ACBCCS
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Workshop on Awareness and Capacity Building in
Carbon Capture, Storage and Utilization:
Towards a Low Carbon Growth Strategy
27th - 31st July, 2015, New Delhi, India

Pre-Workshop Bulletin of Lecture Notes

Workshop Highlights

- Inauguration Session
  Keynote Address
- Carbon Dioxide Removal Processes in Energy Industry
- Case Studies in Energy Intensive Industry for CO_2 Utilization
- Sequestration / Storage of captured Co_2
- Round Table
  Towards a Low Carbon Growth Strategy

Workshop Theme

Carbon Dioxide Removal Processes in Energy Intensive Industry

Organized by

Climate Change Research Institute

Supported by

सत्यमेव जयते

Ministry of Earth Sciences
Government of India

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ENERGY CENTRE

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Awareness and Capacity Building in Carbon Capture, Storage and Utilization: Towards a Low Carbon Growth Strategy,

ACBCCS - 2015

India International Centre, New Delhi
From July 27-31, 2015

Climate Change Research Institute
Presents
Pre-Workshop Bulletin of Lecture Notes

Workshop Highlights

- Key Note Address
- Carbon Dioxide Removal Processes in Energy Industry
- Case Studies in Energy Intensive Industry for CO_2 Utilization
- Sequestration/ Storage of Captured CO_2
- Round Table Discussions

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Convener
Dr. (Mrs.) Malti Goel
Former Adviser and Scientist 'G' and CSIR Emeritus Scientist, Ministry of Science & Technology, New Delhi

सत्यमेव जयते
डॉ. शैलेश नायक
DR. SHAILESH NAYAK

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MESSAGE

I am glad to know that a national level workshop is being organized by Climate Change Research Institute on **Awareness and Capacity Building on Carbon Capture, Storage and Utilization (CCSU): Towards a Low Carbon Growth Strategy** during July 27-31, 2015 at IIC, New Delhi.

I understand Indian scientific community has evinced considerable interest in pursuing research in CCSU. There are many challenges of CO_2 removal processes, e.g. in understanding and forecasting carbon storage on the surface as well as in the oceans and below the ground, documentation on CO_2 sequestration inventories in forest land across the country, and modelling of CO_2 interactions in underground reservoirs, that can help in removing uncertainties.

There is a need not only for creating awareness but also capacity building among young scientists and engineers, who are keen to know about CCSU as an option for dealing with climate change concerns. Specialized capacity building workshops such as ACBCCS 2009 & 2013 did a great job to sensitize the youth. I am sure, ACBCCS 2015 will help to maintain a regional CCSU knowledge sharing initiative to improve public awareness, support accelerated technology diffusion, and eventually lead to cost reduction in future projects in the long run.

I must congratulate the organizers and Dr. Malti Goel for taking this initiative and doing a timely job by spreading scientific awareness about climate change issues.

(Shailesh Nayak)

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Dr. G. N. Qazi
Vice-Chancellor

MESSAGE

I am glad to learn that Climate Change Research Institute is organising its third national level workshop on **Awareness and Capacity Building in Carbon Capture, Storage and Utilization: Towards a Law Carbon Growth Strategy (ACBCCS 2015)** at India International Centre, New Delhi from July 27-31, 2015.

India ’s energy is coal dominated. The coal combustion also causes the highest CO_2 emissions of all fossil fuels. With the growing concerns for global warming and climate change threats in the 21st century, there has been increasing interest in research and development of carbon dioxide removal technologies. Carbon Capture and Storage (CCS) appears to offer a feasible solution through which the impact of growing fossil-fuel reliance would be minimised and capturing and storing the CO_2 instead of allowing it to escape in the atmosphere will be ensured. However, the great challenges posed by CO_2 emission need to be addressed by creating greater awareness of the pressing issues and focussing on science & technology solutions to these problems.

I convey my best wishes to Prof. Malti Goel, Convener of the ACBCCS workshop for taking up this initiative for the benefits of young engineers and researchers, in order to bring forth the problems and challenge of global warming and identify solutions leading to a sustainable energy need for times to come.

I wish the Workshop all the best.

(Dr. G.N. Qazi)

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Science & technology solutions for sustainable energy future

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Message

It gives me immense pleasure to inform that a national level workshop on **Awareness and Capacity Building on Carbon Capture, Storage and Utilization (CCSU): Towards a Low Carbon Growth Strategy** is being organized by Climate Change Research Institute from July 27-31, 2015 at India International Centre, New Delhi. In 2013, a highly successful national level workshop has also been held by the Institute about CCS. TERI Press has brought out its proceedings as a book.

Indian scientific community is very keen to research new technologies. Keeping industries interest in view in development of CCSU technologies, it has become necessary to review the scenario, particularly in India for a possible change in its social acceptance. This multi-disciplinary technology has to be understood not only from the point of view of considerations of International acceptance but also its feasibility at commercial scale with special reference to priorities at the national level in India, for its adoption by the energy industries.

The ACBCCS 2015 is sponsored by Ministry of Earth Sciences and ONGC Energy Centre. I appreciate diligence and scholarship of, Dr (Mrs) Malti Goel, President of the Institute, who is also convener of the workshop for taking this initiative. The CCSU is an emerging area of energy & climate change and the workshop has participation from academic institutions and industry across the country. It is necessary to develop a road map on the research needs on CCSU in India and submit the recommendations to the concerned agencies.

My best wishes are always with CCRI. Let these climate change awareness workshops continue to capture attention of our policy makers to deal with challenges ahead.

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

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

July 27-31, 2015 at IIC, New Delhi

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PREFACE

According to IPCC assessments the carbon dioxide concentrations in the atmosphere have increased from pre industrial value of 280 ppm to 400 ppm at present. A safe limit of 450 ppm has been set for the year 2050 to save the Planet Earth. The 21st Meeting of Conference of Parties (COPs) in December 2015 will discuss the target Intended Nationally Determined Contributions (INDCs) for each country as Post Kyoto Commitments beyond 2020 for CO_2 abatement.

With the growing concerns for climate change threats in the 21st century there has been increasing interest in carbon dioxide sequestration technology as insurance for continuation of coal use in our energy supply. Capturing of excess carbon dioxide, its utilization and permanent fixation away from the atmosphere and utilization are emerging technology options worldwide for CO_2 mitigation. The challenges are immense and solutions are to be found by scientific & technological means.

In this context, after two capacity building workshops held successfully on Carbon Capture Storage and Utilization in 2009 & 2013, we present third workshop on **Awareness and Capacity Building in Carbon Capture, Storage and Utilization: Towards a Low Carbon Growth Strategy** (ACBCCS-2015) from July 27-31, 2015, New Delhi. The workshop is being organized under the aegis of Climate Change Research Institute (CCRI) at India International Centre.

On this occasion I would like to thank Prof. D. P. Agrawal, Chairman, CCRI Governing Council and Members of the National Advisory Board for their support and encouragement. I feel indebted to overwhelming response from the eminent experts and delegates from various institutions and industry across the country. The support from Ministry of Earth Sciences, Government of India and ONGC Energy Centre for this capacity building workshop is thankfully acknowledged.

Dr. (Mrs) Malti Goel
Convener, ACBCCS 2015
Former Adviser, DST

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

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Pre-Workshop Lecture Notes

CARBON DIOXIDE REMOVAL PROCESSES IN ENERGY INDUSTRY AND CAPACITY BUILDING IN CCS

Malti Goel
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Workshop Theme Paper

1. Carbon Dioxide Removal Processes

It is well known that the atmospheric carbon dioxide cycle (Carbon Cycle in short) has a vital role in maintaining the earth dynamic system, components of that act on different time scales, varying from less than a second to hundreds of years. Increasingly, CO_2 is being added in the atmosphere from growing energy use and its generation from fossil fuel combustion. This is affecting the natural carbon cycle. Thus, the motivation for carbon capture and storage comes from developing ways to remove excess carbon dioxide in the atmosphere.

Both biotic and non-biotic (engineering) processes are being developed for carbon dioxide removal. Among the engineering processes carbon capture, storage and utilization (CCSU) is a promising technology as a low carbon growth strategy (LCGS) to climate change provided it is scalable to the desired extent. The other alternative is geo-engineering approach which suggests management of solar radiation in the outer space. Mechanics of reflecting part of the radiation back to space thereby preventing it to enter the earth's atmosphere is being worked out. Biotic processes on the other hand relate to enhancement of natural carbon sinks viz., terrestrial sequestration, ocean sequestration, biofuels production among others.

Sequestration of carbon dioxide by capture and storage is one of the most researched option for excess carbon dioxide removal (CDR) getting accumulated in the atmosphere. Intergovernmental Panel on Climate Change brought out the Special Report on Carbon Capture and Storage (CCS)[1] in 2005. In this not only scientific, technical, environmental, economic as well as social aspects of CCS, but also legal and safely aspects of deployment as well as gaps in knowledge for CCS as climate change mitigation option are covered. Utilization of carbon dioxide is also included.

Three major components of CCSU are; (i) Carbon Capture, (ii) Carbon Storage, which includes transportation and (iii) Carbon Utilization. Carbon capture technology is further broken into **Post combustion**, **Pre combustion** and **In combustion options**. Captured CO_2 is then transported to its storage sites. The capture technology is cost intensive, material intensive and has high energy penalty. 1st generation, 2nd generation and transformational technologies are being researched to make them feasible at large scale. It involves not only materials research, but also process improvement and novel equipment design. The CO_2 solutions however, may emerge from its utilization using chemical or biological methods into value added products. The various S&T flows are summarized in Fig.1.

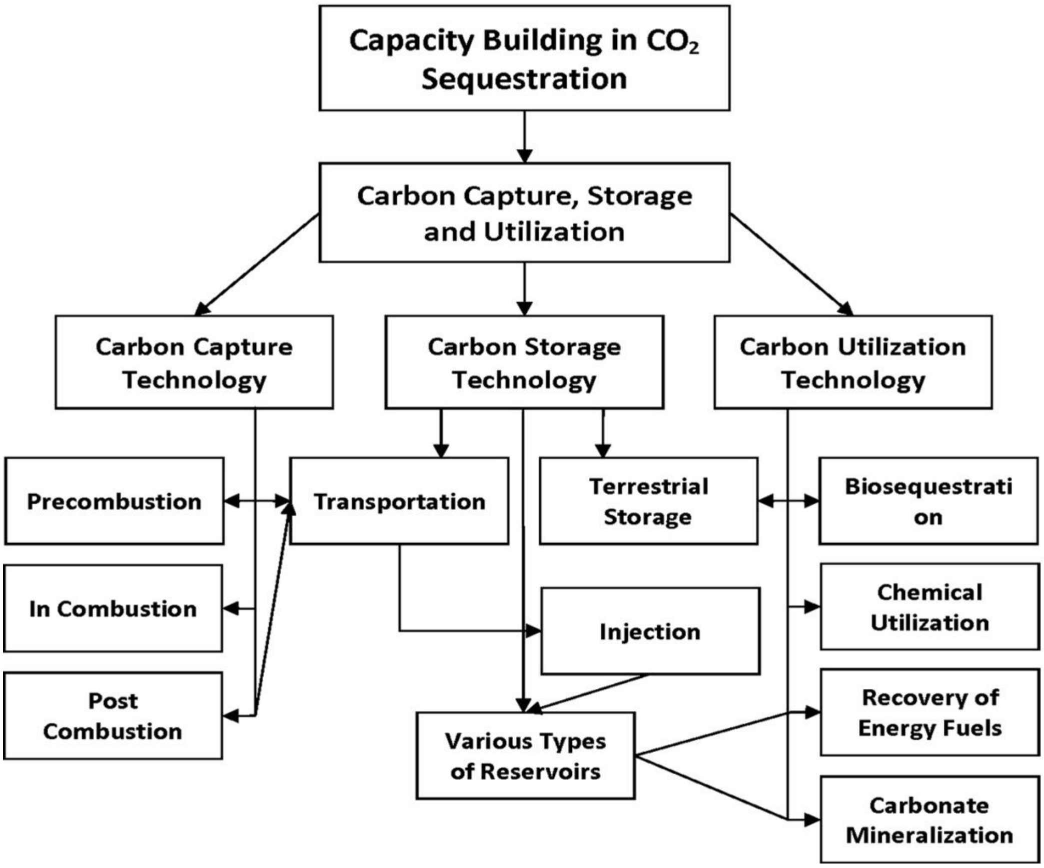

Fig. 1: CCSU as multi-disciplinary Interactive Science, Technology and Engineering

Understanding of technology sub-systems requires knowledge of basic science & technology from Chemical Engineering, Biochemical Engineering, Geological Engineering as well as Energy Engineering besides Environment Engineering and others. Evidently, R&D efforts are on worldwide to develop learning curve by which one can expect future growth in technology.

