/yr could be provided by microalgae derived bio fuels.

IV. To produce 13.4 million tonnes biodiesel as per national target of 20% blending, 48 million tons of biomass needs to be produced. Based on our estimates of algal biomass yield, only 0.2 million hectares land is required which is just 0.06 % of the Indian land area.

V. Huntley projected Annual average productivity of 50g/$m^{2/}$day for Hawaii condition (Huntley.M.E. et.al, 2007). Slightly lower values of 20g/m^2/day have been reported for small scale pilot pond system at Israel (Ben Amotz, A.2009). Sheehan et al., 1998, reported an average productivity of 30 g/m^2/day for a large open pond system.

VI. The annual biomass and oil yield calculated by the present model based on the solar energy available at the site and various loss factors matches with the other literature data.

This work provides new quantitative support to researchers working on micro algae bio-fuel and also a useful model for predictions of algae biomass potential in any regions of the world. The values obtained from the study can be used for optimizing parameters for maximum oil production and could be of great benefit for the evaluation of large scale algal mass culture system.

In view of the challenges being faced in CO_2 storage in terms of environmental risks involved in the storage of CO_2 particularly in geological formations and oceans have to be evaluated in detail by monitoring and modeling for long term stability. Carbon sequestration has potential for great societal benefits. Carbon sequestration using microalgae may be one of the more sustainable methods.

This study assesses the energy and carbon balance of an algae biodiesels process which does not exist at this stage at industrial scale, and for which many technological issues remains unsolved. More refined methods for harvesting, lipid extraction, and transesterification, and advances in bioreactor technology would surely improve the energy balance in biodiesel production and make it commercially viable. The last stage, the recycling and disposal of residual biomass, provides the greatest opportunity for the largest gain in energy. This stage allows for creativity in research because the residual algal biomass has many useful applications. Omega-3 and omega-6 fatty acids extracted for vitamin supplements are potentially more valuable than biodiesel. The profit from selling these extra compounds could be used to help offset the energy cost of biodiesel production. Finally, it was concluded that

(i) Continuing research is sure to bring about further breakthroughs, particularly in the field of carbon capture

(ii) Institutions, Industries, R&D organizations, Governments, societies, and individuals need to work toward a solution for today and tomorrow

(iii) Climate change policies shouldn’t be all or nothing: while carbon sequestration isn’t *the* answer, it is *an* answer

LONG TERM MICROBIAL CARBON SEQUESTRATION OPTIONS FOR ENHANCED CO_2 UTILIZATION

Prof. T. Satyanarayana
Department of Microbiology
Delhi University- South Campus, New Delhi

Prof. T. Satyanarayana, in his presentation described biological systems at work using carbonic anhydrase. Carbonic Anhydrase catalyzes the reversible hydration of carbon dioxide in the following reaction

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$$

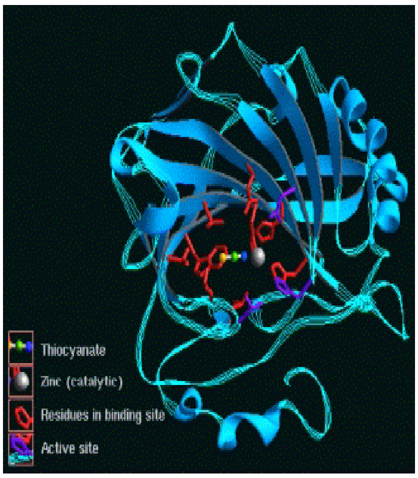
Classes of Carbonic Anhydrases are**:**

- α-class – mammalian carbonic anhydrases
- β-class – plant and bacterial carbonic anhydrases
- γ-class – carbonic anhydrase of *Methanosarcina thermophila*
- δ-class – carbonic anhydrase of *Thalassosira weissflogii*
- ε-class – carboxysomal shell protein, CsoS3, from *Halothiobacillus neapolitanus*

Carbonic anhydrase (CA, EC 4.2.1.1) is among one of the fastest enzymes known that catalyses the reversible hydration of carbon dioxide into bicarbonates.

The Bio-mimetic sequestration of carbon dioxide can be explained by the following equations

$$E\text{-}Zn^{2+}\text{-}OH^- + CO_2 \leftrightarrow Zn^{2+}\text{-}HCO_3^- \qquad (2a)$$
$$Zn^{2+}\text{-}HCO_3^- \leftrightarrow E\text{-}Zn^{2+}\text{-}H_2O + HCO_3^- \qquad (2b)$$
$$\left.\begin{array}{ll} E\text{-}Zn^{2+}\text{-}H_2O \leftrightarrow H^+\text{-}E\text{-}Zn^{2+}\text{-}OH^- & (2c) \\ H^+\text{-}E\text{-}Zn^{2+}\text{-}OH^- + B \leftrightarrow E\text{-}Zn^{2+}\text{-}OH^- + B\text{-}H^+ & (2d) \end{array}\right\} \text{Rate limiting steps}$$



Carbonic Anhydrase

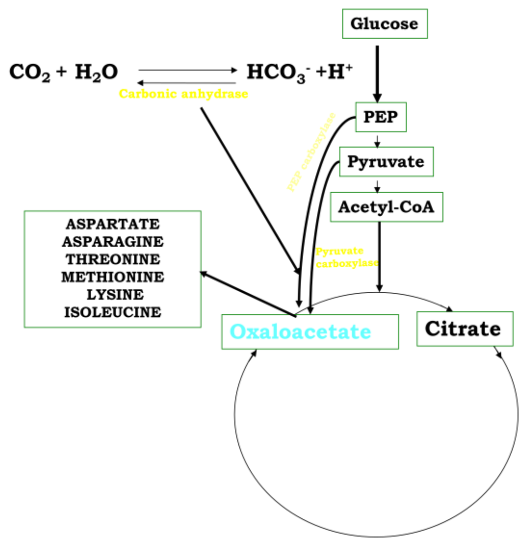
Structure of active site of α-CA

Bio-mimetic sequestration system offers several advantages, including:

- Avoidance of cost intensive CO_2 concentration and transportation steps
- A safe, stable, environmentally benign product
- An environment-friendly process, performed in aqueous solution at near ambient temperatures
- A site-specific solution to CO_2 sequestration

Alkalistability and Thermostability are desirable characteristics for an ideal CA to be used for carbon sequestration. They are dependent on composition of flue gas. Biocatalysts have several advantages over conventional chemical catalysts.

- High-grade catalytic efficiency
- High degree of specificity
- Substantially higher reaction yields
- Substantial process energy savings and reduced manufacturing costs
- No disposal problems, since they are biodegradable and easily removed from contaminated streams



Simplified TCA Cycle Showing Anapleurotic Sequence

Effect of CO_2 on the growth and enzyme production

CO_2 (%)	Glucose consumption (gL^{-1})	Extracellular CA production (Uml^{-1})	Intracellular CA production (Ug^{-1})	PEP Carboxylase (mUg^{-1})	Biomass (gL^{-1})
0.03	6.56	3.14	32.3	71.4	2.87
2.5	3.28	0.94	8.82	85.7	1.44
5	2.63	0.51	5.42	92.9	1.01
10	**1.97**	**0.32**	**1.12**	**105.0**	**0.84**

Increase in Carbonic Anhydrase Production

Approach	Extracellular CA production (Uml^{-1})	Fold improvement	Intracellular CA production (Ug^{-1})	Fold improvement
Unoptimized medium	0.52	1	8.9	1
Optimized medium	3.25	6.25	30.5	3.4

Characteristics of carbonic anhydrase

Enzyme characteristic	Respective values
V_{max}	7.5 mmol mg^{-1} min^{-1}
K_m	3.75 mM
Optimum temperature	55°C
Q_{10} value	2.13
Thermostability in terms of $T_{1/2}$ values	1.7 hours at 50 ^{o}C 1.5 hours at 55 ^{o}C 19 minutes at 60 ^{o}C.
Optimum pH	9.0
Molecular mass	29 kDa

Prof. Satyanarayana also presented attempts for reaching the recombinant enzyme and results of amplification of V-CA. Comparison of sequestration efficiency with other microbial carbonic anhydrases was made

Comparative Sequestration Efficiency with other Microbial Carbonic Anhydrases

Source of CA	$[HCO_3^-]$ (mM)	$[CaCO_3^-]$ (mM)	Precipitation time (s)
Bacillus pumilus TS1	30.4	27.5	24
Bacillus subtilis	19.7	13.3	56
Corynebacterium glutamicum	14.2	12.7	47
Escherichia coli K12	07.7	4.4	44
Sporosarcina pasteurii	25.9	21.1	48
Bovine CA (Sigma, USA)	34.3	30.2	19

SE* [HCO3$^-$], sequestration efficiency in terms of bicarbonate formation
SE† [$CaCO_3$], sequestration efficiency in terms of cation utilization

From studies carried out on application of CA in CO_2 sequestration in his laboratory and elsewhere the following conclusions were drawn

1. Microbial enzymes such as carbonic anhydrase can be employed in mitigating CO_2 by carbon sequestration.
2. Microbes can be used in carbon sequestration leading to the production of lysine, melanin and hydrogen.
3. Microbes can be employed in producing methane and other hydrocarbons.
4. Microbial calcite has been shown to act as a sealing agent for filling the gaps or cracks and fissures in constructed facilities and natural formations.
5. Conversion of CO_2 to hydrocarbons and biofuels is desirable for long term utilization.

ACBCCS 2015

TECHNICAL SESSION-III & IV

Industry Perspectives

29.07.15

EFFICIENCY IMPROVEMENT STRATEGIES: ENERGY INDUSTRY

Dr. Ajay Mathur
Director General, Bureau of Energy Efficiency (BEE)

At the outset Dr. Ajay Mathur said that he shall begin with the thought that how would we see the industrial sector grow and more particularly how do we see accelerated growth in energy efficiency implement? He described background to the discussions that have been held regarding Perform, Achieve and Trade (PAT) programme which has just completed in 2015 its First Cycle. To recapitulate what was seen in the Indian industrial sector was that no matter which energy intensive sector (energy intensive sector is defined as a sector where energy cost are at least 20 percent of the total cost) was considered, one of the first thing was that in every sector there were among the world most energy efficient plants. At the same time there was also a plant which used two or three times more energy. In case of Pulp & Paper four times the energy was consumed in production of paper in some cases. Similar was case with steel, iron or cement etc. The public policy problem as a starting point was that efficient plant and non-efficient plants co exist. Most importantly since energy efficiency plan which is win-win for the plant is good for the consumers as well, something should happen and inefficient plant should disappear.

As we spoke to the industry we learnt two things; first was in a growing India demand for all commodities is increasing like cement, steel, fertilizers etc. So really plants whether efficient or non efficient are not going out of business. In fact there are new plants that need to be set up all the time. The older plants using more energy to producing say steel, textile etc. could continue to remain in business because of depreciation they got and were essentially competing on the cost basis. Whereas new plants would have to complete both in the form of depreciation in capital cost as well as operating cost.

Then come second question, how to be beneficial by becoming more efficient. The prices of energy that Indian industry incurs are about the most expensive in the world. Around the world, bulk consumers get energy at lower prices. But in India for variety of reasons industry get it at much higher prices. In the existing situation what is the motivation for plants to become more efficient by themselves. Industry had at least three choices so that they could make some money. They can either use it to enhance energy efficiency, expecting good return in a growing market. They could use it to expand capacity which makes great sense. As demands are increasing they could get even higher rates or they could invest in something else. Many plants had to be closed with Government of India norms for energy consumption industry up to 2015. To follow these norms every plant had to reduce specific energy consumption. There were nine designated sectors in all.

In the next cycle of PAT there will be these 473 units in all sectors with new plants coming up. These will be about 600 plants. Some new sectors would be added, which includes electricity distribution companies, refineries and probably Railways (zonal railways). By including these, total coverage of social impact of the scheme would be more than 50% of the total energy consumption in the country. The first draft of the second cycle would be available by September and industry would be expected to notify before March every year their targets to be met in next three years cycle.

Generally speaking the sectors that had already been covered by PAT, specific energy consumption by 2020 (i.e. over four or five year period) should come down by more than 10-12 percent on an average. It could be more for some sectors for example; for Pulp and Paper. Cement is already pretty good so amount of saving would be relatively less. Alternative fuels are can come up so as to reduce fossil fuel consumption, which in turn would reduce CO_2 emissions further.

Next challenge is the norms for new sectors viz.; Refineries, Electricity distribution companies and Railways. In case of Electricity Distribution Companies, there are a large number of supply side options that have been provided to help them to become better. Integrated power development scheme which provides financial support to utilities to enhance their physical infrastructure losses to come down and the measurement infrastructure so that the billing can also increase. Regulation in the PAT to be such that on one side resources can be provided and on other side the targets that are required can be met.

In the case of Refineries, there is a rather well developed processes for Measurement and Verification. Challenge is that there are three different sections of measures that are used across the Indian refineries for measuring and normalizing the complexity. Not every refinery is the same and therefore how do we compare the losses they incur on every tone of crude they process. Challenges are being addressed in consultation with Centre for High Technology, Ministry of Petroleum & Natural Gas.

In case of Railways, we are looking at amount of the energy that is used per gross ton of kilometre travel. The gross ton kilometre has been measured and electricity that is used has been measured. Diesel consumption is also known. There have been large debate whether electricity and diesel can be used separately or together in the regulations.

We are looking at energy efficiency increase or specific energy implementation decrease of approximately 1½ to 2% in the year 2020 and more than 1% in the year beyond 2020 to 2030. This obviously implies that as the industry grows the carbon dioxide emission would be increasing though the trajectory of increase would become progressively lower. One of the challenges, we have to see what happen as far as on site CO_2 emissions are concerned. One of the scenarios we wonder in future may be five years from now that all plants grids to be connected and consumer get reliable electric supply that they need. Oxy fuel combustion technology also appears promising as it would increase efficiency, save water and provide CO_2 rich flue gas which can be directly utilized.

AQUEOUS NH_3 IN CO_2 CAPTURE FROM COAL FIRED THERMAL POWER PLANT FLUE GAS: N-FERTILIZER PRODUCTION POTENTIAL & GHG EMISSION MITIGATION

Dr. Amitava Bandyopadhyay
Associate Professor
Department of Chemical Engineering, University of Calcutta

Dr. Amitava Bandyopadhyay, University of Calcutta began by introducing CO_2 Capture Value Chain for a thermal power plant, The CO_2 Capture Methods are;

- Absorption [in liquids]
- Adsorption [in dry sorbents]
- Membrane based Separation
- Hybrid (combination of above)

Current literature revealed that the growth in world wide patents in Absorption, Adsorption and Membrane separation is 37.5%, 35.5% and 27.0% respectively up to 2012 in CO_2 capture processes.

Countrywide patent data and publications have also been studied. Genesis of amine based capture and important considerations for development of capture process were summarize; maturity of CO_2 capture method/technology, contaminants present in the flue gas, cost & availability of utilities and regulatory requirement/environmental are important considerations.