Current R&D status in CCSU technology will be presented during the workshop. In the following we discuss capacity building, national and international efforts and the current workshop theme.

2. Need for Capacity Development

In most parts of the developing world, governments are committed for reporting actions for climate change mitigation. It has been said that there have been limited efforts in educating public at large in developing scientific & technological actions. The carbon capture, storage & utilization (CCSU) technology is a multi-disciplinary scientific &

engineering topic, it requires inputs from diversified fields. Therefore basic understanding of various topics and its implications in the global context are needed through capacity building.

Soon after the 1992 Rio Earth Summit, research programmes were started in USA[2], Japan and other countries to develop scientific methods of CO_2 sequestration. Intergovernmental Panel on Climate Change has commented on wide spread applications of CCS (U is silent in this), which would depend on technical maturity & the cost of technology and its overall potential, as well as the need for diffusion and transfer of technology to developing countries. This includes their capacity development to apply the technology, knowledge sharing on scientific developments and skills, regulatory aspects, environmental issues and public perception.

2.1 International Efforts

International efforts in capacity building in Carbon Capture and Storage (CCS) formally began around 2003. Asia Pacific Economic Corporation (APEC) was first to initiate a three phase capacity building project in APEC region countries to explore potential for geological CO_2 capture & storage technology with the objectives of enhancing the capacity of APEC developing economies to undertake CCS projects and building awareness, knowledge & skills for implementation of CCS projects. The major initiative came from Carbon Sequestration Leadership Forum (CSLF)[3] of Department of Energy, USA which also began in 2003. The CSLF formed a Capacity Building for Emerging Economies Task Force (CBTF) in 2005 and began a series of capacity building workshops focusing on awareness raising and participatory dialogue.

Under the umbrella of CSLF Task Force first Capacity Building in Emerging Economies was held as Round Table Discussion in Pittsburg, USA in 2007 in conjunction with the 6th Annual Conference on Carbon Capture and Sequestration participated by Indian researchers and policy makers. Initially these were held in conjunction with its Technical Group meetings. Developing country member countries are expected to participate in these to gain knowledge about global CCS implementation. The CSLF having 23 countries as its members formally approved a Capacity Building Programme in 2009 with the object to develop knowledge tools, expertise and institutions. A Capacity Development Fund (CDF) has been established in 2011 with a projection of nine capacity building projects in its five developing member countries. India is one of these, however no workshop has yet been held in India under CDF.

Need for CCS training continued to grow. World Bank[4] and other multi-lateral organizations like, UN Industrial Development Organization (UNIDO), Asian Development Bank (ADB) have been instrumental in funding awareness raising capacity building programmes, while commissioning specific studies on CCS in a number of developing countries with the object of identifying pilot projects. The Global Carbon Capture and Storage Institute (GCCSI) has added another milestone by launching a target work programme as Capacity Development Country-of-Focus in non-Annex I countries of

UNFCCC. Several Universities in UK[5] and USA have begun Post-Graduate level courses to create experts in the area of CCS and learning new technologies.

2.2 Indian Efforts

The capacity building efforts in CCS in India have been started soon after it joined Carbon Sequestration Leadership Forum (CSLF) in 2003 as founder member with Ministry of Power as the nodal agency. Department of Science & Technology (DST) under the guidance of Ministry of Power took the lead under its inter-sectoral programmes to initiate research. Initially two Inter-Sectoral CO_2 Sequestration Science & Technology Interaction Meets were held in 2004 and 2006 with Coal India, NTPC, ONGC, Geological Survey of India, R&D laboratories and academic institutions participating.

Specific highlights of these workshops included industry participation in scoping studies and preliminary results from application of CO_2 EOR in a mature oil field of Ankleshwar in Gujrat, pre-feasibility study in saline aquifers[6], in stratigraphic horizon of coal deposits in India, feasibility of oxy fuel technology and possibility of further research on enhanced coal bed methane recovery from CO_2 storage in coal seams[7]. On carbon capture; several CSIR laboratories presented research on new materials viz., amine functionalized materials including natural biopolymers and synthesized nitrogenous activated carbon, zeolites and alumina with further optimization in progress. Potential of PSA processes for higher CO_2 recovery from power plant flue gases and possibility of using Hydrotalcites-materials as anionic clays for CO_2 adsorption were discussed[8].

India's CCS policy s focused on pursuing Research, Development & Demonstration. It was projected as an arm of clean coal technology to control CO_2 emissions along with SO_2, NO_x from coal use. Visits of scientists & engineers to project sites were encouraged. To provide a greater thrust to R&D, DST launched a National CO_2 Sequestration Research Programme in 2005 with the objectives as follows; (i) CO_2 Sequestration through Micro-algae Bio-fixation Technique (ii) Carbon Capture Process Development (iii) Terrestrial Agro-forestry Sequestration Modeling Network (iv) Policy development studies[9]. A number of academic institutions and R&D laboratories evinced interest in pursuing scientific research on CCS through support from the Government.

Concurrently, Indian Industry's initiatives for capacity building continued. National Thermal Power Corporation workshop on Carbon Capture and Storage was held in 2011. Attended by policy makers in power, coal and oil sectors, and academic scientists, another follow up Round Table on CCS was held in 2012 at Power Management Institute Noida. The Bharat Heavy Electricals Ltd., Trichy training workshops on CCT and CCS were held in 2011 & 2012. BHEL hosts a EU TREC – STEP CCT-CCS cluster for advancement of technologies. 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 ONGC, SAIL and Tata Steel have carbon neutral research centers.

Among the energy demand sectors Fertilizer industry is one the target industry for high CO_2 emissions, which can be recycled. In the Indian fertilizers sector National

Fertilizer Ltd (NFL), Indian Farmers Fertilizer Cooperative Limited (IFFCO) and Nagarjuna Fertilizers and Chemicals Limited (NFCL) have adopted Japanese MHI carbon capture technology. We conducted policy studies to develop strategies for carbon reduction in metal industry viz. Steel[10] and aluminum[11], which are energy intensive.

As India has not opted for International trainings in CCS, Awareness and Capacity Building in Carbon Capture and Storage (ACBCCS) workshops were conceived in-house with the support from subject experts and academicians. Young researchers, engineers and manpower generated under CCS projects needed a greater exposure on India specific issues. In the two Workshops held (2009 and 2013) so far there has been a huge motivational effect on the work being carried out in various research centers in the country as the participants were exposed to practical utilization of their research. ACBCCS 2009[12] and 2013[13] both supported by Ministry of Earth Sciences are acclaimed as very good and timely initiative, and raised momentum for research.

3. ACBCCS 2015

After having two successful capacity building workshops ACBCCS 2009 and ACBCCS 2013, third in the series is ACBCCS 2015 - **Awareness and Capacity Building in Carbon Capture, Storage and Utilization: Towards a low Carbon Growth Strategy**, being organized from July 27-31, 2015. The workshop objectives are; (i) to provide understanding of science & technology of Carbon Capture, Storage and Utilization and its growing importance in the energy industry (ii) to learn about CO_2 Capture - chemical, biochemical, biological options and identify terrestrial CO_2 storage processes in the context, (iii) to put forth perspectives on carbon removal and utilization processes in knowledge domain and submit recommendations to concerned agencies.

In this context UNIDO Global Technology Roadmap Project[14] for CCS having a focus on developing countries with energy-intensive industries is worth mentioning. The project aims to analyze the status of CCS in key industrial sectors and to create a roadmap to chart the course needed to apply the technology at scale in these sectors. The Technology Road map identified five focused sectors as; high purity CO_2 sources, iron & steel, cement, refineries and biomass based sources for a low carbon growth strategy. The roadmap also addresses cross cutting issues and long term vision up to 2050.

Carbon sequestration has been formally cited in the UNFCCC, it is discussed in climate change negotiations which take place in Conference of Parties (COPs) every year. Subsidiary Body for Scientific and Technological Advice workshops on carbon capture and storage are being held since 2006[15]. Therefore, to discuss the role of CCSU towards low carbon growth strategy post 2020 and targets to be defined in currently proposed INDCs for discussion in Paris meeting, an Open Roundtable discussion is planned on 31st July. It will deliberate on role of CCS in the future climate action plan up to 2030. Niche gathering of experts, researchers and students would participate to deliberate on processes and industry perspectives. It is hoped to trigger education curricula and further R&D.

4. Conclusions

Globally, CCS has been promoted as a solution to address the problem of global warming. In the context of CCSU India has taken the first step to recognize the scope but has yet to put it on the policy agenda. Even though Indian industry is keen to participate, the challenges of economics, energy penalty and safety of CCS technology related to power generation for emissions abatement and energy intensive industry are major hurdles towards low carbon growth strategy. These can be resolved by further R&D.

It is time to revisit the policy and create enabling environment for industry for technology development and make planned investment in CCS research as a long-term energy security. As was recommended in ACBCCS 2013 an **Institution** through knowledge networking of ongoing efforts would lead to enhance the utilization of resources in the country and active participation from industry. The energy intensive industry can thus achieve significant benefits and co-benefits from CO_2 mitigation for public good.

Keeping above in view I would like to summaries **five point agenda** as below.

(i) Carbon sequestration is to be recognized as an important component in climate change agenda requiring development of 'carbon neutral technology' and not a 'policy neutral strategy'.

(ii) Industry should participate in technology development with policy support from the Government.

(iii) Creating an institution and knowledge sharing among the various stakeholders in the ongoing projects would lead to accelerated growth by meaningfully application of research output

(iv) Technology of CO_2 sequestration in terrestrial ecosystem should form the basis of future energy policy.

(v) Towards a low carbon growth strategy, India's efforts in CCSU should also be included in the INDCs in the Paris meeting.

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About Author

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Dr. Malti Goel is former Adviser & Scientist 'G', Department of Science & Technology, Govt of India and was heading Inter-sectoral Science & Technology Division. She supported greenhouse gas emission mitigation research in industry and spearheaded national programmes on Atmospheric Science Research and Carbon Sequestration among others. She obtained Masters' degree in Physics from BITS, Pilani, and Post Graduate Diploma DIIT and Ph.D in Physics, from IIT, Delhi. She has work experience in teaching and research at IIT Delhi and other Universities before and after being in the government. Her current research interests are in Clean Energy and Green Technology development.

She is author of the book '*Energy Sources and Global Warming'*, Allied Publishers Pvt. Ltd., New Delhi, which was released by Hon. A.P.J. Abdul Kalam, President of India in 2006. Dr. Malti Goel has contributed quite a few books on carbon sequestration namely; *Carbon Capture And Storage R&D Technologies for Sustainable Future,* Narosa Publishing House Ltd., 2008; *CO_2 Sequestration Technology For Clean Energy,* 2010; and *Carbon Capture, Storage and Utilization*, Teri Press. 2015. Her work has received national and international recognition, which includes citations in patents of her research and invitations to lecture from world's distinguished Scientific Academies. Recipient of several awards and honors she became Fellow, National Environment Science Academy in 2008.

CARBON DIOXIDE MANAGEMENT–ALUMINIUM INDUSTRY PERSPECTIVE

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Extended Abstract

Aluminum represents the second largest metal in the world and it has played an important role in the development of human society civilization. The metal industry contributes about 7% of total global carbon dioxide emissions from all sources, led by iron and steel (4.4%) and aluminum (1.7%). Global warming and greenhouse gases have become key issues for aluminium industry. The aluminium sector has committed itself to reduce emissions of greenhouse effect gases in the coming years. Several actions have been taken to reduce the CO_2 equivalent per tonne of aluminium; especially by reducing energy consumption and the emission of perfluorocarbon (PFC) arising from anode effects. Primary aluminium production is the largest source of emissions of two PFCs i.e. tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6). Primary aluminium producers are already setting an example for other industries by taking steps to evaluate and reduce emissions of one of the most potent greenhouse gases i.e. perfluorocarbons (PFCs). The perfluorocarbon emissions are related to the "anode effect" and have a high global warming potential (GWP) of 6500 (CF_4) and 9200 (C_2F_6).

The aluminum industry worldwide produced 53 million tons of material in 2014, a mere about 3% of the total volume produced by the iron & steel industry. Although the carbon footprint of the iron & steel industries is about three times larger than that of the aluminum industry, unit carbon emission for the aluminum industry (12.7 metric tonnes of CO_2eq per tonne) is about 13 times greater than that of iron & steel.

In the 21st century, sustainability is widely regarded as the new corporate culture, and leading aluminium industries are striving towards carbon neutrality. The current carbon footprint of the global aluminum industry is estimated at 500 million metric tonnes carbon dioxide equivalent (CO_2eq), representing about 1.7% of global emissions from all sources. For the global aluminum industry, carbon neutrality is defined as a state where the total "in-use" CO_2eq saved from all products in current use, including incremental process efficiency improvements, recycling, and urban mining activities, equals the CO_2eq expended to produce the global output of aluminium.

The carbon-based emissions associated with the aluminium production come from following sources:

Bauxite mining: 2-3 tonnes of bauxite yield one tonne of alumina. More than 250 tonnes of bauxite is mined annually. 150MJ primary energy consumed per dry tonne of bauxite which produces 20 kg CO_{2eq} per tonne of aluminium produced.

Alumina refinery: Fuel combustion for heat and steam represent the bulk of Bayer process emissions, with 10% from indirect sources. In the Bayer process of refining bauxite two tonnes of alumina yield one tonne of aluminium. 15,000MJ primary energy consumed per tonne of metallurgical alumina. All this amounts to about 1000 kg CO_{2eq} per tonne of aluminium produced.

Anode production: The carbon anodes consumed in the Hall-Heroult Process are often baked before use (Prebake technology) in gas- or oil-fired furnaces. Around 430kg of anodes are used to produce 1 tonne of molten aluminium. 4,000MJ primary energy consumed per tonne of anodes produced. This produces about 200 kg CO_{2eq} per tonne of aluminium produced.

Reaction products: CO_2 from anode consumption now constitutes around two thirds of the process direct emissions, with PFCs making up the remainder. The reaction produces oxygen that reacts with the carbon anode to produce CO_2 and small quantities of CO; this reaction produces about 1500kg of carbon dioxide equivalents for each tonne of aluminium produced. Total absolute direct GHG emissions from electrolysis are today 35% below 1990 levels despite a tremendous increase in primary aluminium production capacity over the years. This has been driven by a reduction in the emissions of perfluorocarbon gases (PFCs) by more than 90% per tonne aluminium between 1990 and 2013.

Air burning: The carbon anode loses mass to oxidation with the atmosphere which produces 0.130 kg of CO_2 for each kilogram of aluminium produced.

Electricity Generation and Transmission: Global average smelter electrical (AC) power consumption is in the range 14-15 MWh per tonne of aluminium. Potlines operating on electricity obtained from coal-fired power plants produce 16.0 kg of CO_2 gas for each kilogram of aluminium produced, while potlines using electricity from hydro-power plants produce close to zero CO_2 gas emissions.

Ingot casting: Molten aluminium, along with process scrap, is cast into primary metal products, for which heat is required. GHG emissions from casthouses constitute both direct sources of fuel combustion (66%) and indirect sources from electricity consumption. 10,000MJ of primary energy are consumed per tonne of aluminium ingot. During this process about 90kg CO_{2eq}/ tonne of aluminium is produced.

Semi fabrication: Primary and recycled aluminium ingots are reheated and reformed into semi-fabricated products sheet for aircraft, foil for packaging, extrusions for windows, castings for cars and buses. Each process has a different energy and emissions profile, but the average GHG emissions are around 800kg CO_{2eq} per tonne of product.

Recycling: It requires only 5% of the energy required for primary aluminium production. Recycling avoids the process emissions associated with primary production and produces only 125kg of CO_{2eq}/ tonne of aluminium

Global aluminium industry is working on following integrated and quantifiable plan for achieving "carbon neutrality"

1. Increase use of green electrical energy grid
2. Reduce process energy needs
3. Deploy products in energy saving applications
4. Increase in recycling of aluminium
5. Use of aluminium intensive efficient machinery in industry
6. Efficient aluminium cabling, turbines, solar panels
7. Consumer durables and intelligent control systems in energy supply networks
8. Lightweight vehicles;
9. Green buildings in construction sector
10. Protective aluminium packaging

Finally as it takes 20 times more energy to make aluminum from bauxite ore than to recycle it from scrap, the global aluminum industry is on the verge of setting up reasonable, self-imposed energy/carbon neutrality goal to incrementally increase the supply of *recycled aluminium* for every tonne of incremental production via primary aluminum smelter capacity. Furthermore, the aluminium industry is striving to take a global leadership position by actively developing internationally accepted and approved carbon footprint credit protocols.

About Author

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Dr. Anupam Agnihotri is B.Tech, IIT Kanpur and M.Tech & Ph.D from VNIT, Nagpur. Presently as Director Jawaharlal Nehru Aluminium Research Development & Design Centre (JNARDDC), he was served awards including Letters of appreciation and has 54 papers to his credit.

Dr. Agnihotri is Metallurgist and smelting specialist deeply involved in research activities on Aluminium Electrolysis, Electrical, thermal and magnetic studies of electrolysis cells, Infrared Thermography, Energy audit of Aluminium plants etc. Pioneered various projects related to aluminium technology especially in area of smelter, energy audit, environmental monitoring, modernization programs, low cost material alternatives and mathematical modelling of Indian aluminium industry. Has made effective contributions in the Electrolysis of Aluminium (Hall-Heroult Process) for improving the process efficiency, material consumption, thermal & magnetic balance for Indian Aluminium plants are remarkable. Presently involved in national level projects such as like Development of Super Thermal Aluminium Conductor and National mission of enhanced energy efficiency assessment studies in India and also associated with the DRDO's ambitious project on indigenization of Aluminium Alloys. Dr. Agnihotri is member of many professional bodies.

CLIMATE CHANGE MITIGATION VIAUTILIZATION OF CARBON DIOXIDE

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Extended Abstract

Carbon dioxide is a waste product in many industries and is a major contributor to global warming. It has potentially devastating effects with the steadily increasing concentration of CO_2 in the atmosphere. The only large scale solution to the problem of CO_2 emissions currently being considered is carbon capture and storage. However, this is an energy intensive and hence expensive process which will result in increased fossil fuel consumption and increased energy costs. Carbon capture and storage (CCS) does not eliminate carbon dioxide; it just stores it. Environmental threats of escape are spurring re-evaluation of carbon capture strategies to eliminate carbon dioxide rather than move and store it. A more attractive solution would be carbon capture and utilization in which the waste CO_2 was not dumped, but converted into a commercially valuable product. The growing re-evaluation of carbon capture strategies emphasizes transforming carbon dioxide (CO_2) to valuable chemical rather than storing it. The aim of this paper is to give an overview to cover the work carried out on this waste CO_2 from flue-gas could be converted into a valuable chemical for which there is a large scale demand.

Passing carbon dioxide through slag left over from steel-making turns the waste product into a strong material that can be used for construction. Put into tanks of algae, it can be used to make biofuels. Waste carbon dioxide can even be cleaned up to “food grade” and injected into fizzy drinks. There are a few examples of the development of processes to use CO_2 like these technologies known as Carbon Dioxide Utilisation (CDU). CDU efforts focus on pathways and novel approaches for reducing CO_2 emissions by developing beneficial uses for CO_2. But these processes are rare – instead, carbon dioxide from power generation is normally simply vented into the atmosphere, where it contributes to global warming. When the gas is needed for an industrial process, it is manufactured from scratch.

There are real possibilities here that we are still only at the beginning of exploring. Some of the technology we need has already been developed, some is at an early stage, and in some cases we need to develop new chemistry. Chemical activation of carbon dioxide could help to reduce its concentration in the atmosphere while at the same time exploiting it as a carbon feedstock for the production of useful organic compounds. Various possible chemical processes that may be used for CO_2 utilization. There are non-catalytic chemical processes, processes using catalysis, photo-catalytic reduction, bio-chemical and enzymatic conversion, electrochemical reduction, as well as solar-thermal/catalytic processes.

Chemical processes for CO_2 conversion in chemical industry, for which synthesis of urea from ammonia and the production of salicylic acid from phenol and CO_2 are representative examples. Soda lime (mixture of sodium and calcium hydroxides) are well known for their assistance in the stoichiometric transformation of carbon dioxide to carbonate salts. Mixtures of glycol and amines (glycol-amine) as well as coordination complexes of polyamines have been reported to bind CO_2 reversibly through the formation of carbamates.

Reductive conversion of CO_2 into useful products of industrial significance such as formaldehyde, formic acid, methanol, or oxalic acid has proven more challenging to achieve selectively. Photoreduction of CO_2 on irradiated semi conductor surfaces has been widely reported to give a range of C1 and C2 products, including CO, formate, methanol, methane, formaldehyde, oxalic acid and glyoxal. CO_2 photoreductions are observed on a variety of metal oxides, including WO3, TiO2, ZnO, as well as on GaP. ZnS and CdS. Reductions are believed to result from photopromotion of hole/electron pairs in the oxide/sufide conduction bands, capture of electrons by CO_2 and hole oxidation of water or some added reducing agent. Photoefficiencies for CO_2 reduction appear to range from less than 1% to 23% on certain quantized oxide particles. The high efficiencies also appear to require large band gaps, thus reducing efficient use of the full spectrum of sunlight. Electrochemical activation of carbon dioxide using metallic and modified cathodes have long been studied, and significant progress has been made. Various reduction products can be formed via different reaction pathways; the main products include formic acid oxalic acid formaldehyde (CH2O), methane (CH4), and many others.

In this direction, we have carried out investigation of converting CO_2 into sodium carbonate by modified Solvay process (Textile dye bath effluent) , carbamate from 4-AMP and vegetable oil and resorcylic acid from resorcinol (under sonication). The CDU technologies especially for stationary industrial sourceshold promise by helping to mitigate significantly its environmental impactwith simultaneous generation of saleable chemical products in a sustainable way from this waste CO_2 gas.

About Author

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Dr. K. Palanivelu is working as Professor at the Centre for Environmental Studies and Director of Centre for Climate Change and Adaptation Research of Anna University, Chennai. He had a first class career throughout his education. He obtained his B.Sc. (Chemistry) from Madras University in 1983. He completed his M.Sc from Annamalai University and Ph.D fromIndian Institute of Technology Madras, Chennai. He worked as project officer at IIT Madras for a brief period and moved on to Centre for Environmental Studies, Anna University, Chennai in 1992.