Amine based processes are well developed but awaiting cost-effective large scale applications. Key requirements of MEA based CO_2 Capture Plant are;

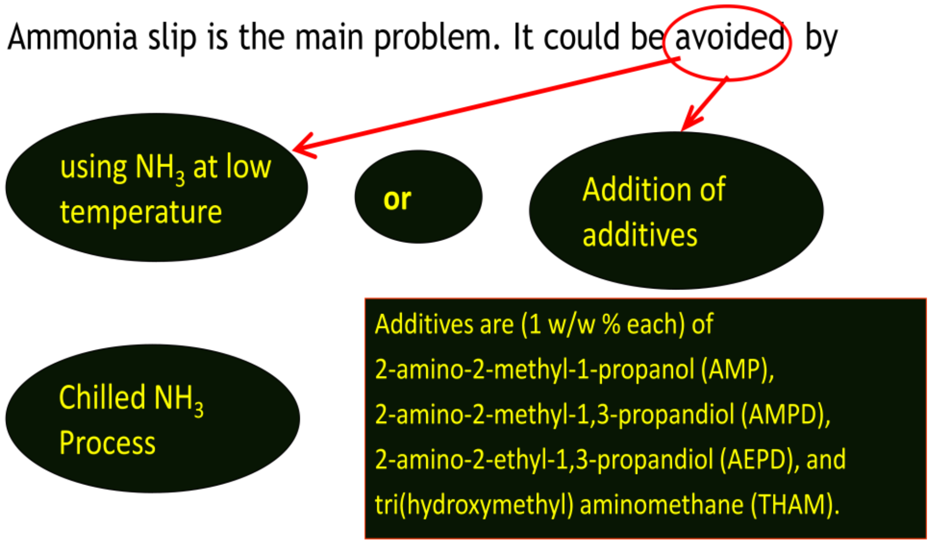
Flue Gas should have

- SO_2 : 10–30 mg/Nm^3
- NO_2 : 40 mg/Nm^3
- Particulate Matter: < 5 mg/Nm^3
- Larger Space and Larger Heat Duty

As these parameters in the flue gas differ considerably in actual plants, thus pretreatment of flue gas to qualify for Amine Absorption system for CO_2 Capture is required. In addition, the problems of Amine Absorption system for CO_2 Capture remain as;

- Solvent loss [Heat stable salt & Oxidative degradation]
- Corrosion problems [Inhibitor required]

Developments of NH_3 based CO_2 Capture process was presented with a vast scenario of applications of NH_3 based CO_2 capture in the Integrated Iron & Steel Industry, which has considerable CO_2 emissions. Initial studies have suggested major issue for commercialization of aq. NH_3 based CO_2 capture is ammonia slip.



Major issue for commercialization of NH_3 based CO_2 capture

Low energy Tapered Bubble Column has been investigated in recent years for studying hydrodynamics, interfacial area of contact & dust laden SO_2 removal. The same system could be an interesting option for investigating CO_2 capture. The system developed is energetically highly favorable than other bubble column reactors. A comparison of amine vs aq. NH_3 based CO_2 capture process, suggested benefits than can be accursed in NH_3 – CO_2 process.

In conclusions, he said that amine based systems have certain deficiencies and serious problems. A NH_3 based process is better than Amine based process due to following reasons:

(a) Showed better performance than amine based processes
(b) Ammonium bicarbonate & other products from NH_3 scrubbing can be put into soil
(c) The multi-pollutant capture capability is unique
(d) Life cycle analysis seems very encouraging
(e) Attractive process in weaker economies

Dr. Bandyopadhyay also presented an outline of a multi-sectoral program with scope of R&D in India for a NH_3-CO_2 process for consideration of Government of India. It was recommended that the NH_3 based CO_2 capture process may be further explored through R&D in India.

CARBON MANAGEMENT – STEEL INDUSTRY PERSPECTIVE

Dr. Supriya Sarkar
Head Environmental Research, Tata Steel Limited
R&D and Scientific Services Dept., Jamshedpur

Dr. S. Sarkar, Tata Steel, began by introducing how industries can participate in CO_2 emission reduction and described energy regulation processes. He said R&D Tata Steel has more than 75 years experience of R&D in the industry under the leadership of eminent steel industry experts like Mr. Rata Tata, Dr. J. J. Irani. There are total 13 groups working in different fields from raw materials to finish products. There is large collaboration with institutions in India and abroad. Most of the IITs, universities and institutions are covered under this collaboration. Tata steel is also nominee to the World Steel Association.

Tata Steel has focus on greenhouse gas emissions control, water conservation research, solid waste utilisation and life cycle assessment analysis in these collaborations. Different areas of research work to find out solutions of environment concerns in the integrated steel plant are:

(i) Different sources of carbon dioxide is associated with steel industry
(ii) Motivation of reduction of CO_2 emissions
(iii) Strategies of the capture of CO_2 emissions.

The presentation based on initiatives taken in Steel Industry covered the topic of CO_2 capture. As steel industry starts from Mining to Finished products, it is called the Steel Integrated Industry. Tata is a steel integrated industry. In fact more than 35 areas exist for CO_2 reduction opportunity in steel industry because of complexity of the processes. First process is iron making process. In which Blast Furnace uses coke and Tata Steel has achieved great success in coke oven process. This is an area where huge amount of ammonia liquor is generated and CO_2 is also generating. H_2O is 50-51%, rest is carbon dioxide, carbon mono oxide and methane. The technology which is available from abroad may not be applicable directly and require research for its adaption.

Individual processes for major sources for CO_2 are, first is Blast Furnace gas, second is the lime plant and third is the power plant. Steel industry first step should be technology to be adopted to reduce the emission of CO_2 rather than absorption of CO_2 or capturing CO_2. The steel industry consumes coking coal that has 13-14 percent ash content. Indian coal is very high ash content and therefore most of the low ash content coal is imported. Initiatives have been taken to reduce ash content in Indian coal not only be physical method but also by chemical method. Super refining chemical method was tested for reduction of ash content.

Ash content reduction contributes indirectly to reduction of CO_2 emission. A pilot plant for leeching of the coal or organic extraction of the coal has been built.

Industry is also looking at how to utilize BF CO_2 gas with algae conversion route into methanol. This process technology is right now available. Government permission and other formalities are awaited. Steel plant is also using LD slag in combination with coke gas to form methane. It increases the calorific value and has scope for using it as fuel.

Both recovery and non recovery coke oven plants have been built. Better technology is a non recovery as the gases which are generated in conversion from coal to coke can be entire used as energy. Tata Steel has a coke oven non recovery plant in Haldia. In Jamshedpur. The recovery coke plant materials like sulphur are produced and its recovery is required. Steel plant had recovered ammonium sulphate earlier but right now most of the steel plants are not using ammonium sulphate.

Optimization in the coke consumption in blast furnace and using gaseous fuels in place of coal are other options for CO_2 emission reduction. Optimization of fuel consumption can be both in the lime plant and in the coke plant. It is big challenging area. Maximum utilization of coke gas and LD gas for heating purposes is being attempted.

Other important issue in steel plants is that there is huge amount of water requirement and in water huge amount of TDS is present. Steel plants use carbon dioxide purging into the some of the water purifiers/calcinator to convert the dissolve calcium and magnesium into the calcium carbonate and magnesium carbonate. Most of the steel plants purchase CO_2 for purging water because in some of the area you cannot use other chemicals. This is an area which need to be further explored for utilizing CO_2 emitted in the plant for purging to reduce the TDS in the water.

Thank you!

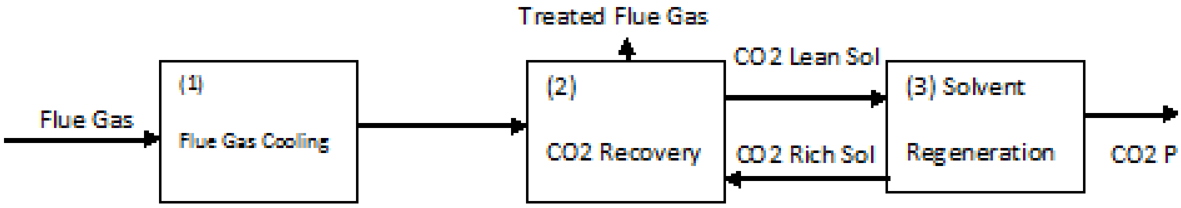
CARBON CAPTURE IN FERTILIZERS INDUSTRY

Shri Nirmal Jit Singh
Chief Manager (P), National Fertilizer Ltd., Vijaipur

Shri Nirmal Jit Singh, National Fertilizer Ltd., introduced the climate change occurring due to emission of Green House Gases (GHGs). He said that on per capita basis though India is among lowest emitter of Green House Gases at 1.4Te CO_2 per person against global average of 4.5Te CO_2 per person as per survey conducted in 2010, yet India is highly vulnerable to climate change, which manifest in the form of climate extremity and natural disasters. Low-carbon development seeks to promote economic development while keeping GHG lower than without interventions. The ultimate aim of a Low-Carbon Development Strategy (LCDS) is to catalyze concrete actions that support development, but with less emissions than without intervention. The term LCDS is used to describe strategies that reconcile development and mitigation, only including adaptation technologies that do have a mitigation component.

National fertilizers Ltd., a Public Enterprise has made a contribution to fulfill the promise of India to International community by installing a Carbon Dioxide Recovery (CDR) Plant from the flue gas Stack of Primary Reformer Furnace of Ammonia Line-I Plant at their NFL Vijaipur Unit. This is in line with the goal to bring down the emission intensity of its GDP by 20-25% over 2005 levels by the year 2020. The NFL Vijaipur unit is located on HBJ pipe line, having 02 nos. of Gas based Ammonia and Urea Plant, commissioned in 1987 and 1997 with original Plant capacity of 1350MTPD of Ammonia each, which has been enhanced to 1750MTPD and 1864MTPD respectively in March-May-2012. Natural Gas which contains mainly Methane, Ethane and CO_2 is processed in Primary Reformer tubes filled with Nickel based catalyst through an endothermic reaction, for which required heat of reaction is supplied through 576 nos of Natural Gas fired burners of Primary Reformer furnace and the flue gas thus generated containing approx 9.0 to 9.6% CO_2 by volume goes to Stack, as a green house gas.

Keeping this in view a Carbon Dioxide Recovery Plant (CDRP) having capacity 450MTPD of CO_2 on dry basis designed by M/s MHI Japan was setup and commissioned in April-2012 successfully and is in operation on continuous basis since then. The objective of setting up of CO_2 recovery Plant was not only to utilize additional CO_2 from CDR Unit to increase Urea Production without carrying out any modification but also explicitly reiterates NFL`s commitment to check climate change and its contribution to fulfill promise of India to world community.



ACDR Plant

The process was explained in detail. Sh. Singh said Absorbent solvent is available in market as KS-1 Solvent, and is available as 70% Solvent. The recommended concentration to be maintained in circulating KS-1 is 48-50%. The cost of KS-1 Solvent keeps on varying depending upon the international market price of Naphtha (Rs440/ Litres). The reaction of absorption in CO_2 Absorber is exothermic in nature so the flue gas at approx 140 deg C (with 9.6% CO_2 by vol) from the stack of the furnace of Primary Reformer is cooled first to 40 deg Cl through a flue gas blower in an quencher prior to sending it to CO_2 Absorber.

The CO_2 Absorber has broadly two sections, CO_2 absorption section in the lower part and the treated flue gas washing section I (Ist wash & IInd wash) in the upper part. The cooled flue gas from the flue gas quencher is introduced into the bottom section of the CO_2 Absorber through blower. The flue gas moves upward through the packing, while the lean KS-1 Solvent is distributed on rising flue gas the rich Solvent of KS-I (with absorbed CO_2) is pumped to solvent regeneration system to make KS-1 Solvent lean by heat stripping of soln. The Flue gas from Absorber carries with it small quantity of KS-1 Solvent and is washed in the wash section just located in the upper part of the Absorber.

The CO_2 loaded rich KS-1 solvent from the bottom of CO_2 Absorber is pumped through solvent heat exchanger and is steam stripped (Steam at 3.5 Kg/cm2) and CO_2 is removed. The lean KS-1 Solvent at the bottom of regenerator at 115 deg cel is further cooled and sent to CO_2 Absorber. The CO_2 bearing vapor at 95 deg cel at top of the regenerator is cooled to 40 deg cel in CO_2 condenser and sent to Urea Plant for Urea Production. The condensate thus separated is returned to top of Absorber and regenerator and also used in the KS-1 Reclamation procedure.

The SOx and NOx present in Flue gas are stronger acid than CO_2 and react with KS-1 Solvent in the CO_2 Absorber and form Heat Stable Salts (HSS). The accumulation of HSS causes the solvent foaming and degrades it. The recommended maximum level of HSS in KS-1 Solvent is 2% (Wt) besides due to corrosion Iron contents in circulating KS-1 Solvent keeps on increasing. The upper limit of Iron is 5ppm. If these impurities (HSS and Iron) are allowed to be accumulated in circulating KS-1 Solvent, then this will lead to foaming and corrosion. Foaming to some extent is controlled by dosing Antifoam agent. Further to keep check on HSS and Iron level, side stream carbon filtration is kept in line on continuous basis. Appox 10% of total circulation of KS-1 is passed through Carbon filter on continuous basis also.

Even if HSS and Iron goes beyond the recommended value, reclamation of KS-1 Solvent has to be carried out by boiling out the KS-1 Solvent in separate reboiler so that HSS contents are concentrated and Iron settles down at the bottom of Reboiler and is subsequently discarded. The Reclaimer (Reboiler) operates as a simple batch distiller. The reclaimed waste sludge contains Na_2CO_3 (10-10.5 wt %.), $NaNO_3$ (2.4 wt %), (COONa) 2 (0.2 wt %), Na_2SO_4 (10.6 wt %), organic compounds (45 wt %) and amines (balance). The reclamation is carried out by adding calculated quantity of caustic in advance followed by injecting KS-1 Solvent and reflux condensate to reclaimer in the ratio of 1:3. It takes 4-5 days for the reclamation batch process; if the desired results are not achieved then the reclamation procedure is repeated immediately after discarding the sludge of reboiler.

Shri Nirmal Jit Singh concluded by saying that the CDR Plant having capacity 450MTPD designed by M/s MHI consumes 0.24Kgs of KS-I Solvent per tonne of CO_2 produced. The corrosion tendency looms large but can be kept under check by keeping the KS-1 Solvent clean and the level of HSS and Iron with in recommended values and with proper selection of material. Besides CDR Plant has not only reduced the emission of CO_2 gas (Green House gas) from NFL Vijaipur complex, but has increased the Urea Production capacity also.

LOW CARBON GROWTH STRATEGY FOR INDIA BASED ON OXY-COMBUSTION CARBON CAPTURE & CO_2 UTILIZATION FOR ENHANCED COAL BED METHANE RECOVERY

Mr. Thomas Weber
President, Jupiter Oxygen Corporation
USA

Mr. Thomas Weber began with a brief introduction of Jupiter Oxygen Corporation. He said Clean Energy Technology Solutions are Key for Sustainable Development. Carbon Capture, and Storage and Utilization [CCSU] technologies offer an essential solution to clean up the existing coal power plant fleet, as well as newly build plants. It is also the only viable mitigation option to decarbonize the production of commodities such as iron, steel and cement. He said Bioenergy carbon capture and storage [BECCS] appears to be the only currently available technology capable of delivering large-scale negative CO_2 emissions.

A CO_2 pipeline infrastructure transporting CO_2 from anthropogenic CO_2 sources [power plants, industrial plants] to CO_2 utilization sites will help to effectively enhance; for example, domestic oil [EOR] and coal bed methane [ECBM] recovery, thus reducing costs of carbon capture technology implementation. With that, CCSU technologies provide strategies to responsibly manage the challenge of massive global fossil energy consumption even beyond 2040, controlling related CO_2 emissions as well as air pollution. The CO_2 Utilization options can be summarized as

► Enhanced oil recovery [EOR]: 40 years+ experience in USA
► Enhanced coal bed methane recovery [ECBM]: pilots in Canada, USA, China
► Algae production from CO_2 / algal biomass/fuel industry
► "Frozen methane": submarine gas hydrates

The solution is therefore turning carbon into a commodity. CO_2 market opportunities exist worldwide and from EOR US expects a range of 1.6 – 4 barrels of additional oil per metric ton of CO_2 injected. Advanced Resources International's (ARI) projections for the US indicate utilization potential of 19 billion metric tons of CO_2 producing 66 billion barrels of economically recoverable oil. Current CO_2 -EOR demand in the US is 62 million tons of CO_2 (equivalent of 6% of crude oil production in the US)* ARI's CO_2-EOR projection for China's oil basins is estimated at 43 billion barrels, utilizing 19 billion tons of CO_2. While Mexico's EOR potential is estimated by ARI at 24 billion barrels of oil utilizing up to 9 billion tons of CO_2.

Mr Weber presented results of oxy fuel combustion technology to aluminum remolding, results as follows.

- Improved Energy Efficiency

- 750 to 900 Btu per pound [417 – 500 Kcal / Kg] for continuous runs
- Elimination of airborne nitrogen
- More radiant heat transfer
- Longer gas residence time
- Natural gas fuel reduction up to 73%
- Oil fuel usage reduction up to 68%
- Increased melt rate

In India, ARI (2009) has estimated 70 to 90 trillion cubic feet (2.0 to 2.6 Trillion cubic meters) of Coal Bed Methane in place, of which 20 trillion cubic feet are recoverable with CBM, and another 20 % of the gases in place are potentially recoverable with ECBM, by storing billions of tons of CO_2. Reviewing the ECBM potential for CBM sites currently in operation or being developed in India, ARI further estimated a ECBM potential of 2 trillion cubic feet, potentially utilizing close to 1 billion tons of CO_2 (Estimated CO_2:CH_4 Ratio by ARI is between 0.60 : 1 up to 6.3 : 1).

Main costs associated with CCSU technologies are related to carbon capture process from fossil fuel power plants and industrial sources. These are reduced on oxyfuel combustion. Further scope of work and ECBM Potential in India were discussed- Opportunities may exist for mixing N_2 into the injection stream to improve infectivity and gas recovery from ECBM.

Giving an example he said low-rank sub-bituminous coals of the Raniganj South and East areas -- a 20% N_2/80% CO_2 mixture would be ideal. In higher rank low to medium volatile bituminous coals in the Sohagpur (East) and the Parbatpur Area of the Jharia Coalfield (and perhaps also in parts of the East Bokaro area), -- 30% N_2/70% CO_2 may give optimum results. In highest rank anthracitic areas in Sohagpur (East and West), -- 45% N_2/55% CO_2 may be preferred. However, it should be noted that the more N_2 injected and less CO_2 injected, lowers the opportunity for CO_2 storage.

Possible “win-win” opportunities were identified by assessing the following factors, in relative importance:

(i) The availability of existing infrastructure to be utilized to allow cost-effective ECBM and/or CO_2-EOR.
(ii) Proximity to existing CO_2 emissions sources
(iii) Willingness, need, and/or ability of existing producers to pursue an ECBM or CO_2-EOR pilot
(iv) Characteristics for viable ECBM or CO_2-EOR, including areas amenable to CO_2 mixed with N_2 for ECBM.

In conclusion a CCSU Demonstration was recommended. Project synergies could be developed as all of the areas with current CBM activities underway could contain good prospects for CO_2 storage-ECBM project depending on the geographic location and local geological characteristics of the target coal seam.

COALBED METHANE RECOVERY: STATUS AND TECHNOLOGICAL ISSUES IN INDIA

Dr. V. A. Mendhe
Principal Scientist, Central Institute of Mining and Fuel Research
Barwa Road, Dhanbad

Dr. V. A. Mendhe, CIMFR, Dhanbad, introduced the CBM Technology comprising of a three step process of Drilling, Hydraulic Fracturing and Well Completion. Total Gas (TG) content of coal is the volume released by the coal in three steps i) desorbed gas – volume of gas measured through canister test ii) lost gas - portion of the total gas that escapes from the sample during its collection and retrieval prior to being sealed into an airtight desorption canister and iii) residual gas - volume of gas obtained after crushing of coal sample in closed container. The total gas content of the coal is determined by addition of lost gas, desorbed gas and residual gas and dividing by the desorbed sample weight.

$$Q = \frac{Q_1 + Q_2 + Q_3}{W} \text{ Cc/g}$$

Where, Q = Gas content, Q_1= Lost gas, Q_2= Desorbed gas
Q_3= Residual gas, W = Weight of sample

In India, the coal bed methane (CBM) recovery and utilization on large commercial scale is gaining importance. Experiences concurred that improving efficacy in extraction of methane from coal seams will help to tackle the dual challenges of reducing carbon dioxide and improving quality of life through clean energy exploitation and adding many more on-grid. There are many technological barriers and different challenges have been overcome in the initial stages such as land acquisition, complex geologic conditions, drilling in heterogeneous formations, multiple hydro fracture and economic recovery techniques. The time has come to have thorough CBM advance phase and structured evaluation programme right from fairway identification to full scale developmental stage to enhance recovery of gas. CBM has a very bright future in India if proper steps are taken in this direction. Currently, 7 CBM blocks have been operated by ONGC, ESSAR, RELIANCE and GEECL producing methane commercially. India, having the 4th largest proven coal reserves (298 billion tonnes) and being the 3rd largest coal producer in the world, holds significant prospects for commercial recovery of CBM on large scale, it is anticipated that by 2022, CBM may contribute 10 to 16% of natural gas requirement.

The prognosticated CBM resource based on the CSIR-CIMFR determined in-situ gas content and sorption capacities has been estimated to be around 4.6 TCM by DGH. Till now, thirty two CBM blocks have been awarded in 4 rounds of international competitive bidding and on nomination basis. CIMFR has carried out detailed investigation to evaluate the coal bed methane reservoir parameters such as in-situ gas content, molecular gas composition, sorption capacity, petrography, coal quality, thickness of coal seams, porosity, permeability and geo-mechanical properties. In-situ gas content obtained through the direct method and initial recovery of methane from production wells encourages the large scale future commercial production in coalfields such as Jharia, Bokaro, Raniganj, North Karanpura and Sohagpur. The CBM production may rise from the current 0.9 million metric standard cubic meters per day (mmscmd) to 16 mmscmd in 2022, reflecting a tremendous growth in CBM production.

India is endowed with bituminous coal of Paleozoic and Tertiary ages within the CBM window at depths of nearly 200-1500 m. It is emphasized that Gondwana coal rank varies both laterally and vertically and changes from volatile sub-bituminous to bituminous coals (0.62–1.79% Ro). Coals are composed of 60 to 85% vitrinite, 15 to 40% inertinite, small amount of liptinite maceral and a trace amount of minerals. Methane adsorption isotherm determined as 13.91 to 29.54 m^3/t revealed that the maximum sorption capabilities of coals are affected by coal rank, high ash percentage, coal maceral, coal lithotype and especially to the high moisture content. Estimated gas contents ranges from 0.5 to 22 m^3/t. In combination with the geological information, the data indicated that the tectonic evolution of the basin had important influences on gas accumulation, preservation, and escaping. The permeability is between 0.1 to 10 mD and the porosity ranges from 2 to 7%.

In Raniganj South, GEECL is the first commercial producer of CBM gas in India. It is engaged in exploration, development, production, distribution and sale of CBM gas. It currently owns two CBM gas blocks, one in Raniganj (South), West Bengal and other in Mannargudi, Tamil Nadu. The company started producing CBM gas commercially at the Raniganj (South) block in 2007. It has an estimated 2.4 trillion tcf of original gas reserve in this block, spread over approximately 210 sq km, and produced 88.02 million metric standard cubic metre (mmscm) in FY13 from 157 wells. The company delivers CBM gas to more than 31 industrial customers through its own pipeline network in the Asansol-Durgapur industrial belt, which includes steel plants, steel rolling mills, glass, chemical and food industries. Compared with the other major U.S. CBM basins, GEECL's Raniganj (South) block displays remarkable similarities with the Black-Warrior basin of USA where multiple coal seams with significant gas content and favourable permeability account for high productivity.

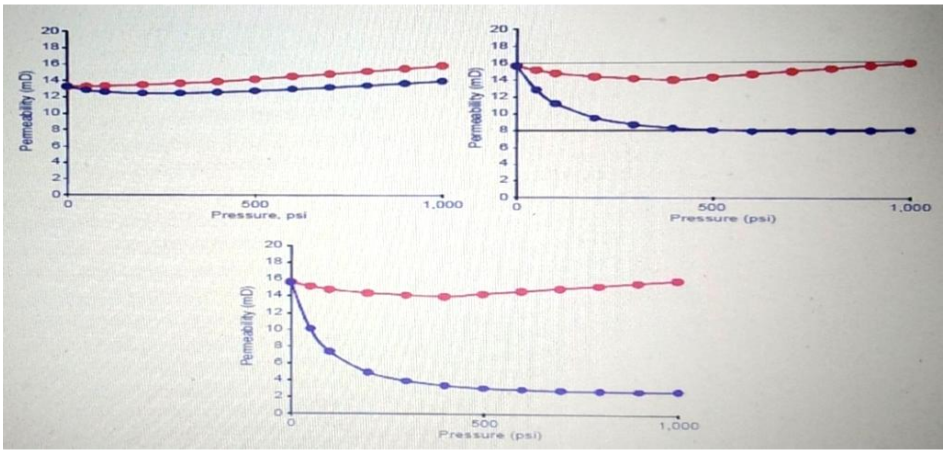
In Raniganj East, Essar Oil producing around 5,00,000+ scm/d of gas. The total proven and probable reserves at Raniganj, evaluated as 113 bcf gross. Nearly 100 wells have been placed on gas production; additional 155 wells have been drilled and are at various stages of the hydro fracking-completion-dewatering cycle for further gas production. In Sohagpur, Reliance Industries Limited (RIL), has done 12 core hole and 2 test wells in the block. Gas-In-Place of the order of 54.5 BCM has been established. It is quoted that gas-in-place estimates are much more than the initial estimates done by DGH. Two test wells are producing incidental gas, from day one of dewatering, with rate more than 4000m^3/day. The commercial quantities of CBM gas once produced from Sohagpur block can be consumed for captive power generation. Alternatively, it can be transported to nearby HBJ pipeline, which is at a distance of about 300 km, to reach wider markets through a dedicated pipeline. Usage through CNG is also possible in this area.

CBM reservoirs are low pressure, after few years of production through primary reduction of hydrostatic pressure rate of recovery decline’s and harm the well economics. In secondary drive, the CO_2 or CO_2+N_2 or other mixture of gases can be injected to enhance the methane recovery and to maintain reservoir pressure. Studies conducted so far supports stronger affinity of CO_2 to the coal molecule, displacing each methane molecule by 2 to 3 molecules of CO_2. Coal may adsorb more carbon dioxide than methane and that carbon dioxide is preferentially adsorbed into the coal structure over methane (with 2:1 ratio). CIMFR has carried out measurements of CO_2 and methane adsorption isotherms for various coal seams in India. On the basis of CO_2 storage capacity, seam thickness and extension. The suitable sites and their storage capacities estimated to be 4459 Mt for CO_2. It is assumed that this quantity of storage is sufficient to store over 20% of total gas emission from the present power plants over their life time. The sites close to the operating thermal power units may be the most appropriate for CO_2 sequestration as the transportation cost of the gas will be minimum. The rate of CO_2 generation and total CO_2 generated within the life span of a thermal power station presuming 20 years more from the date will be helpful for ECBM process in the close vicinity of CBM blocks. It is also required that geologic data and experimentally determined mineralization reaction rates and kinetics should be incorporated into geochemical models to predict the permanent storage of CO_2 in unmineable deep coals.

Dr. Mendhe said that Permeability is a key factor of CBM reservoirs and is a measure of the ability of a material to transmit fluids. Coal itself is a low permeability reservoir and almost all the permeability of a coal bed is usually considered to be due to fractures, in which coal are in the cleats.

Permeability evolution due to coal swelling

Understanding controls on CO_2 and CH_4 adsorption in coals is important for the modelling of both CO_2 sequestration and CBM production. Indian coal beds are classified into grey,



concealed and unmineable based on its depth of occurrence and grade characteristics. CO_2 storage potential in Indian coal beds is estimated to be 4459 Mt. (i.e. 4.459 Gt).