Dr. Palanivelu worked on 'Determination and Separation of Trace Amounts of Arsenic' for his Ph.D. He was a visiting professor at Chungnam National University, South Korea during 2007 under Brain-Korea Fellowship. He was an exchange Professor to University of Bologna, Italy under Erasmus Fellowship. Dr. Palanivelu's research interests include Pollution Control, green Chemistry, CO2 utilisation for climate change mitigation, Trace Analysis of Organics and Heavy Metals. He has been teaching courses on Environmental Chemistry, Environmental Pollution

Control, and Instrumental methods of analysis since last 22 years. He has guided 60 students for M.E, and M.Sc., and 14 PhDs. He has published 114 papers in journals with more than 3500 citations and 80 in conferences and symposiums. He has completed 4 sponsored projects as principal investigatorand two are in progress. Currently 8 students are doing PhD under his supervision. Dr. K. Palanivelu is recipient of four environmental awards for his research contribution.

CO_2 UTILIZATION IN COAL-FIRED POWER PLANT: INDUSTRIAL PERSPECTIVES

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Extended Abstract

A promising biological solution for the utilization and conversion of CO_2 from a power plant into viable economic products are discussed in this study. Microalgae are the potential source of food, feed, polymer, nutrients. It consumes 1.7-2 Kg CO_2 to produce 1 Kg biomass so it act as good CO_2 scrubber. Algae biomass can use as potential source for green fuel production, which will help the high energy demand of the world. Algae live on a high concentration of carbon dioxide and nitrogen dioxide. These pollutants are released by automobiles, cement plants, breweries, fertilizer plants, steel plants. The biotechnology of microalgae production can be divided into the following types (i.e., cultivation systems, ponds and/or PBRs with associated harvesting and processing equipment) and the wetware (i.e., the specific algae species and strains being cultivated).These pollutants can serve as nutrients for the algae.

Using algae for reducing the CO_2 concentration in the atmosphere is known as algae-based Carbon Capture technology. The algae production facilities can thus be fed with the exhaust gases from these plants to significantly increase the algal productivity and clean up the air. An additional benefit from this technology is that the oil found in algae can be processed into a biodiesel. Remaining components of the algae can be used to make other products, including Ethanol and livestock feed. This technology offers a safe and sustainable solution to the problems associated with global warming. The value-added products that can be produced from these four main technologies are: biomass (high and low grade), biomass derived products (pharmaceutical, chemical or nutritional), synthesis gas (methanol, fuel and chemical production), specialty products (extracted using supercritical technology), organic carbonates (linear, cyclic or polycarbonates), carboxylates (formic acid, oxalic acid, etc), salicylic acid and urea.

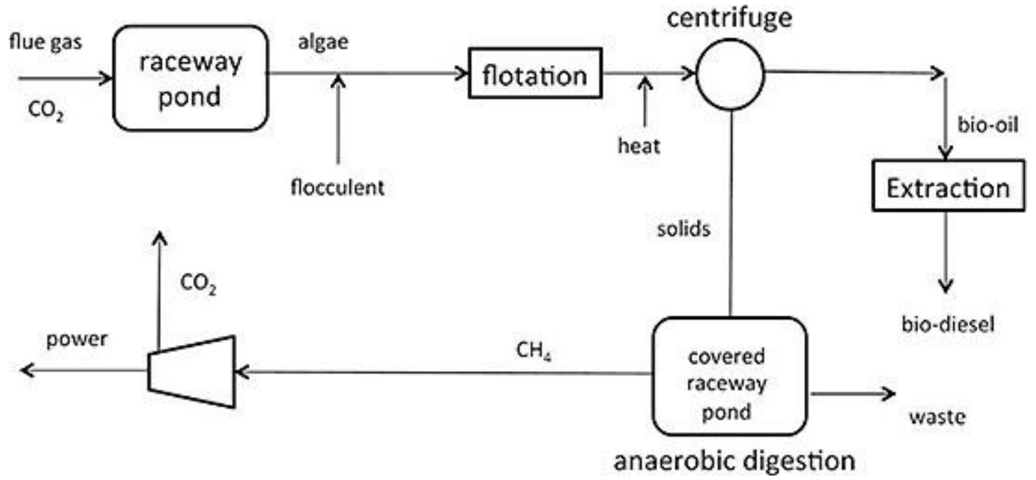

Figure . Schematic diagram of algae process from Campbell ***et al.*** **(2009).**

It should be noted that the amounts of CO_2 consumed for making the chemical products are relatively small, but the advantages of the value-added products and the environment friendly processing plus the CO_2 avoidance compared to the conventional energy intensive or hazardous processes make CO_2 utilization an important option in CO_2 management. The main areas of interest were microalgae biomass production (pond and bioreactor production), fixation of CO_2 into organic compounds (production of various chemical products), and direct utilisation of CO_2. Carbon dioxide must be captured, purified and concentrated prior to employment in most utilization methods. The feasibility of these processes was evaluated according to their thermodynamics, energetics, production rates and yields, product values and economics.

Industrial Strategies:

Major Factor: CO_2 aeration rate and light intensity. Enhancement of light utilization efficiency is substantial to obtain higher CO_2 fixation ability:

-increase surface area
-shortening the light path and layer thickness
-using genetic engineering
Improvement of CO_2 transport efficiency
-Getting the extensive air/liquid interface area
-Increase mixing time/intensity
Maintain CO_2/O_2 balance
-Increasing turbulence
-Stripping the culture medium with air or inert gas

CO_2 fixation rate of microalgae are lower than the available physicochemical methods.
Large capacity and well defined photo bioreactor is required

Major Problems.

The major problems faced by companies implementing algae based CO_2 sequestration techniques are:

The high cost of infrastructure

The limited availability of land space near power plants

Specific operational problems as well as inefficiencies

High CO_2 concentrations cause the algae suspension to become acidic, thereby stunting algae growth.

Conclusion:

In this study, it was determined that CO_2 fixation using micro algal species is very promising and competing alternative technologies to conventional sequestration. The various aspects associated with the design of microalgae production units (photo-bioreactors and open ponds) are to be studied in detail due to the flue gas processing (e.g., mercury, arsenic, and particulate removal, etc.) that must be performed prior to exploitation; CO_2 utilization directly from a coal-fired power plant is not currently feasible with the available technologies. Despite only a small percentage of CO_2 being utilized when compared to the total amount emitted by a 500 MW power plant, CO_2 sequestration by microalgae are recommended for the creation of value from CO_2. Microalgae cultivation for CO_2 sequestration is more feasible than geological sequestration it helps in maintaining environmental balance thus reducing the threat of global warming

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About Author

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Dr. K. Sudhakar obtained his B.E in Mechanical Engineering from Government College of Engineering, Salem, Madras University and M.Tech in Energy Management from School of Energy & Environment Studies, Devi Ahilya University, Indore. He obtained his Ph.D from National Institute of Technology, Tiruchirapalli for his thesis entitled “Technical and Economic Feasibility of $C0_2$ Sequestration using microalgae in India. He has received MHRD GATE and DST Senior research fellowship from Government of India for his Doctoral Research and worked in National Institute of Technology, Tiruchirapalli from 2008-2010. He has been actively involved in teaching & research in the area of Energy & Environment. His major research areas include Climate Change, Carbon Sequestration, Biofuel, Solar Thermal and PV Systems, Sustainability assessment, Hybrid Energy systems; Mathematical Modeling, Exergy analysis and Energy Conservation. He has published around 70 research papers both in referred national & international journals and

conferences proceedings. He has authored more than 10 technical books. He is a certified Energy Manager & Auditor by BEE, Ministry of Power.
He has a various meritorious awards to his credit. Few of those are:

1. Best Young Teacher Award by Annai Teresa College of Engineering, TN in 2006
2. Brightest young Climate Leader Award by British Council, New Delhi in 2008
3. Young scientist Award by MPCOST, Bhopal in 2012.
4. National Citizenship Gold Medal Award by GEPRA, New Delhi in Jan -2015
5. Rashtriya Gaurav Award, India International Friendship Society, New Delhi in 2015

LONG TERM MICROBIAL CARBON SEQUESTRATION OPTIONS FOR ENHANCED CO_2 UTILIZATION

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Extended Abstract

The atmospheric CO_2 concentration has increased from 280 ppm in 1800, the beginning of industrial age, to 396 ppm today. Without any mitigation, it could reach levels of 700-900 ppm by the end of the 21st century, which could bring about severe climate change. This abrupt imbalance has disturbed the Earth's carbon cycle that is normally kept in balance by the oceans, vegetation, soil and the forests. The most pressing technical and economic challenge of the present day is to supply energy demand for the world economic growth without affecting the Earth's climate. That is why the current focus is on reducing fossil fuel usage and minimizing the emission of CO_2 in atmosphere. In spite of the advances made in the field of renewable energy, it has not been possible to replace gas, coal and oil to meet the current energy needs. If fossil fuels, particularly coal, remain the dominant energy source of the 21st century, then stabilizing the concentration of atmospheric CO_2 will require development of the capability to capture CO_2 from the combustion of fossil fuels and store it safely away from the atmosphere. The hazards of global warming have reached to a magnitude that irreversible changes in the functioning of the planet are seriously feared. It is, therefore, necessary for the whole scientific community to restore permissible levels of CO_2 by using the existing knowledge.

Carbon sequestration or carbon capture and storage (CCS) has emerged as a potentially promising technology to deal with the problem of global warming. Several approaches are being considered, including geological, oceanic, and terrestrial sequestration, as well as CO_2 conversion into useful materials. Biological systems have solutions to the most dreaded problems of all times. The photosynthetic fixation of atmospheric CO_2 in plants and trees could be of great value in maintaining a CO_2 balance in the atmosphere. Algal systems, on the other hand, being more efficient in photosynthetic capabilities are the choice of research for solving global warming problem. The biomass thus produced could be used as fuel for various heating and power purposes.

Mankind is indebted to microbes for bringing and maintaining stable oxygenic conditions on the Earth. A proper understanding of microbial systems and their processes will help in stabilizing atmospheric conditions in future too. Investigations are underway for exploiting carbonic anhydrase and other carboxylating enzymes to develop a promising CO_2 mitigation strategy. The recent work on biomimetic approaches using immobilized carbonic anhydrase in bioreactors has a big hope for the safe future.

Photoautotropic organisms ranging from bacteria to higher plants have evolved unique carbon concentrating mechanism (CCM) in response to the declining levels of CO_2 in their surrounding environment. Photosynthesis is much more efficient in microalgae than in terrestrial C_3 and C_4 plants. This high efficiency is due to the presence of both intracellular and extracellular carbonic anhydrases and the CO_2 concentrating mechanism. The present focus is on exploiting the ability of microalgae to convert solar energy and CO_2 into O_2 and carbohydrates. Microalgal mass cultures can use CO_2 from power plant flue gases for the production of biomass. The algal biomass thus produced can directly be used as health food for human consumption, as animal feed or in aquaculture, for biodiesel production or as fertilizer for agriculture. A fast growing marine green alga *Chlorococcum littorale* is reported to tolerate high concentrations of CO_2. The wastewater containing phosphate (46 g m^{-3}) from a steel plant has been used to raise cultures of the photosynthetic microalga *Chlorella vulgaris*. Flue gas containing 15% CO_2 was supplemented further to get a CO_2 fixation rate of 26 g CO_2 m^{-3} h^{-1}. Research is in progress on the development of novel photobioreactors for enhanced CO_2 fixation and $CaCO_3$ formation. CO_2 fixation rate has increased from 80 to 260 mg $l^{-1}h^{-1}$ by using *Chlorella vulgaris* in a newly developed membrane-photobioreactor. A novel multidisciplinary process has recently been proposed that uses algal biomass in a photobioreator to produce H_2 besides sequestering CO_2.