ACBCCS 2015

TECHNICAL SESSION-V

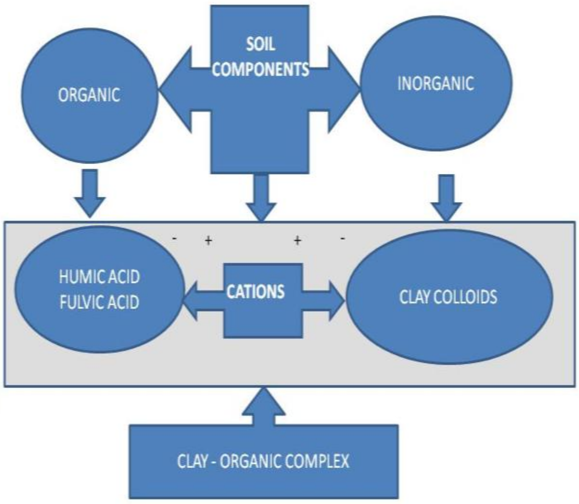
CO_2 Sequestration

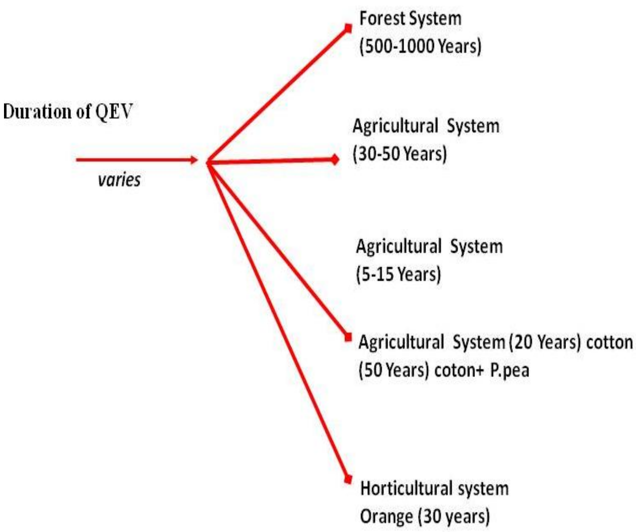
30.07.15

SOIL AS SOURCE AND SINK FOR ATMOSPHERIC CO_2

Prof. Tapas Bhattacharyya
Visiting Scientist
ICRISAT Development Centre
ICRISAT, Patancheru , Telengana

Prof. Tapas Bhattacharyya, ICRISAT, said that soils sequester organic carbon, where it can remain in free form or absorbed with amorphous materials present in soil like Fe/Al oxides, hydroxides. The content of organic carbon stored changes and increases with depth. Prof Bhatacharya explained the concept of quasi-equilibrium value of organic carbon fill and said that under natural vegetation/adopted system carbon values in soil reach a near steady-state/quasi-equilibrium value (QEV) as shown below.





Soil Sequester Organic Carbon **QEV or Organic Carbon**

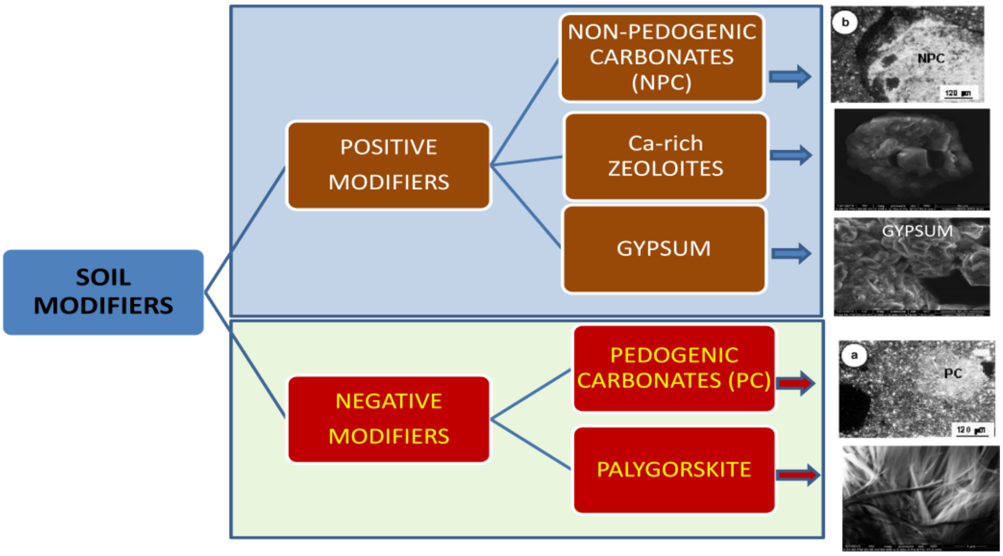
How much Organic and Inorganic carbon is stored in Indian soils? Organic carbon has active and passive pools. Active pool is more variable than passive pool. Inorganic carbon is mostly present as carbonates. Soil organic and inorganic carbon is affected by weather and climate. For carbon management inorganic carbon sequestration in soil must be reduced. Thresholds of soil organic carbon storage are

- 0.03 Pg mha^{-1} : used for identifying systems for crop productivity
- 0.05-0.06 Pg mha^{-1}: to maintain green belt in North Eastern Region

Effect of global warming on modeled TOC stocks has been studied. To estimate global warming effect of organic C held in terrestrial soil, Roth C Model considers the top soil with varying depth as a single homogenous layer. It was observed that modeled total organic carbon stocks in Kheri site subjected to an average increase in temp of 2.5ºC during 1990 to 2090. The per cent fall in Total Organic Carbon (TOC) content is more in single layer as compared to combination of 5 different layers. Therefore that soil must be considered as an entity of different layers which will be more effective to mitigate the effect of global warming due to increase in temperature.

Changes of soil carbon occur over time and require

I. Temporal soil datasets
II. Soil carbon as well as soil health monitoring
III. BM spots soils reached QE stages for SOC
IV. The increasing trend in SIC stock in the BSR is a warning signal for potential soil degradation in spite in increase in SOC stock



Soil carbon and soil modifiers

SOC and SIC sequestration compared

Particulars	SOC	SIC
Carbon capture	Organic matter through leaf fall etc	Carbonic acid absorbing atmospheric carbon-di-oxide
Carbon storage	As humus	As carbonates
Advantages	Maintain soil quality and health --morphological --physical --chemical --mineralogical properties	✓Huge source of hidden calcium ✓Dissolution through ❖ Phytoremediation ❖ Chemicals like gypsum

Disadvantages	➢ Huge loss due to high tropical climate ➢ 60-65% organic matter in passive pool: not useful for plants	➢ SIC as $CaCO_3$ is the root cause of chemical soil degradataion

Studies carried out on soil minerals as evidence & carriers of climate change in soils of the Peninsular & Extra-Peninsular India were discussed. The following are key observations.

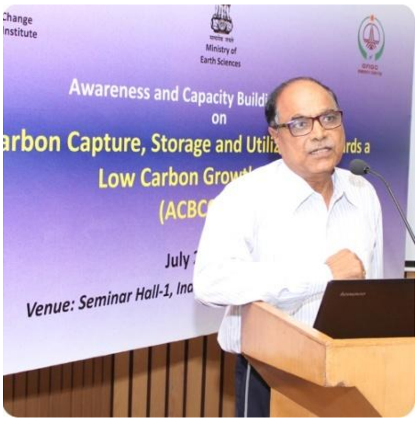
- Di- and trioctahedral smectite as evidence for paleoclimatic changes.
- Red and black soils in semi-arid climatic environments: Smectite/Kaolin interstratified minerals.
- Clay minerals and Holocene climate change in soils of the Indo-Gangetic Plains (IGP)
- Vertisols, carboniic minerals and climate change
- Clay minerals record from drill cores of the Ganga Plains and their implications for climate change in the Himalayan foreland.

Benefits of soil carbon and pedalogy

The carbon transition curve conveys the impact of major land use changes on soils with examples from arable, grazing and forest land in different parts of the world. A rapid decline of soil carbon due to human clearing of natural vegetation for agricultural land use and management practices has been observed followed by a crisis phase of diminished soil fertility. Good agricultural management practices are required for its
recovery.

SOIL CARBON STOCK AND CO_2 FLUX IN DIFFERENT ECOSYSTEMS OF NORTH EAST INDIA

Prof. P.S.Yadava
Department of Life Sciences
Manipur University, Imphal



Prof. P. S. Yadava from Manipur University presented Soil carbon stock and soil CO_2 flux in North- East India. He said that soil carbon flux is the flux in forest, grassland and bamboo ecosystems and strategies for enhancement and management of SOC have been discussed in NE India.

Major components of carbon budget and carbon cycle in the different terrestrial ecosystems of the world are different. About three times more carbon is contained in soils than in the world's vegetation and soils hold double the amount of carbon that is present in the atmosphere. Soil can be source or sink of greenhouse gases depending on land use and management. Soil CO_2 flux is the production of CO_2 by an organism and the plant parts in the soil. Soil CO_2 efflux differs among ecosystems and also varies with environmental conditions. Nearly all model of global climate change predict a loss of carbon from soils as a result of global warming.

He described how soil CO_2 flux is the main carbon efflux from terrestrial ecosystems to the atmosphere and is therefore an important component of the global carbon cycle balance. He presented data on Soil organic carbon (SOC) stock in different tropical Subtropical, term pleurae forests of N.E. India

Soil organic carbon stock in different tropical forests of north eastern, India.

S. No.	Forest type	C-stock (Mg C ha^{-1})	Location	References
1.	Tropical wet evergreen forest a)Undisturbed b)Mildly disturbed c)Highly disturbed	<u>18.75</u> 15.93 13.54	Arunachal Pradesh	Barbhuiya et al.(2002)
2.	Moist Deciduous forest	<u>48.03</u>	Moreh, Manipur	Yadava (2012)
3.	*Dipterocarpus* forest a) Undisturbed b) Disturbed	14.77 12.99	Moreh, Manipur	Yadava (2015)
4.	*Dipterocarpus* forest	47.04	Barak valley, Assam	Rabha et al.(2014)

Soil organic carbon stock in different sub- tropical and temperate forests of North Eastern India

S. No.	Forest type	C-stock (Mg C ha^{-1})	Location	References
1.	Broad leaved hill forest	47.73	Maram, Manipur	Yadava (2010)
2.	Oak forest a)Undisturbed b)Disturbed	21.36 20.66	Imphal, Manipur	Yadava (2015)
3.	Pine forest plantation	22.56	Imphal valley, Manipur	Yadava (2010)
4.	Castanopsis – Lithocarpus forest a)Undisturbed b)Disturbed (Temperate)	33.87 30.86	Senapati, Manipur	Yadava (2015)

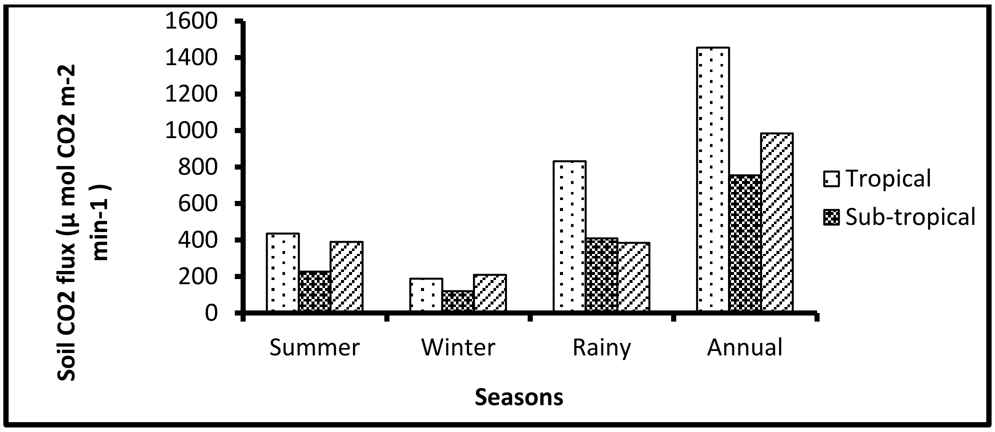
Soil organic carbon content in the soils of different grasslands and bamboo ecosystems of North Eastern India

S. No.	Bamboo forest type	C-stock (Mg C ha^{-1})	Location	References
1.	Shizoastachyum pergracile bamboo forest	57.30	Moreh, Manipur	Thokchom and Yadava (2015)
2.	Village bamboo groove(Bambusa cacharensis,B.vulgaris,B.balcooa)	55.95	Barak valley, Assam	Nath et al.(2009)
3.	Bamboo forest	51.20-56.87	Arunachal Pradesh	Arunachalam and Arunachalam(2002)

Soil organic carbon stock in the different grasslands ecosystems of north eastern India

S. No.	Grassland ecosystem type	C-stock (Mg C ha^{-1})	Location	References
1.	*Imperata-sporobolous* grassland a) Unburnt b) Burnt	57.28 44.74	Imphal valley, Manipur	Thokchom and Yadava(2015)
2.	Grassland	69.75	Arunachal pradesh	Arunachalm and Arunachalam (2002)

There are several factors which affect Soil Organic Carbon content in soil, including; Climate-(precipitation & temperature), Altitude measured soil texture and Biomass carbon. Rate of CO_2 flux in different seasons in tropical and sub-tropical regions is given below.



Rate of soil CO_2 flux in different seasons in all the forests ecosystems

Natural disturbances i.e. wind, fire, drought, insect and diseases affect SOC. Other factors are succession of forest species with different quality & quantity and Change in canopy, soil erosion, change in soil moisture, temperature etc.

Biotic disturbances i.e. burning, deforestation decreases SOC. SOC was largest in temperate regions in the order of temperate>Subtropical>Tropical forests. SOC variations are due to climate contributions to emission of CO_2 from the soil.

Soil carbon management strategies can be summarized as follows**:**

- Soil carbon stock and soil CO_2 flux is highly variable and influenced by vegetation type, rainfall and other climatic factors in North East region. Sustainable management of forests to optimise carbon sequestration can help.
- 41 % of Forest cover falls under open forest therefore great opportunities for reduction of CO_2 through afforestation and reforestation through funding from GEF,CDM and REDD
- This is need to encourage agroforestry practices utilizing indigenous tree of species like Bamboo plantation in highly degraded wasteland, being very fast growing plant species and control burning of forests and grasslands to minimise CO_2 release from soil.
- These activities will enable us to accurately estimate regional carbon fluxes and manage carbon budget in different ecosystems of North-East India.

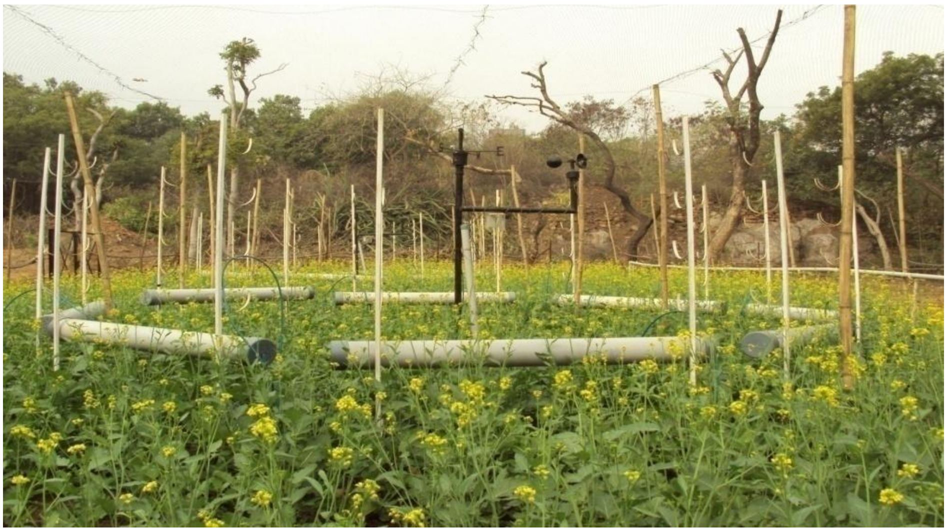
ENHANCED CARBONDIOXIDE UTILIZATION BY PLANT GROWTH IN FREE AIR CARBON DIOXIDE ENRICHMENT FACILITY

Prof. Baishnab C. Tripathy
Dean, School of Life Sciences
Jawaharlal Nehru University, New Delhi

Prof B. C. Tripathy, JNU, explained triggers for biodiversity as follows

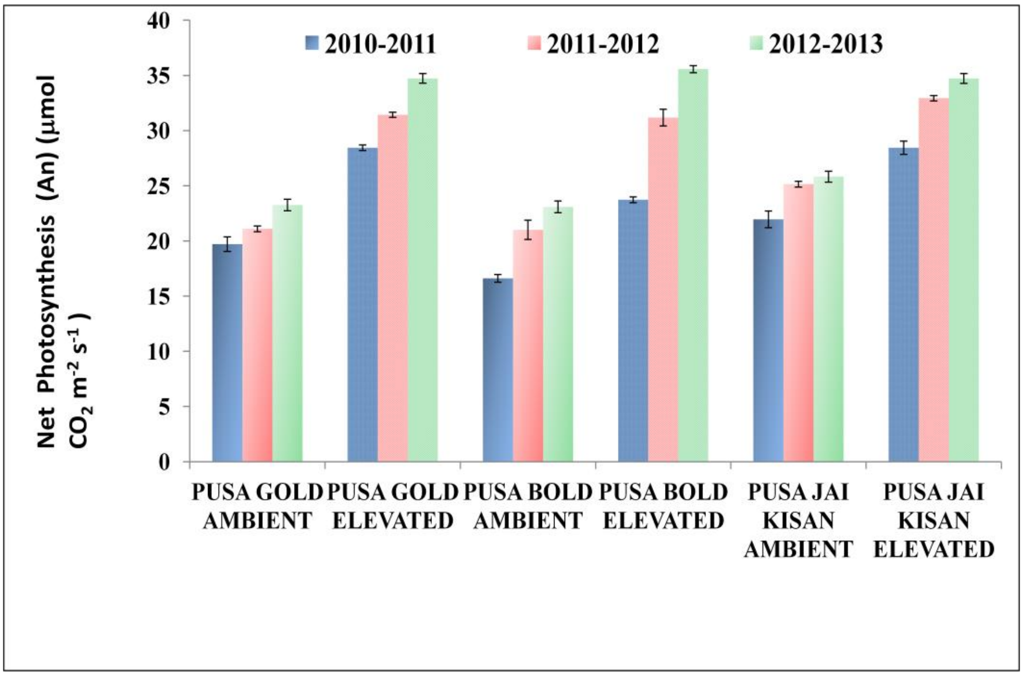
- Greenhouse Earth
- Oxygen metabolism & photosynthesis
- Competition & selection forces: evolution
- Increase & decrease of niches: Permissive Ecology
- Extinction Events

Tracing the Genesis of Earth and Paleobotany he gave an overview of observed global warming features. The Free Air Carbon Dioxide Enrichment (FACE) pilot project was set up in JNU way back in 2007 through support from Department of Science & Technology (DST) to study enhanced photosynthesis in C3 Plants. He said increase in carbon dioxide concentration results in a stimulation in photosynthetic carbon fixation of between 30 and 50%, primarily due to a reduction in photorespiration as the ribulose 1·5-bisphosphate carboxylase/ oxygenase (Rubisco) carboxylation reaction is favoured in these conditions.



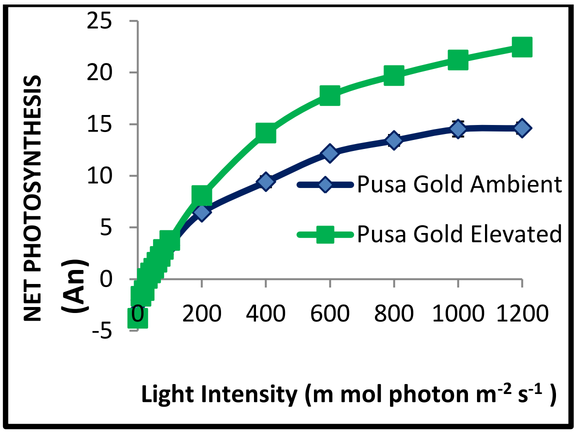
Free Air Carbon dioxide enrichment (FACE) facility built in the campus of Jawaharlal Nehru University. Mustard (*Brassica*) plants are grown inside FACE Rings maintained at elevated CO_2 (550 ppm).

CO_2 assimilation Studies for 2010 to 2013 were presented for Pusa Gold and Brassica juncea cv. Pusa Bold and Pusa Jaikisan grown in ambient and elevated carbon dioxide.

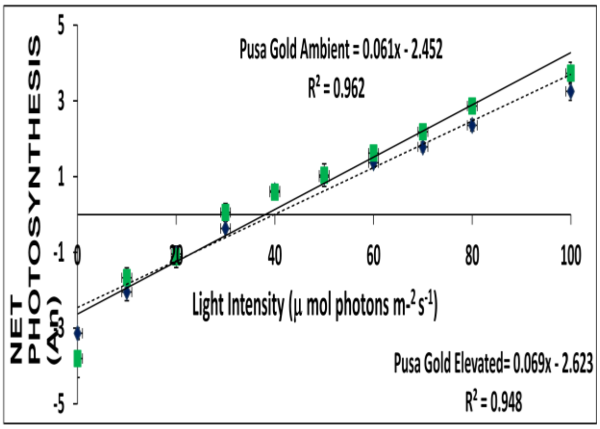


Response of the net photosynthesis (An) to incident light intensity (1200 m mol photons m^{-2} s^{-1}) in *Brassica campestris* cv. Each data point represents the mean value of six individual replications, (error bars indicate the standard deviation).

New photosynthesis in various crops has been studied to determine CO_2 assimilation rate Photosynthesis (net CO_2 assimilation rate) light response curves and quantum yield of attached leaves of Brassica campestris (Pusa Gold) plants grown in ambient and elevated CO_2 concentrations. A, Net CO_2 assimilation rates of attached leaves of Brassica campestris (Pusa Gold) plants were monitored by IRGA (Licor 6400-XT portable photosynthetic system) in ambient and elevated CO_2 at different light intensities. Light response curves were measured upto 1200 µmol of photons m^{-2} s^{-1} at 25^{0}C. B, Relative quantum yield of CO_2 fixation by leaves from Brassica juncea (Pusa Jaikisan) plants grown in ambient and elevated CO_2.



PUSA GOLD Light Response Curve



CO_2 Assimilation Rate

Quantum yield was measured from the above photosynthetic rate after the IRGA chamber reached to a steady-state. Light intensity curves at limiting light intensities i.e., up to 100 μmol of photons m^{-2} s^{-1}; the slopes of these curves provide relative quantum yield of CO_2 fixation by leaves. Leaves were pre-exposed for 15 minutes at 700 μmol photons m^{-2} s^{-1} prior to CO_2 assimilation measurement. These experiments were done thrice with similar results. Each data point is the average of six replicates and the error bar represents SE.

Total fresh weight per plant of *Brassica campestris* cv. Pusa Gold, Brassica juncea cv. Pusa Bold and Pusa Jaikisan grown in ambient carbon dioxide (380ppm) and elevated carbondioxide (550 ppm) in three different years has been studied. It was concluded that plants grown in elevated CO_2 had larger number of leaves, larger roots and higher biomass. Seeds weight of Brassica campestris and Brassica juncea cultivars grown in ambient CO_2 (385 ppm) and elevated CO_2 (585 ppm) inside the FACE ring were more.

ACBCCS 2015

TECHNICAL SESSION-VI

CO_2 Storage

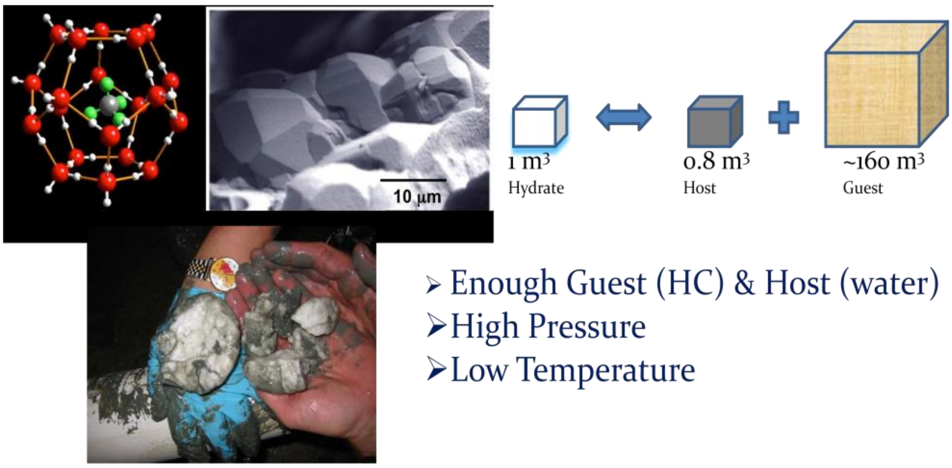
30.07.15

CLATHRATE HYDRATES: MATERIALS FOR MITIGATING GREENHOUSE GASES

Dr. P.S.R. Prasad
Principal Scientist
National Geophysical Research Institute (CSIR-NGRI) Hyderabad (India)

Dr. P.S.R. Prasad, Principal Scientist, NGRI, Hyderabad presented role of Clathrate Hydrates in CO_2 Sequestration. He explained reaction of CO_2 with mineral rocks and described results of early laboratory experiments carried out with Basalts. The experiments were conducted with CO_2 (@ 6 MPa); T = 370 K & t = ~ 5 months, Basaltic rock chips with 25 wt% H_2O were tested and Characterized using FTIR; Micro-Raman; DSC & SEM etc.

Gas hydrates are clathrate compounds in which a guest molecule is surrounded by an organized solid architecture (i.e., crystalline) consisting of water molecules. Depending on the guest molecule, the crystalline framework arranges itself into one of three structures (structure I, II, or H), thereby providing an internal void volume with an average radius that usually ranges from 3.91 to 5.79Å. If the cavities are considered to be spherical, the cavity volume ranges from 0.25 nm^3 to 0.81 nm^3.



Clathrate (Gas) Hydrates

Dr. Prasad said that our prime objective is to get basic understanding of gas hydrate formation, kinetics, stability and dissociation under laboratory conditions. Our goal is also to understand the effect of sediment mineralogy, porosity, particle size etc., on hydrate kinetics. Hydrate formation/dissociation mechanism in porous medium. In Indian scenario both in clay and sandy sediments are relevant and experiments are being conducted to probe kinetics and storage capacity and structural stability. Presence of smaller amount of higher hydrocarbons, particularly, in natural gas has known to have significant impact on structural stability in gas hydrate systems.

For the fuel gas recovery methodologies being employed worldwide revolve around the following fundamental concepts:

- Heating the Gas Hydrate deposits – Raise *'T'* to cause local melting
- Depressurization – Decrease *'p'* to cause local melting
- Molecular substitution – Exchange of encased CH_4 to CO_2

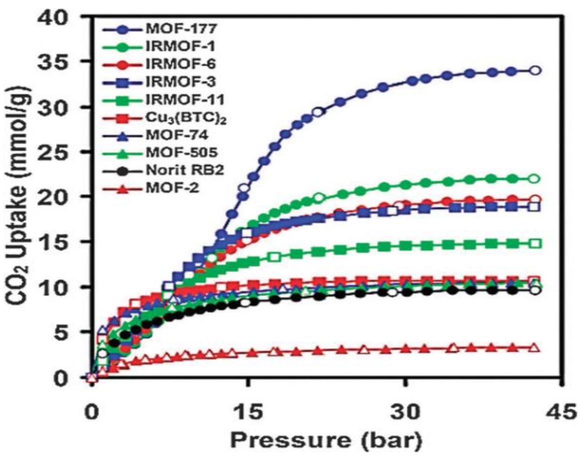
Safer recovery of the fuel gas from the hydrated core deposits is a topic of enormous fundamental interest. Ideal material should have features-high capacity & fast kinetics and the out gassing should be as close to ambient conditions.

a. Both thermodynamic and kinetic parameters for the methane hydrates.
b. Other porous materials with open pore and channel structure like Zeolites and Clathrasils; Metal Organic Frame works (MOF).
c. High Volumetric and Gravimetric capacity and also higher duty cycles.

Laboratory studies were initiated on gas hydrates at NGRI for the first time. We used hollow silica for methane gas storage in the form of hydrates. Advantages offered by the such material are:

I. Stirring is not necessary in methane hydrate formation in water-silica suspensions
II. There is an optimal ratio of silica to water to achieve larger hydrate yield
III. Bulk fraction of capillary water can be converted into hydrates at moderate pressures- in fact it is nearly half of the pressure required to get similar hydrate conversion in stirred reactor

Studies indicated rapid hydrate conversion in mixed hydrates (sII) with CH_4 + THF, CH_4 occupies empty 5^{12} & $5^{12}6^{4}$/ $5^{12}6^{2}$ cages. CH4 gas release is governed by the stability conditions of mixed hydrates. Carbon Molecular Sieves have been reported to have Max Adsorption 2065 mg/g (or 50 mmol/g) @5 MPa, 298K. Metal Organic Framework (MOF) - Max Adsorption 50 mmol/g) @ 5 MPa, 298K.



Dr. Prasad summarized simulation studies results in gas hydrates as follows.

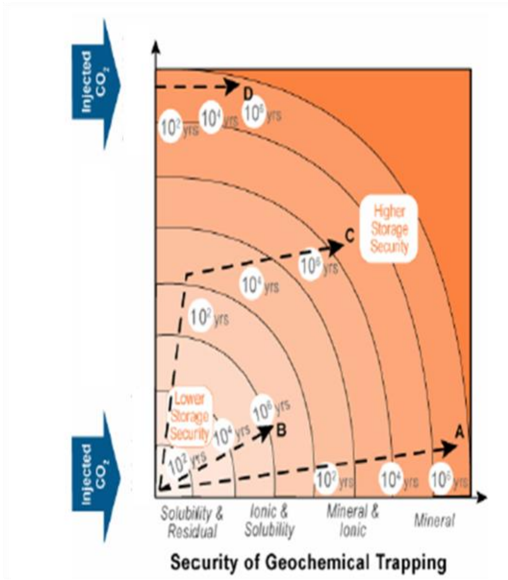
Sample	R = H2O/SiO2	ConsumCO_2(m mol)	Yield %	Stored CO_2 (/g)
H-SiO2 (C)	4	154	84.5	27.7
H-SiO2 (L)	10	66	42.5	29.7
SiO2 (C)	2	112	61.5	5.6
SiO2 (L)	2	88	59.6	9.8
SiO2 (Ald)	1.6	50	40.5	5.6

ALTERNATIVE & CHALLENGES FOR CO_2 STORAGE: INDIA'S PERSPECTIVE

Dr. B. Kumar
Former Chief Scientist
Hydrocarbon Research & Exploration and Carbon Management,
National Geophysical Research Institute, Hyderabad

Dr. B. Kumar, Ex- NGRI, Hyderabad explained alternatives & challenges for carbon dioxide storage. He said carbon capture and storage is a new R&D initiative for storing of CO_2 to mitigate global climate change. It involves the integration of 4 elements: CO_2 capture; transportation of liquid carbon dioxide from point of capture to storage location; geological storage and monitoring & modeling for safe storage. The fossil fuel based thermal power stations are the largest point sources of CO_2 emissions, which is a green house gas and is the major cause of global climate change. He also described storage security mechanisms and explained changes that take place when CO_2 is injected in geological environment

When the CO_2 is injected, it forms a bubble around the injection well, displacing the mobile water laterally and vertically within the injection horizon. The interactions between the water and CO_2 phase allow geochemical trapping mechanisms to take effect. Over time, CO_2 that is not immobilized by residual CO_2 trapping can react with in situ fluid to form carbonic acid i.e., H_2CO_3 called solubility trapping that dominates from tens to hundreds of years.