Non-photosynthetic CO_2 fixation occurs widely in nature by the methanogenic archaea. These are obligate anaerobes that grow in freshwater and marine sediments, peats, swamps and wetlands, rice paddies, landfills, sewage sludge, manure piles, and the gut of animals. Methanogens are responsible for more than half of the methane released to the atmosphere. The methanogenic bacteria grow optimally at temperatures between 20 and 110 ^{o}C. Carbon monoxide dehydrogenase and/or acetyl-CoA synthase aid them to use carbon monoxide or carbon dioxide along with hydrogen as their sole energy source. Waste gases from blast furnaces containing oxides of carbon were used for converting them into methane using thermophilic methanogens. A column bioreactor operated at 55 °C and pH 7.4 was employed for the process. A mixture of three cultures of bacteria (*Rhodospirillum rubrum, Methanobacterium formidium* and *Methanosarcina barkeri*) was used for complete bioconversion of oxides of carbon to methane.

The enzymatic approach of CO_2 utilization is much faster, cleaner and easier to operate that results in higher yields and provide selectivity even under milder conditions. Carbonic anhydrases (CAs) are the fastest enzymes known which can be employed for converting CO_2 directly from industrial emissions into bicarbonate, and finally mineralized to environmentally safe and stable carbonates. Bicarbonates can also be converted to oxaloacetate or salts which can be used in electrochemistry. The efficient CAs from various microbial sources are being tested for carbon sequestration. Efforts are also underway to immobilize microbial CAs for their reusability in carbon sequestration. Another enzymatic approach involves the conversion of CO_2 into methanol by reversing the biological metabolic reaction pathway involving three dehydrogenases (formate dehydrogenase, formaldehyde dehydrogenase and alcohol dehydrogenase). The process of microbial electrosynthesis, in which microbes reduce CO_2 into multi-carbon extracellular products using electrical energy, harvested from renewable sources such as Sun or wind, is also a promising approach for CO_2 bioconversion. A possibility of converting CO_2 to hydrocarbons such as ethane, propane and butane has also been recently demonstrated. The biochemical processes occurring in nature can, therefore, provide sustainable, economical and environment-friendly breakthroughs for the conversion of CO_2 from industrial emissions to value added products.

Biomimetic approach involves identification of a biological process or structure and its application to solve a non-biological problem. Carbonic anhydrases are the fastest enzymes known for their efficiency in converting carbon dioxide into bicarbonate. Efforts are underway for using carbonic anhydrases from various microbial sources for CO_2 sequestration. The possibility of an on-site scrubber that would provide a plant-by-plant solution to CO_2 sequestration, apart from eliminating the concentration and transportation costs, is the potential advantage of the biomimetic approach. Immediate need for utilizing carbonic anhydrases in CCS economically is the development of a robust enzyme immobilization strategy that allows the reuse of the enzyme 50 – 100 times with sustained capacity of hydration of CO_2 to bicarbonate. The recent developments in cost-effective production of bacterial carbonic anhydrases and their immobilization strategies will be discussed.

About Author

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Prof. T. Satyanarayana, after M.Sc. and Ph.D. at the University of Saugar (India), T. Satyanarayana had post-doctoral stints in France. In 1988, he joined the Department of Microbiology, University of Delhi South Campus as Associate Professor and became Professor in 1998. His research efforts have been focused on understanding the diversity of yeasts, and thermophilic fungi and bacteria, their enzymes and potential applications, heterotrophic carbon sequestration and metagenomics, and cloning and expression of yeast and bacterial genes encoding industrial enzymes. Ha has 3 Indian patents for his credit.

He has published over 200 scientific papers and reviews, and edited six books. He is a fellow of the National Academy of Agricultural Sciences, Association of Microbiologists of India, Mycological Society of India, Biotech Research Society of India and A.P. Academy of Sciences, and a recipient of Dr. G.B. Manjrekar award of the AMI in 2003, Dr. V.S. Agnihotrudu Memorial award of MSI in 2009 and Malaviya award of BRSI in 2012 for his distinguished contributions.

Dr. Satyanarayanan has guided 24 students for Ph.D. and completed several major research projects and visited several countries. He is now president of MSI and AMI.

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

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Extended Abstract

Carbon dioxide (CO_2) as one of the green house gases (GHGs) is important component of Earth System. It's emission from stationary point sources connected to combustion facilities using fossil fuels in addition to other industrial sources is adversely affecting the climate on earth. Climate change is emerging as a growing global risk that has generated public concern for the last few decades. Thus capturing CO_2 from the combustion sources followed by its safe stabilization or storage constitutes an important target. A legion of researches have so far been undertaken to develop absorbents, adsorbents and membranes to remove CO_2 from combustion facilities.

The classical method of absorption of CO_2 in organic amines has so far been known to us for long. But this option has shown to have problems when planned for application for a coal fired thermal power plant (TPP). Importantly, the amine based CO_2 capture plant requires (i) Sulfur Dioxide (SO_2) concentration: 10–30 mg/Nm^3 [3.82–11.46 ppm_v], (ii) Nitrogen Dioxide (NO_2) concentration: 40 mg/Nm^3 [21.26 ppm_v] and (iii) Particulate Matter concentration: < 5 mg/Nm^3. Clearly, it demands a very sophisticated gas cleaning operation prior to deal with the flue gas for CO_2 capture. Besides, solvent loss (in the form of heat stable salts) and oxidative degradation of the solvent are now known. The development of blended solvents (amines) has thus now become an intense field of research. However, the health-safety related issue is becoming equally important that also concerns the researchers now-a-days.

In these lights, capturing CO_2 from the post-combustion flue gas by the chemical absorption method using aqueous ammonia (NH_3) has been given serious attention by the researchers and developers considering the advantages of high CO_2 capture efficiency, ease of operation and lower investment cost. Investigation on the life cycle CO_2 emission for the absorption of CO_2 from the exhaust flue gas stream of a coal fired TPP using aqueous NH_3 could be a plausible option for CO_2 capture. Literature also revealed that CO_2 capture using aqueous NH_3 yielded 90% CO_2 removal efficiency with 98%+ product purity for safe geologic storage indicating proven technical feasibility. Operating a plant keeping in view of capturing multi-pollutants likely to present in the flue gas stream such as SO_2, NO_2 and CO_2 is a challenging task. The possible solid reaction products of aqueous NH_3 based gas absorption of the flue gas from the TPP targeting for CO_2 capture would be ammonium sulfate [$(NH_4)_2SO_4$], ammonium nitrate [NH_4NO_3] and

ammonium bicarbonate [NH_4HCO_3] (ABC). These products have the potential to serve as N-fertilizer. In addition to the solid reaction products, the uncollected fly ash from the highly efficient electrostatic precipitator (particulate matter emission limit of 50 mg/Nm^3) could serve as micronutrients since elements present in the fly ash have shown to offer such effects. The presence of mercury (Hg) in the flue gas stream of a coal fired TPP has also gained considerable attention in the developed nations. However, there is no sizeable data available in India that necessitates the treatment of Hg in the flue gas. In any case, Hg needs to be removed, if it is present in the flue gas prior to NH_3 absorption.

In this communication, the present status of investigations on the aqueous NH_3 based CO_2 capture process are analyzed gathering information from the existing literature. Also the fundamental studies on post-combustion CO_2 absorption by aqueous NH_3, emphasizing its efficiency taking into consideration of the multi-pollutant capture option is described. A scheme is proposed for developing an understanding for Research & Development on the operation of the aqueous NH_3 based CO_2 capture process yielding solid reaction products having the potential as N-fertilizer under Indian conditions, instead of applying the recovered CO_2 underground for geologic storage.

Given the tremendous scope of research in India, the current national research potential could be gainfully utilized for envisaging the CO_2 capture by aqueous NH_3 in coal fired TPP for the purpose as mentioned earlier. In this regard, a research programme could be proposed in a planned manner for making use of the available resources in the country with the coordinated approach of few important streams such as academia, thermal power, fertilizer, agriculture, environment and climate change. Ostensibly, these areas are covered under Indian Ministries and could coordinate the proposed research programme. For instance, the Ministry of HRD for inducting the academic potentials, the Ministry of Power for utilizing the knowledge of the Power Plant Engineers, the Ministry of Chemicals & Fertilizers for extending the knowledge of ABC manufacturing plants and others, the Ministry of Agriculture for exploring the efficacy of land application of ABC and its concomitant products, and finally the Ministry of Environment, Forests & Climate Change to formulate strategy for developing a technology-based regulatory standard in the form of CO_2 capture plant for the coal fired TPPs in India.

About Author

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Dr Amitava Bandyopadhyay is an Associate Professor of Chemical Engineering at the University of Calcutta. He earned his B.Tech. in Chemical Technology (1988) from the University of Calcutta. Later, he earned his M.Tech. (1990) and PhD (1996) in Chemical Engineering from the Indian Institute of Technology, Kharagpur. Prior to his university position for the last seven years, he spent more than ten years in a senior position at the West Bengal Pollution Control Board. He also spent eight years working with other academic institutions and with organizations addressing environmental engineering and process formulations. Recently, he has finished the

Faculty Secondment assignment (January 2014 term) nominated by the MHRD to the School of Environment, Resources and Development, Asian institute of Technology, Bangkok, Pathumthani, Thailand.

Dr. Bandyopadhyay has published more than 70 articles in international and national journals of repute. He has edited the book entitled *Carbon Capture and Storage:* CO_2 *Management Technologies* published by Apple Academic Press. For the past 5+ years he has served as one of the topical editors in the Water and Environmental Engineering section of the international journal *CLEAN - Soil, Air, Water*, published by Wiley-Blackwell. He also serves on the editorial boards and advisory boards of several international journals important to *Greenhouse Gases: Science and Technology* and *Environmental Quality Management* of Wiley-Blackwell and has chaired several technical sessions at national and international events on environmental sciences and engineering. He has been one of the Guest Editors for the topic entitled CO_2 *Capture* published by the Elsevier in Separation & Purification Technology. He has received a number of awards for his research, including the Outstanding Paper Award 2012 for an article entitled *Amine versus ammonia absorption of* CO_2 *as a measure of reducing GHG emission: a critical analysis* published by the Springer in Clean Technologies & Environmental Policy, The Institution Prize 2009 as well as the Prof. S.C.Singh Gold Medal 2000 from the Institution of Engineers (India). He has been a reviewer of CO_2 removal projects at national- and state- level funding authorities.

CURRENT SCENARIO OF CO2 EMISSIONS AND REDUCTION IN STEEL INDUSTRIES

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Extended Abstract

The iron and steel making industries are the largest industrial sources of CO_2 and this type of industry contributes more that 2% of anthropogenic CO_2 emissions among the global emission (Fig. 1).The integrated steel mill in which steel is made by reducing iron ore in a blast furnace and subsequent processing in a primary steelmaking plant (BF-BOF Route). The integrated steel mills contribute 60% of the global production of iron making process.Among all technologies of steel production, BF-BOF and EAF routes are dominating in steel production since several decades and may be in next fifty years. The major threat due to emission of CO_2 is very much well known. Therefore, it is the high time to take necessary action against this alarming global threat.

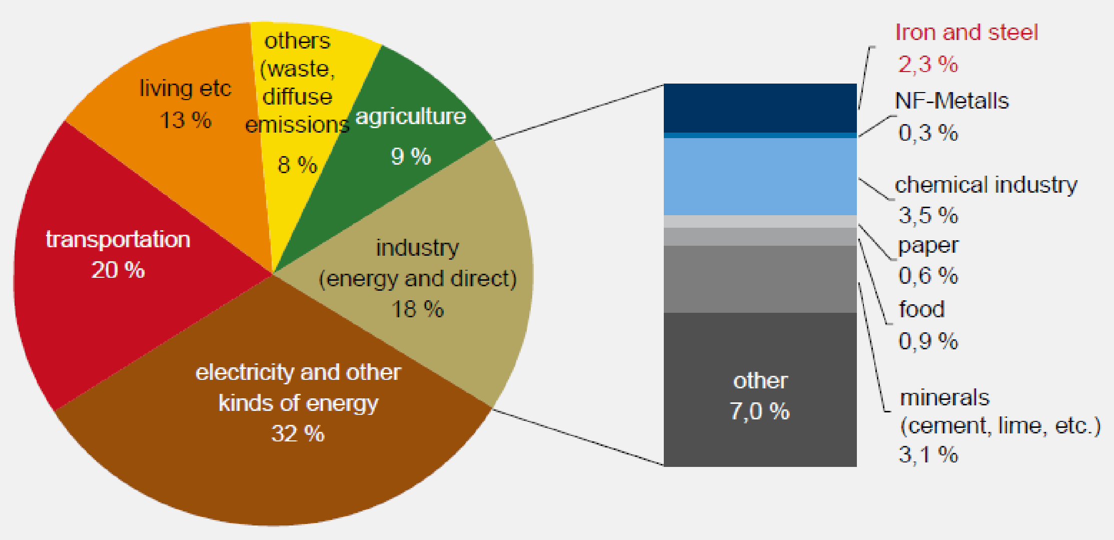

Fig. 1. Global CO_2 emission contribution by different type of industry.

Several process are involved in iron extraction from ore and steel making processes and during the whole process CO_2 emission takes place from several steps. In a steel mill, some processes contribute maximum CO_2 emission such as iron extraction and steel making process. The rate of emission of greenhouse gas is 0.4 tCO_2/t crude steel produces from an EAF, 1.7–1.8 tCO_2/t crude steel for theBF-BOF route and 2.5 tCO_2/tcrude steel for coal-based DRI processes. Moreover, there are number of side stream processes which, also contributes in CO_2 generation such as lime (CaO) production, coal to coke conversion, power generation, transportation of raw materials & finished product, mining, etc.

The current study aims to highlight the sources of CO_2 in steel making process as well as the several aspects of current and future practices carbon dioxide capture and storage (CCS) technology.

All steel plants have taken initiative to lower down their CO_2emissions either by capturing CO_2, which is coming out from the process, or by developing new process technology. The oldest and most efficient technique of CO_2 capture can be carried out by physical or chemical absorption process using aqueous ammonia or different type of ammine. Several companies have adopted this approach though it has not been implemented in full-scale due to some process intricacy. Very recently, a group of companies have taken an initiative to reduce CO_2 emission during steel making, which is called ULCOS stands for Ultra-Low Carbon dioxide (CO_2) Steelmaking. It is a consortium of 48 European companies and organisations from 15 European countries. They have launched a cooperative research & development initiative to enable drastic reduction in CO_2 emissions from steel production. The consortium consists of all major EU steel companies, energy and engineering partners, research institutes and universities and is supported by the European commission. The aim of the ULCOS programme is to reduce CO_2 emissions of today's best routes by at least 50%. Four major process has been proposed under ULCOS initiative such as ULSOC-BF (revamping of existing BF having CO_2 capture facilities), Hlsarna (It requires significantly less coal usage and thus reduces the amount of CO_2 emissions. Furthermore, it is a flexible process that allows partial substitution of coal by biomass, natural gas or even Hydrogen), ULCORED (modification of direct reduction process, iron extraction will be carried out by electric arc furnace) and ULCOWIN ULCOLYSIS (Electrolysis of iron ore, the least developed process route currently being studied in ULCOS. This process would allow the transformation of iron ore into metal and gaseous O_2 using only electrical energy).

Except above mentioned possible outcomes for CO_2 capture technologies, there are several attempts have been made by different organisations to fulfil the same purpose. However, as CO_2 emission has become major concern for the human race, CCS technology is a lucrative area of research for both academia’s and people from industries.

ENHANCED CARBONDIOXIDE UTILIZATION BY PLANTS GROWN IN FREE AIR CARBON DIOXIDE ENRICHMENT (FACE) FACILITY

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Extended Abstract

The concentration of carbon dioxide in the post-industrial era has tremendously risen due to high anthropogenic activities and is expected to reach upto 550 μmol mol-1 by the next 50 years. Plant metabolism is directly affected due to elevated concentrations of CO_2. Our knowledge of plant responses to elevated CO_2 concentrations mostly stems from studies in plant growth chambers or open top chambers (OTC) under controlled conditions with adequate water and nutrient available to plants, and in the absence of weeds, diseases and interaction with insects. Responses of plants to elevated [CO_2], known as the CO_2-fertilization effect, have been studied in a few crop species. Currently, ambient CO_2 concentration is a limiting factor for C3 photosynthesis and elevated atmospheric [CO2] is known to increase CO_2 fixation because of acceleration of carboxylation over oxygenation mediated by Rubisco (ribulose-1,5-bisphosphate carboxylase/oxygenase). The enhanced carboxylation results in a reduced photorespiration.

Increased atmospheric [CO_2] affects photosynthesis, plant growth and yield potential of plants. Mustard (Brassica juncea L.) is an important oil seed crop that is widely grown in India. Therefore, the impact of elevated [CO_2] (585 μmol mol-1) on pigment and protein content, chlorophyll *a* fluorescence, photosynthetic electron transport reactions, CO_2 assimilation, biomass production and seed yield potential was measured in *Brassica juncea* cv Pusa Bold, grown inside free air carbon dioxide enrichment (FACE) rings installed on the campus of Jawaharlal Nehru University, New Delhi, India. Plants were grown for three consecutive winter seasons (2010—2013), in ambient (385 μmol mol^{-1}) or elevated [CO_2] (585 μmol mol^{-1}), in open field conditions. Elevated [CO_2] had no significant effect on the minimal chlorophyll fluorescence (F_0), while the quantum efficiency of Photosystem II, as inferred from the ratio of variable ($Fv= Fm-F_0$) to maximum fluoresence (Fm), increased by 3%. Electron transport rate, photosystem I, photosystem II and whole chain electron transport rates increased by 3-5% in elevated [CO_2]. However, the net photosynthesis rate increased by ≈50% in 3 growing seasons under elevated [CO2] condition.

In our study, stomatal conductance decreased in mustard plants with elevated [CO_2] that might have helped leaves to prioritize water for leaf expansion over transpiration. The decreased stomatal conductance resulted in reduced transpiration rate. Increased photosynthesis and decreased transpiration rate per unit leaf area led to increased photosynthetic water use efficiency of mustard plants grown under elevated [CO_2]. Water use efficiency is strongly affected by stomatal density. Both stomatal density and stomatal index of leaves, which are negatively correlated with elevated [CO_2], have decreased over the past 100 years. Improved water status of plants, due to partial closure of stomata, causes a higher turgor pressure, which could stimulate leaf expansion.

Photosynthetic Light response curve

When the PAR rises, photosynthesis increases up to a certain limit beyond which further higher PAR results in a decrease in light harvesting efficiency and photosynthetic capacity. The light response curve of all the three cultivars reveals that 95% of saturation of CO_2 assimilation is achieved at ~1000 μmol photons m-2 s-1 both in ambient and elevated CO_2 conditions. As expected the photosynthetic assimilation rate was always higher 38 to 53% in high CO_2 grown plants measured at 585 μmol mol-1 of CO_2 in saturation light intensities. Although CO2 assimilation rate increased, the PS II dependent ETR, measured in intact leaves or PS II, PS I and whole chain electron transport rates polarographically estimated in isolated thalakoid membranes increased only by 7-10%. This demonstrates that in elevated CO_2, the increase in CO_2 assimilation rate (30-50%) was not accompanied by increase in electron transport rate. The ATP and NADPH produced due to partially augmented (7-10%) was able to support the increased CO_2 assimilation mostly caused by reduced photorespiration. The quantum yield of photosynthetic CO_2 assimilation measured at limiting light intensities, in ambient CO_2 raised from 16% to 20%. These are well within the values measured for several C3 plants. In elevated CO_2 mostly due to reduced photorespiration the quantum yield of photosynthetic CO_2 assimilation increased by 20% for Pusa Bold, 18% for Pusa Gold and 16% in Pusa Jaikisan cultivar. However, no significant decline in light compensation point was observed mostly due to increased rate of respiration in elevated CO_2-grown plants.

Photosynthetic CO_2 response curve

The CO_2 concentration affects Pn directly since it is substrate for the dark reaction of photosynthesis. CO_2 concentration also affects Pn indirectly by influencing stomatal aperture and CO_2 diffusion. CO_2 response curve (A/Ca) was almost identical in ambient and elevated CO_2 grown plants. This clearly demonstrate that photosynthesis was not downregulated in elevated CO_2 this is further supported by A/Ci curve where at limiting as well as saturating CO_2 concentrations, the rate of photosynthesis was almost similar in ambient and elevated CO_2 grown plants in all the three cultivars. Generalised response of the light-saturated CO_2 assimilation rate (A) to leaf intercellular CO_2 mole fraction (Ci) consists of three phases; first phase – when assimilation is limited by the amount of active Rubisco (slope of the initial phase, Vc, max), second phase- an inflection to a slower rise where Amax is reached due to limitation by the supply of substrate (ribulose 1,5-bisphosphate, RuBP) and third phase of limitation of triose-phosphate utilization.

Vcmax of Rubisco was not affected in elevated CO_2 grown Brassica cultivars. Maximum electron Transport (Jmax) marginally increased by 6-9% in all the three cultivars of Brassica grown at elevated CO_2. This demonstrate that annual crop plant i.e. Brassica grown in elevated CO_2 do not downregulate Rubisco and therefore, their photosynthetic assimilation rate remains unaffected in high CO_2 regime.

Our results reveal that not only photosynthesis rate but photosynthesizing surface, i.e., leaf area per plant and leaf area index increase 30-40% and 25-34% respectively with high [CO_2] indicating a strong morphogenic effect of CO_2 on leaf initiation. Elevated [CO_2] has varied effects on leaf area index from very little or no significant increase to a significant increase in different plant species. The rate of transpiration of plant increases with leaf area of the plant. The increased leaf area per plant is likely to offset effects of reduced stomatal conductance on transpiration. Some studies have shown that increased leaf area can more than compensate for reductions in stomatal conductance and can actually increase water use per plant at elevated [CO_2].

In the present study, the increased photosynthesis rate coupled with a higher leaf area per plant led to increased biomass and yield under elevated [CO_2]. We did not observe any down regulation of photosynthesis per unit leaf area in all the three cultivars of Brassica. The acclimatory loss of photosynthesis, if any, in other species could be offset by morphological characteristics, such as greater leaf area leading to increased biomass and yield. Elevated [CO_2] is known to increase photosynthesis during different phenological phases resulting in increased dry matter production. On average across several species and under unstressed conditions, recent data analyses show that, compared to current atmospheric CO_2 concentrations, crop yield increases at 550 μmol mol-1 [CO_2] are in the range of 10-20% for C3 crops and 0-10% for C4 crops. Increases in economic yield i.e., seed production were 21-26% in three Brassica cultivars at elevated CO2. Furthermore, 1000 seed weight increased by 35-40% demonstrating that the higher seed yield was mostly due to increased grain filling from long lasting leaves whose senescence was substantially delayed by 10 days.

In conclusion, percent increase in seed yield was lower than the increase in total biomass in elevated CO_2. If most of the additional photosynthate produced in elevated CO_2 would have been used for economic yield, i.e., increased seed production, a much higher grain output should have been possible in changing climatic conditions.

Further studies should be directed towards augmenting the economic yield from the available increased photosynthate (increase in harvest index) produced in high [CO_2] environment. We did not observe acclimatory downregulation of photosynthesis and plant productivity in high [CO_2] for three consecutive growing years. These clearly suggest that in the absence of any kind of nutrient limitation, Brassica cultivars are highly responsive to elevated CO_2 whose yield potential shall increase in changing climatic conditions. However, the increases in overall biomass is important towards the goal of obtaining bioenergy for other purposes.