Dissolved CO_2 can eventually react with reservoir minerals if an appropriate mineralogy is encountered to form carbon-bearing ionic species i.e., HCO_3^- and CO_3^{2-} called ionic trapping which dominates from hundreds to thousands of years. Further breakdown of these minerals could precipitate new carbonate minerals that would fix injected CO_2 in its most secure state i.e., mineral trapping which dominates over thousands to millions of years.

An innovative geothermal technique for the use of CO_2 is in geothermal field has been proposed. Unlike conventional water based geothermal energy carbon dioxide can be used as the geothermal heated fluid. The CO_2 is cycled through a heat exchanger in a "binary geothermal system" – the heat exchanger creates stream for the turbines while CO_2 is compressed and re- injected into the geological formation in a close- loop system without atmospheric CO_2 emissions. Getting geothermal power with CO_2 injection would be particularly beneficial in the arid/ semiarid areas where water is scare.

He described BIO – CCS and its international status. GEOGREEN is a member of the European joint taskforce (JTF) on Bio-CCS. Some of the important origin projects on Bio–CCS are following

USA

- One of the most recent algae-inspired projects is being undertaken by Washington-based Columbia Energy Partners (CEP), which plans to convert carbon dioxide from a coal-fired electricity plant into algal oil.
- NASA OMEGA. Project aims to investigate the technical feasibility of a unique floating algae cultivation system for waste water treatment
- Arizona public service Co., USA have taken a loan/grant of $ 70.0 Million to grow Algae from CO_2 released from their coal fired plants.

Australia

- Australian firms, Linc Energy and BioCleanCoal, have partnered together in a joint venture to sequester carbon dioxide emissions from Australian coal-fired power stations to use as fuel or fertiliser, even re-burning it to produce additional energy.
- MBD Energy, Melbourne is planning to introuse technology that will allow algae to capture CO_2 from a power station at no virtual cost to utility.

Israel

The Israel Company Seambiotic has found a way to produce biofuel by channelling smokestack carbon dioxide emissions through pools of algae. The growing algae thrive on the added nutrients, and have become a useful biofuel.

Canada

Trident Exploration Corp. (natural gas Exploration Company) is looking at ways to reduce its CO_2 emissions. Trident approached a number of companies for solutions, and ended up teaming up with Menova last year for Bio- CCS.

Italy

The objective of the Eni Technology R&D project on microalgae biofixation of CO_2 was to evaluate on pilot scale the feasibility of using fossil CO_2 emitted from a NGCC power plant to produce algal biomass.

Germany

RWE, Germany has launched a project; flue gases from the Niederaussem power station are fed into an algae production plant in the vicinity of the station to convert the CO_2 from the flue gas into algal biomass.

India

Pilot project in West Bengal: Kolkata based organization is conducting a pilot project on Bio CCS at the Kolaghat thermal power plant. The 1,260-MW Kolaghat plant emits ~1 5,000 T of

CO_2 every day. It is proposed that this gas be trapped and channelized into a pond where algae will be farmed.

The company is attempting to use the CO_2 from the power plant as follows: Fifty percent of the CO_2 emitted is planned to be used for algal farming, 25% for farming of Spirulina, and the rest to be compressed in its uncontaminated form to produce dry ice. The oilcakes (left over after the oil is extracted) are could be burnt to generate power to run this entire process. It is plans not to design this into a self-sustaining technology. The power plant will be assisted by Sun Plant Agro, and plans to start commercial production of algae bio-fuel has been proposed.

Algal bio CCS plant of NALCO: It is another pilot project proposed for the it's 500 MW power plant generating about 8000 tons of CO_2 per day is a huge resource, if can be utilized. The amount of CO_2 sequestered in Algae Biomass sequestration calculated as a unit of Tons/ Acre/Year (Carbon Content assumed in Biomass is ~ 50 %). Carbon to CO_2: 1 kg of carbon is equivalent to 3.6 kg of $CO_{2.}$
(1 mole of carbon give 1 mol of CO_2, Molecular wt of C = 12 & CO_2 is 44, So Molar ratio = 44/12 = 3.6).
Every ton of Microalgae Biomass would be generated by capturing 1.8 ton of CO_2

Two major possible CDR technologies (in the context of India) can be summarized as key parameter.

S. No.	Microalgae-based Capture Technology	Geological Sequestration Technology
1	Sustainable	Social problems
2	Safe	May be unsafe in longer terms
3	No need to transport CO_2	Need to transport CO_2 to sequestration site
4	Generates biomass	No additional revenue expected
5	Coupled with wastewater treatment	Coupled with oil recovery
6	Carbon credit + nutrient credit + biomass	Carbon credit?

In conclusions he added that India has taken initiatives to establish R&D centers for Carbon Capture and Storage (CCS) and in this CSIR, DST & ONGC have taken the lead. However to meet the challenges of climate change, increasing energy demand and sustainability, the integrated research and development Institute for "CCS" have to be established by Government/Public/Private partnership and International collaboration. The funding mechanism for this technological and intellectual nucleus can be met by cess on coal (~ Rs. 50 per ton) or 0.5% cess on each unit price of fossil fuel based electric power generated. Bio- CCS is a safe and viable alternative for India.

SEAWEED CARBON: A NEW DIMENSION IN THE BLUE CARBON MATRIX

Dr. Abhijit Mitra
Associate Professor and former Head
Dept. of Marine Science, University of Calcutta, Kolkata

Dr. Abhijit Mitra said that seaweeds are a unique gift of nature. Seaweeds are large algae (macro-algae) that grow in a saltwater or marine environment. They are plants (thallophytes), but they lack true stems, roots, and leaves. However, they possess a blade that is leaf-like, a stripe that is stem-like, and a holdfast that resembles a root. Like land plants, seaweeds contain photosynthetic pigments (similar to chlorophyll) and use solar energy to produce food and oxygen from carbon dioxide and water. They grow abundantly in the shallow waters of sea, estuaries and backwaters. They flourish wherever rocky, coral or suitable substrata are available for their attachment.

Seaweeds have been used since ancient times as food, fodder, fertilizer and as a source of medicinal drugs. Today seaweeds are the raw materials for the industrial production of agar, algin and carageenan, but they continue to be widely consumed as food in Asian countries. They are nutritionally valuable as fresh or dried vegetables or as ingredients in wide variety of foods. They belong to three groups namely green, brown and red based on pigmentation, morphological and anatomical characters. The seaweeds show great variation in nutrient contents, which are related to environmental factors such as temperature, salinity, light and nutrients.

A Case Study Area in Sundarban Mangrove in the Lower Gangetic Delta was presented. *Ulva lactuca* and *Catenella repens* are the dominant macroalgae found in Indian Sundarbans (a World Heritage Site and a Biosphere Reserve), which is a Gangetic delta in the north east coast of Indian Sub-continent. In the intertidal zone of this mangrove dominated ecosystem, a distinct zonation is often visualized with respect to distribution pattern of seaweeds. Seaweeds, according to Dr. Mitra are unique reservoir of carbon. The seasonal variations of biomass and carbon content of *Enteromorpha intestinalis, Ulva lactuca* and *Catenella* repens during 2012 is shown in Fig. 1, Fig. 2 & Fig. 3

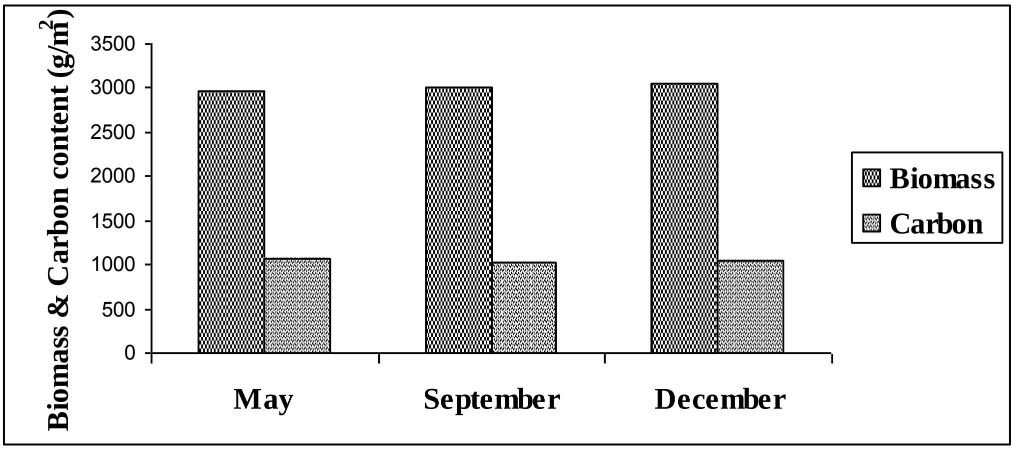


Fig. 1. Seasonal variations of biomass and carbon content of *Enteromorpha intestinalis d*uring 2012

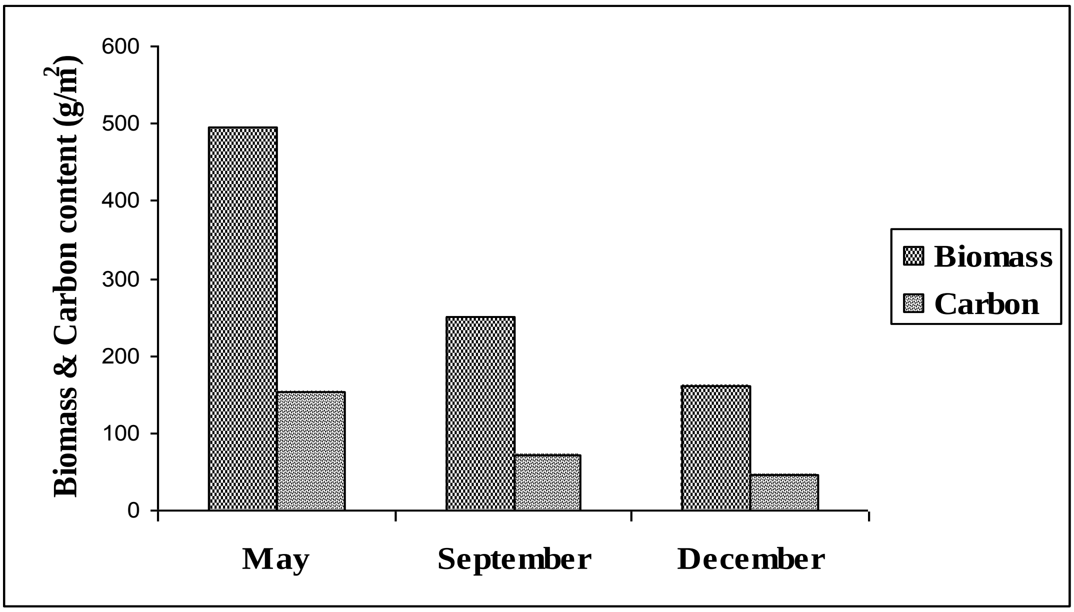


Fig. 2. Seasonal variations of biomass and carbon content of *Ulva lactuca* during 2012

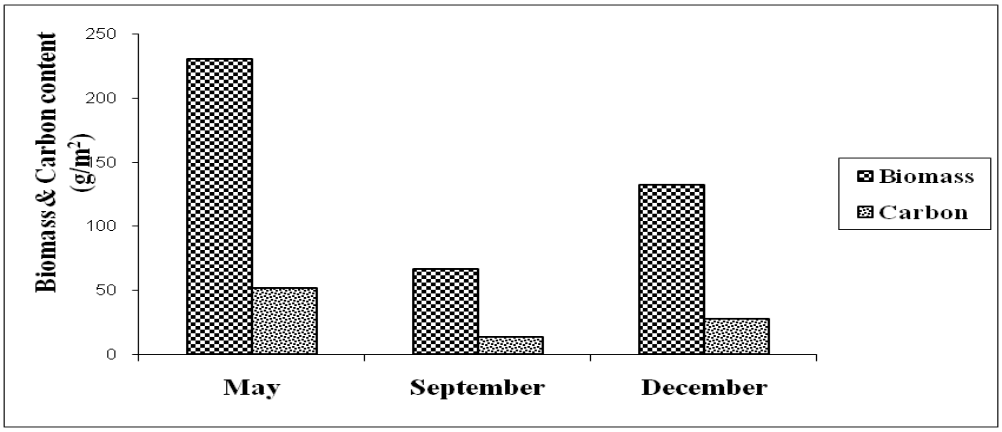


Fig. 3. Seasonal variations of biomass and carbon content of *Catenella repen*s during 2012

Physiographic profile of the study area are as follows.

The Indian Sundarbans (within the latitude 21°13'N to 22°40'N and longitude 88°03'E to 89°07'E) at the apex of the Gangetic delta is one of the most biologically productive and taxonomically diversified, low line, mangrove detritus based, open, dynamic, heterogenous coastal ecotone. The study area is located at Hironmaypur (P.S. Basanti) adjacent to the Bidya River within Sundarban Biosphere Reserve having latitude 22°06′49.4″N and longitude 88°41′28.7″E. The culture ponds (2 in nos.) are located within paddy culture field. The salinity recorded in these ponds is ~10.0 psu which may be due to the salinity intrusion from the adjacent Bidya River.

Nutritional component in Seaweeds characterized by excellent hydrocolloid properties is available locally at the sea farming site. It varies from location to location. Giving an example of China Sea he said, In China Laminaria is important as raw material for its alginated, mannitol and iodine. Recently, the kelp produced in China has been employed in the processing of synthetic feed use in mariculture. These are the rich source of food derivatives, vitamins and proteins. They have outstanding nutritional profiles like essential fatty acids, nucleic acids like RNA and DNA, and phyto-chemicals as carotenoids

In conclusion he suggested further studies from P.1 requested in view of the following benefits. Seaweed culture is environment friendly as the overload of nutrients is reduced.