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About Author

Prof. Baishnab Charan Tripathy is the Professor of School of Life sciences in Jawaharlal Nehru University, New Delhi. He got his Ph.D in Photobiology & Plant Physiology from Jawaharlal Nehru University and M.Sc & B.Sc (Botany) from Utakal University, Bhubaneswar. He is receipt prestigious fellowship and is J. C. Bose National Fellow.

Prof. Tripathi worked as Vice-Chancellor in Ravenshaw University, Cuttak, Odisha. He was also post doctoral fellow in the Department of Phisiological Chemistry & Biochemistry in Ohio State University, Columbus, and in Department of Horticulture in the University of Illinois, Urbana, Illinois. Eighty publications have been published in well known national & international journals. Books are also published like; The chloroplast: Basics and Applications, and Photosynthesis: Plastid Biology, Energy Conversion and Carbon Assimilation.

He serves as reviewer of several prestigious National and International journals.

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

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Extended Abstract

Soil carbon stock and soil CO_2 flux are the major components of carbon budget and carbon cycle in the different terrestrial ecosystems of the world. Soils are the largest carbon reservoirs of the terrestrial carbon cycle. 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. The amount of soil C is determined by net balance between the rate of the Soil organic input in leaf and root biomass and emission of CO_2 from the soil. 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.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.Small changes in soil CO_2 flux across large areas can produce a great effect on CO_2 atmosphere concentration and provide a potential positive feedback between increasing temperature and enhanced soil respiration that may ultimate accelerate global warming.

The North Eastern region is highly variable in climatic condition, topography, rainfall pattern, vegetation, land use pattern and high diversity which influenced the storage of soil organic carbon and soil CO_2 flux in the atmosphere. SOC stock was maximum is under forest and contributed more than 50.15 % of total under land use in the region. The detailed information on soil carbon stock and soil CO_2 flux and its controlling factors is critical for constraining the ecosystem C-budget and for understanding the response of soils to changing land use and global climate change. Therefor soil carbon stock and CO_2 flux in the different ecosystems i.e.forest, bamboo and grasslands of North-East India and its controlling of biotic and abiotic factors have been analysed and discussed.

Soil organic carbon (SOC) stock varied from 11.90 to 48.03 Mg ha^{-1} in tropical forest; 24 to 55.02 in sub-tropical forests and 30.80 to 62.74 Mg ha^{-1} in temperate forest at 0-30 cm soil depth in the North-Eastern India. In bamboo forest, the soil organic carbon stock (0-30 cm) was reported to be 57.3 Mg ha^{-1} in Barak Valley of Assam and 55.95 Mg ha^{-1} in Manipur. The soil organic carbon was reported to be 65.94 Mg ha^{-1} in grassland ecosystem of Manipur and 84.00 Mg ha^{-1} in Meghalaya. The Soil inorganic carbon (SIC) at

a depth of 0-30 cm was estimated to be 9.23 Mg ha^{-1} in tropical forest, 10.03 Mg ha^{-1} in sub-tropical forest ; 6.16 Mg ha^{-1} in temperate forest. SIC was estimated to be and 17.17 Mg ha^{-1} and 16.50 Mg ha^{-1} in bamboo and grassland ecosystem respectively. SOC and SIC stock was in the order of grassland>bamboo>forest ecosystem.

The rate of soil CO_2 flux ranged from 3.77 to 12.00 Mg C ha^{-1}yr^{-1}in tropical forest, 1.58 to 5.37 Mg C ha^{-1}yr^{-1}in sub-tropical forest and 4.46 to 6.73 Mg C ha^{-1}yr^{-1} in temperate forest. In bamboo forest it was between 3.73 and 9.17 Mg C ha^{-1}yr^{-1}and in grassland it ranged from 2.98 to 14.06Mg C ha^{-1}yr^{-1}.Soil CO_2 flux was observed maximum in rainy season than that of summer and winter seasons and was highly influenced by biotic and abiotic variables.

It shows that the soil carbon stock and soil CO_2 flux is highly variable and influenced by vegetation type, rainfall and other climatic factors. Since soil contains a significantpart of global carbon stock, the role of soil as a sink for carbon under different land-use management practices in different terrestrial ecosystems is necessary.Thus theseinformation will enable us to accurately estimate carbon fluxes and carbon budget in different ecosystems not only at regional and but also at national level.

About Author

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Professor P.S.Yadava obtained M.Sc and Ph.D. from Kurukshetra University, Kurukshetra (Haryana) and has 37 years of teaching and research experience. At present he is UGC-BSR Faculty Fellow, Department of Life Sciences, Manipur Central University, Imphal. He is former Head of Department of Life Sciences, Co-ordinator, Centre of Advanced Study in Life Sciences and Dean, School of Science, Manipur University. He is Career Awardee of UGC and Fellow of National Institute of Ecology, New Delhi.

He has directed several research projects funded by CSIR, UGC, DST, MOEF and ICAR, New Delhi.He is member of several academic bodies of Science, participated and chaired session in National and International conferences in India and abroad. He has supervised 22 Ph.D. students and published 107 research papers in national and foreign journals and co-author/edited four books. His research interests are plant biodiversity, phenology, nutrient cycling, ecosystem services, carbon management and sequestration in terrestrial ecosystems.

SOIL AS SOURCE AND SINK FOR ATMOSPHERIC CO2

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Extended Abstract

SOIL carbon (both soil organic carbon, SOC and soil in organiccarbon, SIC) is important as it determines ecosystemand agro-ecosystem functions, influencing soilfertility, water-holding capacity and other soil parameters. It is also of global importance because of its role inthe global carbon cycle and therefore, the part it plays inthe mitigation of atmospheric levels of greenhouse gases (GHGs), with special reference to CO_2.

To reduce the emission of CO_2, carbon capture andstorage (CCS) has been found to be an important option. The technique consists of three basic steps, viz. (i) capturing CO_2 at large and stationary point sources (ii) transporting CO_2 from a source to sink and (iii) injecting CO_2 in suited geological reservoirs or sinks. CCS wasgenerally regarded as an option during the first half of the21st century, to bridge the gap posed by the urgent need to act against climate change and the time needed to fully develop an important renewable energy. Among the other known sources to enhance CCS, the role of soils as an important natural resource, in capturing and storing carbon has not been adequately explained.

The main issue of soil carbon management in India revolves around the fact that a few parts of the country have soils containing high amount of SOC and low amount of SIC, whereas other parts show a reversetrend. The most important fact is that soils act as a major sink and source of atmospheric CO_2 and therefore have a huge role to play in the CCS activity. The soils capture and store both organic (through photosynthesis of plants and then to soils as decomposed plant materials and roots) and inorganic carbon (through the formation of pedogenic calcium carbonates). The sequestration of organic and inorganic carbon in soils and its follow-up requirebasic information of CCS in the soils.

The present study thus assumes importance, since knowledge on CCS of soils will facilitate in deciding areas for appropriate management techniques for carbon sequestration. The most prudent approach to estimate the role of soils to capture and store carbon should require information on the spatial distribution of soil type, soil carbon (SOC and SIC) and the bulk density (BD). To estimate the CCS of soils in spatial domains we have used the agro-climatic zones (ACZs), bioclimatic systems (BCS) of India and the agro-ecosubregions (AESRs) maps as base maps. These three efforts of land area delineations have been used for various purposes at the national and regional-level

planning. We have, however, shown the utility of these maps for prioritizing areas for sequestration in soils through a set of thematic maps on carbon stock. It will make a dataset for developmental programmes at both national and regional levels, to address the role of soils in capturing and storing elevated atmospheric CO_2 due to global climatic change.

Although the unique role of soils as a potential substratein mitigating the effects of atmospheric CO_2 has been conceived, the present study indicates the sequestration of atmospheric CO_2 in the form of SIC (pedogenic carbonate) and its subsequent importance in enhancing SOC in the Semi-Arid Tropics (SAT) of the country through management interventions. The study also points out the fact that the soil can act as a potential medium for CCS.

About Author

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Dr. Tapas Bhattacharyya was born in November, 1956. He is an agricultural graduate and a Ph.D. from the Indian Agricultural Research Institute, New Delhi. As a Soil Researcher he worked as Principal Scientist and Head of the Soil Resource Studies Division, National Bureau of Soil Survey and land Use Planning (ICAR), Nagpur for 30 years. He has been carrying out basic and fundamental pedological research in terms of soil genesis, classification, soil survey and mapping. He has also been working for various national and international projects with special reference to soil carbon sequestration and soil carbon modelling to address global warming and climate change issues. He is an active member, office bearers and Fellows of several scientific societies.

Dr. Bhattacharya has been awarded the Leader of the Best Team Research by ICAR, New Delhi for his contribution in soil carbon research. He has travelled almost the entire part of the country in connection with soil survey and mapping. He visited the USA, Europe and Africa. He has nearly 125 referred journal articles and review articles in books. Dr. Bhattacharyya is now working as Visiting Scientist, ICRISAT Development Center at Patancheru, Telangana, India. He is currently busy in AP Primary Sector and Watershed Research Programme in Karnataka as Capacity Coordinator.

ALTERNATIVES & CHALLENGES FOR CO_2 STORAGE: INDIA'S PERSPECTIVE

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Extended Abstract

Inter-governmental Panel on Climate Change's (IPCC) have suggested that global CO_2 emissions shall not increase beyond 2015, and may have to be reduced by more than 50 % thereafter. The World primary energy demand will be around 14,500 million tons of oil equivalent (Mtoe) by 2015, with fossil fuel contributing to 80 % and CO_2 emissions peaking to ~ 34,000 millions of tons (IEA, 2011) Therefore, scientific and technical measures are necessary to curb carbon dioxide built up in the atmosphere.

Storage of CO_2 in underground geological formations is the most viable alternative for environmental remediation. The options are: i) Geological storage in depleted oil reservoirs for enhanced oil recovery (CO_2 - EOR); ii) Storage in gas reservoirs for enhanced gas recovery (CO_2 - EGR); iii) Sequestration in Basalt formations in mineral form and; iv) Storage in deep saline aquifers in Aqua/ Mineral form.

Geological carbon storage is an expensive and highly S & T intensive & challenging proposition. The geological site for commercial CO_2 storage has to be established based on the detailed geophysical, petro-physical and geochemical studies, including a pilot scale study. CO_2 from fossil based power and industrial plants have to be captured, purified and transported to geological storage site and pumped into the deep geological formations and aquifers. Also, the long and short terms efficacy of CO_2 storage have to be established.

CO_2 storage in India is still in initial stage and there are no detailed studies of geological formations and aquifers for storage site characterization, except that National Geophysical Research Institute has carried out field and laboratory research on selected Basalt formations of India and Oil & Natural Gas Corporation has planned a project for CO_2 – EOR in Ankleshwar, Oil field of Western India

The innovative carbon storage advances have been: Bio- carbon capture and storage (Bio-CCS); getting geothermal power with CO_2 instead of water in the arid areas where water is scarce; and increasing the fertility of ocean and soil by carbon dioxide uptake.

India has to stand with the Global community for accelerating R& D in Carbon Capture and Storage (CCS) technologies. There is an immediate need to set up a CCS Institute in the country with significant funding. India's perspective towards carbon storage and review of new CO_2 storage advances will be presented and discussed.

About Author

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Dr. Baleshwar Kumar obtained B.E. degree in Instrumentation from Uniersity of Pune and Ph.D in Physics /Geochemistry from Indian Institute of Science, Bangalore. He has over 40 years of Research and Development Experience. He has obtained comphrensive training in Isotope Geochemistry (1977-1978) at Federal Institute of Geosciences and Natural Resources, Hannover, Germany. Dr. Kumar has published more than 45 research papers in National and International journals and 20 technical reports. He has coordinated projects sponsored by International Atomic Energy Agency (IAEA), Vienna, Austria; Department of Science and Technology (DST); Oil and Natural Gas Corporation (ONGC) etc.