- Seaweed can act biopurifier in shrimp culture units.
- Seaweeds are rich source of protein, iodine, antioxidants, and several bioactive substances
- Seaweed culture can generate employment (at local scale) in coastal zone
- Seaweeds can serve as potential reservoir of blue carbon

GUEST LECTURE

CO_2 STORAGE AND ENHANCED OIL RECOVERY

Shri Gautam Sen
Ex-Executive Director
Oil and Natural Gas Corporation
New Delhi

Shri Gautam Sen stated that CO_2 sequestration has become a necessity to maintain natural carbon cycle. High pressure injected CO_2 can increase overall recovery in Oil fields. Not only old oil fields, depleted gas fields but coal seams (not covered in this ppt) and saline aquifer also provide the locales for storage of CO_2 in the subsurface. Like oil and gas fields saline aquifers also are found within sedimentary basins. He said recent global study indicates that 50 large basins, Middle East and Africa, can additionally produce 470bbl through injection of 140bmt of miscible CO_2. In many countries viz, EU, Canada, Australia, Algeria and now BRICS are also following suit. It is time for India and already ONGC has initiated pilot projects in Gujarat.

Explaining the process of Enhanced Oil Recovery, he said that super critical carbon dioxide in liquid form has a lower density and lower compressibility as compared to fluid in saline aquifers. Seismic velocities are therefore different and CO_2 plume shows up in the seismic data. In case where CO_2 is injected in Oil field, both for Miscible and Immiscible case the attributes are altered. This change is captured through time lapse seismic/VSP and/or pressure and saturation studies.

Even for immiscible CO_2, due to oil quality (heavy/too light) or too low reservoir pressure there could be some gain in mobility and thus lower residual oil saturation. Industrialization of the process would warrant a steady supply of CO_2 through pipelines, selection of a large number of oil pools as sink candidates and rigorous monitoring of the reservoir. Seismic data acquired aerially at different times in the life cycle of project can detect changes in the reservoir, provided the surveys are repeatable. Interpreting and analyzing changes, occurring inside the reservoirs is a major challenge and this change has to be above noise due to nonrepeatablity as measured in the non reservoir section.

Monitoring, Verification (M&V) and accounting of CO_2 is very important for safe storage. It helps in identifying and quantifying injected CO_2 within the horizon, and leakage of sequestered CO_2. In reality supercritical state of CO_2 phase can get altered incase CO_2 escapes to shallower stratigraphy. and can give rise to patchy porosity. Also CO_2 can interact with host rock and alter its porosity .It can even dissolve rock material and create secondary porosity. Changes in P wave and S wave velocity and consequently their ratio are different in the three cases. Lab SEM studies of core data when integrated can provide inputs for a realistic rock physics modeling. Compressibility of a rock as a function of CO_2 saturation depends on the size of the CO_2 fluid patches. Patches less then quarter wavelength of seismic wave form the non linear lower bound of Gassman equation, while larger patches have a different behaviour. Log data and ultrasonic lab data is also very different from low frequency seismic data.

He explained the process of calibration of compressibility i.e. CO_2 saturation is the key and each case is unique and this is the goal of rock physics modeling. Seismic measures total porosity while it is the effective porosity which decides the volume of stored CO_2 Unlike P waves Shear wave data do not get altered by presence of fluid and its behavior is same for patchy or homogenous porosity. There is a minor increase in velocity due to decrease in density resulting from change in porosity. However when the host rock is altered rigidity modulus is lowered and shear wave velocity drops. Thus increase/decrease of shear wave velocity can throw light on the interaction of CO_2 with the host rock.

In conclusion, the findings were summarized as follows

- Capturing and storing CO_2 from atmosphere is necessary in view of increase in anthropogenic source. Saline aquifier, Coal seams, old oil fields and depleted gas fields in subsurface within sedimentary basin provides ideal storage.
- 140bmmt of CO_2 can be stored in large oil fields in 50 large basins producing additional 470bbl of oil. Although saline aquifier can possibly store up to 20 times this volume based on US experience.
- Rock physics modeling based on SEM of core data, lab studies, with both P and S wave can in principal analyze the changes in VP and VS with saturation of CO_2. Movement of flat spot and other seismic attribute can provide inputs incase of miscible CO_2.
- Monitoring movement of injected CO_2 with time is essential to ensure permanence in storage. Time lapse seismic with all its constraints is still the best way to monitor the movement.

ACBCCS 2015

CONCLUDING SESSION

31.07.15

ROUNDTABLE DISCUSSION ON:

Carbon Capture, Storage and Utilization: Towards a Low Carbon Growth Strategy

Chairman: Mr. R. K. Sachdev

Former Advisor, Ministry of Coal

At the outset Chairman Shri R. K. Sachdev complimented the ACBCCS team for taking the initiative of an awareness workshop on Carbon Capture, Storage & Utilization (CCSU). He said we should look for home grown solutions for carbon sequestration which are viable, workable and realizable. Today our 50% of population are deprived of fuel for cooking. We need to address the basic issue of energy. We are majorly dependent on coal for electricity. In America when clean coal technology was introduced, on research billions of dollars were spent. They did very well in this field, but the technologies could not be replicated for Indian coal. We require financing, management skills, political will to adopt clean coal technologies and CCU. India as third largest coal consumer, need to address this issue. China has targeted 5 BT coal production in 2020. It is also planned to convert 500 Mt coal to gas by gasification route, with higher efficiency. It is targeted that as much as 50% of the coal will not be burned directly. About 300 Institutions are actively working in China on R&D in coal. Can we invest so many resources?

There are issues of increasing pollution, global warming and the efficiency of power plants which need to be addressed. We need to do a lot to improve the coal quality in thermal plants working below average. Washing of coal helps increasing calorific value and increases efficiency of generation, but there is also a limit to reduction of ash in coal where interstitial impurities are meshed with the coal structure. Diesel generator sets constantly in use are big polluters. Transport sector is also contributing to pollution significantly. Methane gas has a global warming potential which is 20-22 times more that of carbon dioxide. Methane comes out from paddy fields and we should take up a study on how much impact on climate change methane has from the agricultural sources, not paddy alone. By one estimate 110 MT of oil equivalent potential exists in utilization of biomass and bio waste, we need to look at If in more integrated manner.

He said that CCU is important and we can think of adapting it in coastal power plants so as to utilize carbon dioxide for EOR. Otherwise significant efficiency losses would make it a unacceptable.

He appreciated participation from young researchers and suggested them that they should come forward to address various issues in the Indian context.

Dr. (Mrs.) Malti Goel, CCRI & Former Advisor, DST

Dr (Mrs) Malti Goel then made a brief presentation. Starting from a introduction to the theme deliberations of past four days was summarized on the summary of deliberations that took place in the first four days. She said that carbon and oxygen are two most valuable gases on earth. Carbon dioxide is very important too, but it has become matter of concern for climate change. We look at solar energy as clean; we can also look coal as clean energy, provided adequate measures are taken for pollution control including CO_2.

Globally industry consumes about 40% of the energy and contributes to 37% of the GHG emissions. With this in view workshop theme was to address issues in industry towards low carbon growth, In the ACBCCS 2015 workshop strategy perspectives from Aluminium, steel, power, fertilizer industry were presented. The recommendations emerging from the workshop can be grouped in four pillars of POLICY, INDUSTRY, COAL POWER SECTOR and INSTITUTION. These were presented and she then invited Panellists' views and discussions on the theme '**CCSU: Towards a Low Carbon Growth Strategy in Energy Industry'.**

Shri V. S. Verma, Former Member, CERC

Shri Verma shared his opinion that storage or burring carbon dioxide in the geological spaces or under the sea are very unpractical and a matter of concern in our conditions. He said that at one point of time Japan has came with a proposal that they had developed the technology of separation of carbon dioxide & storing it into small cubical & freezing etc. and wanted India's assistance of giving them our geological spaces for testing their carbon dioxide. This was not accepted. He also said that at present almost 30,000 MW thermal capacities is shut down in view of non availability of gas. The losses incurred to DISCOMS are very high.

About CCS high energy penalty of up to 12% is estimated. Alternative strategy has been adopted in the power sector to increase the efficiency of power plants by introducing supercritical boilers. In CCS economy of scale is main issue and cannot be accepted despite environmental benefits. .He alsid that as CCS is research intensive the technology options for CO_2 utilization should be identified. He added that feasibility of Oxyfuel technology could be examined. It can be accepted if it is proven sustainable and commercially viable.

This was followed by discussion on applicability of oxyfuel technology vis-à-vis enhanced coal bed methane scenario in the country.

Prof. Baishnab Charan Tripathy, J C Bose National Fellow, Dean, School of Life Sciences, JNU

Prof. Tripathy said that he shall present his view point on the biological aspect of CO_2 mitigation. If CO_2 has to be sequestered, one should think of oceans, where it can be converted into phytoplankton or using micro algae to produce biodiesel.

In power plants CO_2 capture, a lot of energy is consumed. Instead one can think about producing hydrogen gas and expanding use of solar energy. It is possible by biological methods, and also with non-biological methods. We should also focus on wind energy on land and in coastal areas. If we go to Gujarat coast and other coastal areas, there are large numbers of wind mills. Offshore wind energy has large potential. He gave example of Germany. It is decided to close nuclear power plants and expand use of renewable energy including solar and wind. There are many sources from where we can get electricity, and in his opinion these can be considered towards low carbon strategy.

Prof. P. S. Yadava, Department of Life Sciences, Manipur University

Prof Yadava said that he thinks we need to give push to first establish coal washeries. As pointed out by Mr. R. K. Sachdev we should also take actions to save energy though waste management. There is large scope and has to be pursued. Decomposition of waste releases a lot of methane & carbon dioxide and we can also generate electricity out of that.

Agricultural and forestry land is reservoir of carbon dioxide. Deforestation has to be stopped. Giving an example of Haryana and Punjab he said that in many places lot of biomass materials is burnt and carbon dioxide is being released.

As regard to low carbon strategy focus should be towards forest management and CO_2 utilization in plants and trees.

Sh. Shishir Tamotia, Advisor, Jupiter Oxygen Corporation

Shri Tamotia said that by attending the ACBCCS 2015 workshop he has learned so much in the last four days. He thanked the organizers and eminent speakers for this opportunity.

Shri Tamotia said that we need to adopt new technology like oxy fuel combustion for CO_2 sequestration. Giving an example of Ford who decided to test oxy technology for Aluminium which is very energy intensive material, he said CEO of Jupiter Oxygen Corp. suggested using oxygen (100% in place of 21% in air). The process became very efficient and the efficiency increased up to 70%. Generating power from coal in pulverized process produces carbon dioxide, nitrogen dioxide, argon & sulphur dioxide etc. One has to find ways to dispose them in a proper manner. In oxy fuel technology CO_2 is in pure form and 12% excess energy consumed in CO_2 capture can be compensated. There are other benefits of water saving and the savings on energy are good.

Mr. Thomas Weber, President, Jupiter Oxygen Corporation, USA

Mr. Weber said that oxy fuel technology development by Jupiter Oxygen was taken up in USA with Department of Energy and National Energy Technology Laboratory (NETL). The NETL participated and verified results of increase in efficiency up to 5%. He said we urge companies like Coal India, NTPC to relook into these data by having their own test facility of 1 MW oxy combustion electric unit. There is lot of information that can be shared. Although our results are based on eleven types of coal, the challenge is to test results to Indian type of coal. Efforts to do research here are crucial to find as how to utilize CO_2. Once CO_2 market picks up, CCU can be a commercial proposition.

New technology implementation has to address economics, which sometimes comes down when fuel costs change. A beginning should be made.

Dr. K. Palanivelu, Director, Centre for Climate Change & Adaptation Research, Anna University, Chennai

Dr. K Palanivelu appreciated that there has been considerable knowledge enrichment on carbon sequestration by attending the ACBCCS 2015 workshop.

Dr Palanivelu pointed out that he feels there is no geo mapping of carbon dioxide in our country and potential of carbon capture and storage has not been established. Some research from UK and Germany; had evaluated Indian geological storage capacity, but there are also very preliminary and more development is required. He said let us wait to see how CCSU policy emerges in December meeting of COPs.

He added that at present there is no inventory of large scale emitters, where carbon is produced from thermal plant, steel industry or other sources. Certainly storage of CO_2 need be given least preference in policy matters, but how much CO_2 can be utilized, should be assessed in conditions of our geo mapping. Attempts towards utilization of carbon dioxide should accelerate. He recommended a Pilot scale project to be taken up for considering all aspects of chemical and biological utilization.

Dr. Nimmi Singh, DGM (Chemistry), ONGC Energy Centre

At ONGC Energy Centre the focus is on alternative sources of energy like hydrogen, solar thermal, thermo-chemical, uranium exploration etc. As project manager for bio technology projects, since 2007 she is working on screening of different biotechnology which has potential in Indian conditions and are economically viable as well as the issues for large - scale products are well addressed. So far any biotechnology could not be screened. Even algal technology on which work is on from last five decades is still not economically viable and no commercial unit has came up. In the context of CCSU she suggested that one should look for a technology which can go for commercial scale production right from the beginning. One should see that large scale production is possible and that it is socially acceptable, environmentally viable and economically acceptable.

Dr. Suchita B. Rai, Scientist IV, JNARDDC, Nagpur

Dr Suchita Rai praised the ACBCCS content and said that she found presentations very enlightening. A lot of learning about CO_2 sequestration has been there in this five day workshop, and has been a valuable experience. She said by attending the workshop she got new dimension to her ongoing research studies at JNARDDC on Red mud, which is Aluminum industry waste.

She then said that she feels a lot of energy is wasted in separation of CO_2 which require its purification from 10% - 15% present in the flue gas to 85% to 95% in the process of carbon capture, one should think of applying ways to use flue gas directly. It can save the energy penalty. Moreover when sequestering CO_2 one should stress upon making some value added products that can be marketed. In storage some seismic activity might be there and what other hazard could occur should be known. Algae production can take place in waste water, so one can go for algae conversion to produce biofuels. But again different waste water produces different types of algae, so this has to be studied.

PANELISTS IN THE OPEN ROUNTABLE

1. Shri R. K. Sachdev, Ministry of coal - Chairman
2. Shri M. P. Narayanan, Ex- CMD Coal India, New Delhi
3. Shri V. S. Verma, Ec Member, CERC and Member GC, CCRI
4. Dr. (Mrs.) Malti Goel, President & CEO, CCRI, Delhi
5. Dr. Mahavir, School of Planning & Architecture, New Delhi
6. Dr. K. Palanivelu, Anna University, Chennai
7. Dr. B. C. Tripathi, JNU, New Delhi
8. Mr. Thomas Weber, Jupiter Oxygen Crop.
9. Sh. Shishir Tamotia, Jupiter Oxygen Crop.
10. Prof. P. S. Yadava, Manipur University, Imphal
11. Sh. Gautam Sen, Ex-ED, ONGC, New Delhi
12. Dr. Nimmi Singh, ONGC Energy Centre, Delhi
13. Dr. Suchita Rai, JNARDDC, Nagpur
14. Dr. S. Gandhiya Vendhan, Agricultural Eng. College & Research Institute,
15. Mr. Anshu Yadav, TERI University, New Delhi
16. Mr. Himadri Bose, Delhi University, South Campus
17. Dr. A. N. Siddiqui, Directorate of Education. Science Branch, Govt. of Delhi

Climate Change Research Institute

Workshop on Awareness and Capacity Building on Carbon Capture, Storage and Utilization: Towards a Low Carbon Growth Strategy (ACBCCS 2015) on July 27-31, 2015 at IIC, New Delhi

Feedback

- *Very well organized and exchange of ideas on during discussion was very frutfull and created awareness on CCSU.*

-Prof. P.S.Yadava (Professor, Manipur University)

- *An Industry-Academic Partnership Forum needs to be established.*

- Dr. Abhijit Mitra (Associate Professor, Calcutta University)

- *The workshop has given new dimensions to my research. It was excellent and was associated with various problems and solutions in CO_2 sequestration. Stress should be laid on cost effectiveness of the process. Also value added product development from CO_2 sequestration etc. should be studied.*

- Dr. (Mrs.) Suchita Rai (Scientist-IV, JNARDDC, Nagpur)

- *Attended two lectures of Dr. Yadava and Dr. Prasad on 31.07.2015. Excellent interaction….. I found it effective since the group was eager to learn more about the subject Congratulations for your leadership. Hope you will continue to do so to further the case of science.*

- Dr. Tapas Bhattacharayya (Visiting Scientist, ICRISAT Hyderabad)

- *This workshop has given me an immense knowledge and a positive direction to my research. This forum has given me an immense opportunity to interact with industry people & policy makers and it will lead me to think about developing cost effective technology*.

- Mr. Himadri Bose (Ph.D Student, DU)

- *Cost effectiveness was an important topic for the platform which I felt was lacking.*

- Ms. Nidhija Roy (JRF, ONGC Energy Centre)

- *It was a great workshop that covered different facts of climate change having participants from academia, industry and policy making institutions.*

-Prof. B.C.Tripathy (Dean, School of Life Sciences, JNU

- *Let us make it an international event.*

- Dr. B. Kumar (Former Chief Scientist, NGRI)

Workshop on Awareness and Capacity Building on Carbon Capture, Storage and Utilization (CCSU): Towards a Low Carbon Growth Strategy (ACBCCS 2015), held on July 27-31, 2015 at IIC, New Delhi

List of Delegates

Dr. (Mrs.) Suchita B. Rai is Scientist IV in Jawaharlal Nehru-Aluminium Research Development and Design Centre. She got her B. Tech & M. Tech from Chemical Engineering, Laxminarayan Institute of Technology, Nagpur and Ph.D from Chemical Engineering, Visvesvaraya National Institute of Technology, Nagpur. Email: suchitarai1968@gmail.com

Mr. Himadri Bose has completed his graduation in Biotechnology (H) from St. Xavier's College, Ranchi in 2010 and masters from VIT University with specialization in Applied Microbiology. He has worked on characterization of microbial enzymes from marine microbes.
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Mr. Anshu Yadav is chemical engineer by training. He did his Bachelor of Technology from NIT Srinagar and completed his Master in Engineering from Birla Institute of Technology and Science Pilani, Rajasthan. He is currently working as a Research Associate in TERI University.
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Dr. (Mrs.) Swarita Gopal did her Masters in Chemistry and obtained Ph.D. degree from I.I.T. Delhi. She has published a number of research papers in the international Journals.Since then she has been teaching Final Year Undergraduate students at Dyal Singh College, University of Delhi.
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3rd Awareness and Capacity Building Workshop on

Carbon Capture, Storage & Utilization

Towards a Low Carbon Growth Strategy

July 27-31, 2015 at IIC, New Delhi

List of Participants

S. #	Name	Organization
1	Dr. M. O. Garg	Director General, CSIR
2	Dr. (Mrs.) Malti Goel	President & CEO, Climate Change Research Institute
3	Shri R. K. Sachdev	Former Advisor, Ministry of Coal
4	Shri V. S. Verma	Member, GC, Climate Change Research Institute
5	Shri M. P. Narayanan	Ex-CMD Coal India
6	Dr. Mahavir	School of Planning & Architecture
7	Prof. T. Satyanarayana	Department of Microbiology, Delhi University
8	Dr. Ajay Mathur	Director General, Bureau of Energy Efficiency
9	Mr. Gautam Sen	Ex-ED, ONGC
10	Dr. Tapas Bhattacharya	Visiting Scientist, ICRISAT Development Centre
11	Prof. B. C. Tripathy	Dean, School of Life Sciences, Jawaharlal Nehru University
12	Prof. P.S. Yadav	Department of Life Sciences, Manipur University, Imphal
13	Dr. B. Kumar	Former Chief Scientist, Hydrocarbon Research & Exploration and Carbon Management, NGRI, Hyderabad
14	Dr. K. Palanivelu	Director, Centre for Climate Change & Adaptation Research, Chennai
15	Dr. Anupam Agnihotri	Director, JNARDDC, Nagpur
16	Dr. P. S. R. Prasad	National Geophysical Research Institute (CSIR-NGRI), Hyderbad
17	Dr. Abhijit Mitra	Faculty Member, University of Calcutta
18	Dr. Amitava Bandyopadhyay	Associate Professor. Department of Chemical Engineering, University of Calcutta
19	Dr. K. Sudhakar	Assistant Professor, National Institute of Technology, Bhopal
20	Dr. Supriya Sarkar	Head Environmental Research, Tata Steel Limited, Jamshedpur
21	Sh. Santanu Sarkar	Tata Steel Limited, Jamshedpur
22	Mr. Thomas Weber	President, Jupiter Oxygen Corporation, USA
23	Dr. V. A. Mendhe	Central Institute of Mining and Fuel Research, (CIMFR), Dhanbad
24	Dr. Navdeep Joshi	Navyoga, New Delhi
25	Shri Nirmal Jit Singh	Chief Manager (P), NFL Vijaipur
26	Mr. Rabi Mukhopadhyay	NTPC Energy Technology Research Alliance, NTPC Ltd.
27	Mrs. Anjana Sen	Doctor
28	Sh. Suresh Goel	Principal Architect, Suresh Goel & Associates
29	Sh. L. K. Bansal	Member, Climate Change Research Institute
30	Dr. Suchita Rai	Scientist-IV, JNARDDC, Nagpur

31	Dr. S. Gandhiya Vendhan	Agricultural Eng. College & Research Institute, Trichy
32	Mr. Anshu Yadav	Research Associate, TERI University
33	Mr. Himadri Bose	Research Scholar, Delhi University
34	Dr. A. N. Siddiqui	Directorate of Edu. Science Branch, Govt. of Delhi
35	Dr. Swarita Gopal	Associate Professor, Dayal Singh College
36	Ms. Mollika Bannerjee	Project Assistant Level-II, CIMFR, Dhanbad
37	Dr. B. Bhargava	Director General, ONGC Energy Centre
38	Shri Puneet Kishore	GM(P)-Head TRU, ONGC Energy Centre
39	Dr. Nimmi Singh	DGM (Chemistry), ONGC Energy Centre
40	Ms. Nidhija Roy	Junior Project Fellow, ONGC Energy Centre
41	Mr. Ranvir Cheema	Junior Project Fellow, ONGC Energy Centre
42	Dr. J. S. Sharma	Head, Environment Division, ONGC Delhi
43	Mr. S.K. Lijhara	Chief Chemist, ONGC Delhi
44	Mr. H.S. Chawla	CE (D), ONGC Delhi
45	Dr. M. Pal	DGM (Chem.), ONGC Delhi
46	Mr. Farid Haider Khan	CE (P), ONGC Delhi
47	Dr. Vivek Gupta	Docter, LNJP Hospital, New Delhi
48	Prof. Neera Bhalla Sarin	Professor, Jawaharlal Nehru University
49	Prof. Javed Ahmed	Dean (Science), Jamia Hamdard
50	Ms. Shabnam Akhtar	Research Scholar, Dept. of Botany, Jamia Hamdard
21	Dr. Narula	Asstt. Professor, Jamia Hamdard
52	Sh. Shishir Tamotia	Advisor (India), Jupiter Oxygen Crop.
53	Sh. A. K. Pasha	Jawaharlal Nehru University
54	Sh. Ashish Gupta	ORF
55	Sh. Sahani	INSA
56	Ms. Krishma Vohra	TERI University
57	Dr. Neha Tripathi	General Secretary, Climate Change Research Institute
58	Sh. Ravi Jain	Architect
59	Shri B. B. L. Gupta	Engineer, Ex-CPWD
60	Ms. Sumedha	Registration Desk Executive, Climate Change Research Institute
61	Mr. Anand	Office Assistant, Climate Change Research Institute
62	Mr. Farid Hussain	Office Administrator, Climate Change Research Institute
63	Mr. Satyajit	Computer Operator

PROGRAMME

Awareness and Capacity Building on Carbon Capture, Storage and Utilization (CCSU): Towards a Low Carbon Growth Strategy (ACBCCS 2015)

July 27-31, 2015

At

India International Centre, Lodhi Road, New Delhi–110003

Monday - 27.07.2015	
Inaugural Session	
14:30 Hrs	Registration
15:00 Hrs	Welcome Address by Dr. (Mrs.) Malti Goel, CEO, CCRI & Former Advisor, DST
15:10 Hrs	Remarks by Dr. B. Bhargava, Director General, ONGC Energy Centre
15:20 Hrs	Special Address by Dr. Jyoti Parikh, ED, IRADe
15:35 Hrs	Guest Address by Dr. M.P. Narayanan, Ex- CMD, Coal India Ltd.
15:50 Hrs	**Inauguration Address by Dr. M.O. Garg,** Director General, Council of Scientific & Industrial Research
16:05 Hrs	**Key Note Address** – Carbon dioxide Management – Aluminium Industry Perspective, by Dr. Anupam Agnihotri, Director JNARDDC, Nagpur
16:55 Hrs	Vote of Thanks
17:00 Hrs	High Tea

Tuesday – 28.07.15

Time	Session	Lecture Title and Speaker
09:50 Hrs	CO_2 Abatement & Removal	Chairman: Shri V. S. Verma
10:00 Hrs	To Set the Tone	Power Sector Development vis-a-via CO_2 Abatement Shri V.S. Verma, Former Member, CERC
10:30 Hrs		Overview of Carbon Dioxide Removal Processes and Capacity Building in CCSU Dr. (Mrs.) Malti Goel, Professor (Adjunct) Jamia Hamdard
11:30 Hrs	Tea	
11:45 Hrs		Industry Perspective Research Shri Rabi Mukhopadhyay, NTPC
12:00 Hrs	CO_2 Utilization	Climate Change Mitigation via Utilization Dr. K. Palanivelu, Anna University
12:45 Hrs	Q&A	
	Lunch Break	
14:00 Hrs	CO_2 Utilization	Chairman: Dr. K. Palanivelu
14:15 Hrs		CO_2 Utilization in Coal-fired Power Plant: Industry Perspectives Dr. K. Sudhakar, National Institute of Technology, Bhopal
15:15 Hrs		Long Term Microbial Carbon Sequestration Options For Enhanced CO_2 Utilization Prof. T. Satyanarayana University of Delhi
16:15 Hrs	Q&A	
16:30 Hrs	Tea	

Wednesday - 29.07.2015

Time	Session	Lecture Title and Speaker
09:50 Hrs	Industry Perspectives	Chairman: Dr. Ajay Mathur
10:00 Hrs		Efficiency Improvement Strategies: Energy Industry Dr. Ajay Mathur, DG, BEE
10:45 Hrs		'Experience of operation of Carbon Dioxide Recovery Plant at NFL Vijaipur Unit' Shri Nirmal Jit Singh, NFL
11:30 Hrs	Tea	
11:45 Hrs		Carbon Management – Steel Industry Perspective Dr. S. Sarkar, Tata Steel
12:45 Hrs	Q&A	
	Lunch Break	
14:00 Hrs	*Special* Session	Chairman: Dr. Malti Goel
14:15 Hrs		Low Carbon Growth Strategy for India Based on Oxy-Combustion Carbon Capture and CO_2 Utilization For Enhanced Coal Bed Methane [ECBM] Recovery Mr. Thomas Weber, Jupiter Oxygen Corp., USA
15:00 Hrs	Tea	
15:15 Hrs		Coal bed Methane recovery Status and technological Issues in India Dr. Vinod Mendhe, CIMFR, Dhanbad
16:15 Hrs		Beauty Yoga & Immunity – Dr. Navdeep Joshi
16:30 Hrs	Q&A	

Thursday - 30.07.2015

Time	Session	Lecture Title and Speaker
09:50 Hrs	CO_2 Sequestration	Chairman: Prof. P. S. Yadava
10:00 Hrs		Enhanced carbon dioxide utilization by plants grown in Free Air Carbon dioxide Enrichment (FACE) facility Prof. B. C. Tripathy, JNU
10:45 Hrs		Soil as Source & Sink for Atmospheric CO_2 Dr. Tapas Bhattacharya ICRISAT Development Centre
11:30 Hrs	Tea	
11:45 Hrs		Clathate hydrates: A powerful tool to mitigate greenhouse gas Dr. Pinnelli S.R. Prasad, CSIR -NGRI
12:45 Hrs	Q&A	
	Lunch Break	
14:00 Hrs	CO_2 Storage	Chairman: Dr. B. Kumar
14:10 Hrs		Soil carbon stock and CO_2 flux in different terrestrial ecosystems of North East India Prof. P.S. Yadava, Manipur University
14:50 Hrs		Challenges for CO_2 Storage: India's Perspective Dr. B. Kumar, Ex- NGRI
15:30 Hrs		Seaweeds: A Potential Reservoir of Carbon Dr. Abhijit Mitra, University of Calcutta
16:10 Hrs	Q&A	
16:25 Hrs	Tea	

Friday - 31.07.2015	
Open Round Table Discussion: CCSU-Towards a Low Carbon Growth Strategy	
10:00 Hrs	Sh. R. K. Sachdev – Former Advisor, Ministry of Coal - **Chairman**
10:10 Hrs	Summary of 4 days deliberations – Dr. Malti Goel, Convenor
10:20 Hrs	Academia – Prof. P. S. Yadava, Manipur University
10:30 Hrs	Academia – Prof. B. C. Tripathy, JN University
10:40 Hrs	Industry - Jupiter Oxygen Corporation
10:50 Hrs	Discussion from Floor
11:00 Hrs	**Delegates Presentation (5 minutes each)**
12:00 Hrs	Tea Break
12:15 Hrs	CO_2 Storage & EOR – Sh. Gautam Sen, Ex-ED, ONGC
12:45 Hrs	Awards & Certificates to Delegates
12:50 Hrs	Concluding Remarks
13:00 Hrs	Lunch

Vision

Mission

Innovate and become a Center of Excellence in human Resource development and Climate Change Capacity Building

Organizers

Climate Change Research Institute is 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 reducing the emission of Co_2.

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