Dr. Kumar has established National Facility for Surface Geochemical and Microibial Prospecting of Hydrocarbons at NGRI with a grant of Rs. 70 Million from OIDB, comprising of Isotope Mass Spectrometery, Gas Chromatographs, GC- MS and Total Organic Analyzer etc. He led integrated geochemical surveys for Hydrocarbon Research & Exploration in frontier onl and offshore basins and NELP blocks of India covering an area of 0.6x106 Sq.Km. He has been a lead coordinator for project on Geological CO_2 Sequestration in basalt formations of Western India: A Pilot Study (sponsored by DST; Ministry of Power; National Thermal Power Corporation and Battelle Pacific Northwest National Laboratory, USA). Dr. Kumar has edited the Chapter on Carbon Capture and Storage of Global Energy Assessment Report released by International Institute of Applied Sciences, Austria, 2012, 1900 pp.

SEAWEEDS: A POTENTIAL RESERVOIR OF CARBON

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Extended Abstract

Coastal producer communities like mangroves, salt marsh grass ecosystem, seagrass beds, and seaweeds absorb atmospheric carbon dioxide during the process of photosynthesis. This carbon known as the '**blue carbon**' is thus associated with the marine and estuarine ecosystems. The rates of carbon sequestration and storage in these coastal floral communities are often comparable to the rates in carbon-rich terrestrial ecosystems such as tropical rainforests or freshwater peat lands. Unlike most terrestrial systems, which reach soil carbon equilibrium within decades, deposition of carbon dioxide in coastal ecosystem sediment can continue over millennia.

Carbon fixation by seaweeds is an important bio-mechanism to diminish the increment of carbon dioxide in the atmosphere and thereby alleviate the trend toward global warming. Several researches have been initiated on the carbon fixation capacity of seaweeds for the purpose of developing blue carbon register. One of the important problems in the sphere of blue carbon is the turn over time of the marine plants. Most of the terrestrial plants have a relatively high biomass and have a turn over time of several years to decades. On contrary, the turn over time of marine seaweeds is about one year, although they have highest biomass among the marine ecosystems. This means that the seaweeds are more effective carbon sinks than phytoplankton, but less effective than the terrestrial ecosystem.

A study conducted in Indian Sundarbans on three common seaweeds namely *Enteromorpha intestinalis*, *Ulva lactuca* and *Catenella repens* (Figs. 1A - 1C) reveals unique spatial as well as seasonal variations in stored carbon.

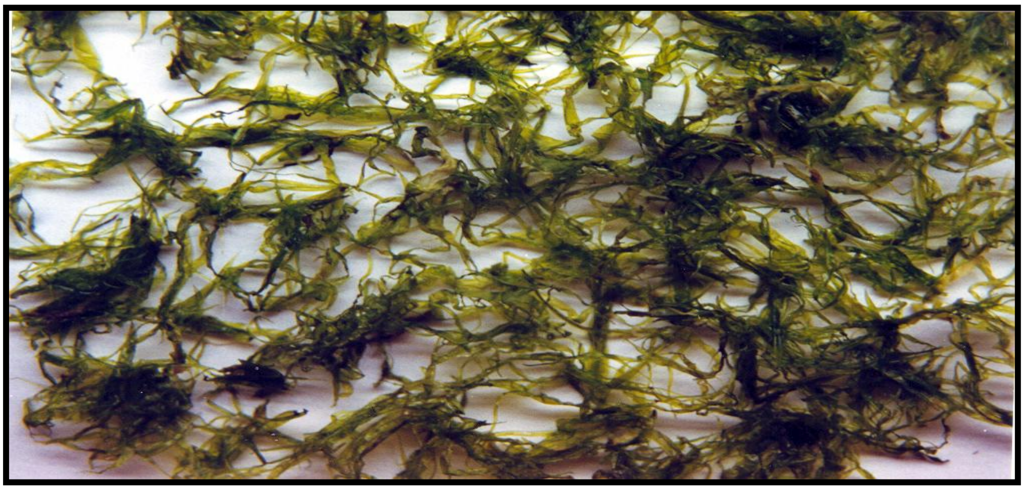

Fig. 1A. *Enteromorpha intestinalis*: a common seaweed in Indian Sundarbans with a wide tolerance range of salinity

Fig. 1B. ***Ulva lactuca*****: a common seaweed in Indian Sundarbans usually found in moderate and high saline zone**

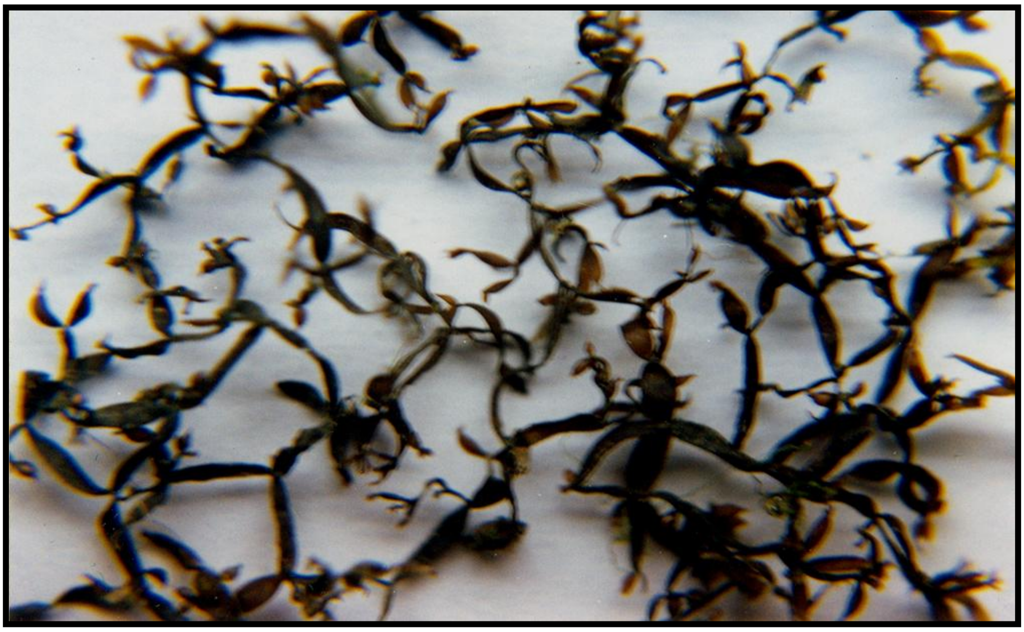

Fig. 1C. ***Catenella repens*****: common seaweed in Indian Sundarbans usually found in high saline zone**

The study was carried for three consecutive seasons (during 2014) in four different stations. A CHN analyzer was used for estimation of carbon percentage in the seaweed samples.

The study revealed uniqueness of each seaweed species in terms of biomass variation, carbon content and seasonality in biomass and carbon storage capacity as discussed here separately.

Enteromorpha intestinalis

The biomass of *E. intestinalis* ranged from 2860.11 gm m^{-2} (at Stn. 3, during May 2014) to 3172.14 gm m^{-2} (at Stn. 1, during December 2014). The carbon content exhibited lowest value at Stn. 3 (921.05 gm m^{-2} during September 2014) and highest at Stn. 2 (1163.02 gm m^{-2} during May 2014). ANOVA reveals the uniformity in the standing stock, but the carbon content showed significant seasonal variation ($p < 0.01$). ANOVA results also confirm significant spatial variations in carbon percentage and carbon content of the species ($p < 0.01$).

Ulva lactuca

The biomass ranged from 96.12 gm m^{-2} (at Stn. 1, during September 2014) to 789.91 gm m^{-2} (at Stn. 2, during May 2014). The carbon content showed the lowest value at Stn. 1 during September 2014 (26.10 gm m^{-2}) and highest at Stn. 2 during May 2014 (250.50 gm m^{-2}). ANOVA results exhibit significant seasonal and spatial variations of carbon percentage and carbon content ($p < 0.01$).

Catenella repens

The biomass of *C. repens* collected from the selected stations ranged from 44.55 gm m^{-2} (at Stn. 1, during December 2014) to 315.90 gm m^{-2} (at Stn. 2, during May 2014). In the thallus body of the species, the values of stored carbon ranged from 9.11 gm m^{-2} (at Stn.1, during December 2014) to 76.89gm m^{-2} (at Stn. 2, during May 2014). ANOVA results also confirm significant spatial and seasonal variations in the carbon content of the species ($p < 0.01$).

The present study indicates that carbon storage in seaweed species is species-specific in nature. In Indian Sundarbans deltaic system, at the apex of Bay of Bengal, the highest value is observed in *E. intestinalis* followed by *U. lactuca* and *C. repens*.

About Author

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Dr. Abhijit Mitra obtained Ph.D & M.Sc from University of Calcutta. He is Gold Medalist in Marine Science. At present, he works as Professor & Advisor in Oceanography Division, Techno India University. He is former Head, Department of Marine Science, University of Calcutta.

Dr. Mitra successfully supervised 22 Ph.D students and 6 M.Phil students under Calcutta & Jadavpur University. He was selected as Fellow & Convener of West Bengal Academy of Science & Technology. He also invited as a chairperson in the Technology Fair & 5th Environment Parnership Summit organized by the Indian Chamber of Commerce, Kolkata. He received the INSA award for 2012-13 to carry on Research Programme. He has over 28 years experiences in Research, Administration and have teaching experience as permanent Faculty in Marine Science. He has 310 scientific papers and 27 books to his credit.

CLATHATE HYDRATES: A POWERFUL TOOL TO MITIGATE GREENHOUSE GAS

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Extended Abstract

In order to meet the increasing energy demands, both the developed and the developing countries will continue to rely heavily on the use of fossil fuels, thus continuously increasing the accumulation of greenhouse gases in the atmosphere. Thus need of our society at present is to look for ways for striking a balance between meeting the energy demands and managing the levels of greenhouse gas emissions. There is paradigm shift in mitigating the emissions of CO_2 not only as greenhouse gas, but also as useful raw material in manufacturing certain agro products and chemicals. Therefore materials are being developed to capture larger fractions of CO_2. Various types of adsorbents like zeolites, metal-organic materials (MOM), porous polymers, metal oxides, carbonaceous materials and porous silica etc., are presently being investigated for CO_2 capture/ storage. The highest CO_2 adsorption capacity for MOMs e.g., MOF-200 and MOF-177 it is 54.5 mmol. g^{-1} (at 5 MPa and 298 K) and 33.5 mmol. g^{-1} (at 3.5 MPa and 298 K) respectively.

However, some of the associated drawbacks with them in practice are; hard to synthesise and expensive; sensitive to moisture; issues with activation, regeneration and recycling of sorbent materials etc. Specially prepared carbonaceous materials (carbon molecular sieves) have also shown higher adsorption capacity for CO_2 (46.9 mmol. g^{-1} at 5 MPa and 298 K). For CCS applications ideally the desired material should be cheaper, robust for recycling, good thermal and structural stability towards moisture. Although the other materials can fulfil some conditions, *e.g.,* recyclable, thermal & structural stability etc., but their CO_2 adsorption capacity is very low. It is 4.27 mmol g^{-1} amine functionalised zeolites with 7% water vapour and 1.25 mmol g^{-1} in metal oxide modified with organic ligands. The gas hydrates on the other hand have proven to be useful and economical alternative for gas separation and storage/sequestration. Gas hydrates (GH), also known as clathrate hydrates, are non-stoichiometric inclusion compounds, in which gaseous guest molecules are trapped in a host lattice, formed by water molecules in an ice-like hydrogen-bonded framework. Essential conditions for its formation and stability are; enough supply of host (water) and guest (of suitable size) molecules, and moderately higher pressure and sub-ambient temperature. The molecular size for methane and carbon dioxide are similar and they crystallize into cubic structure with space group *Pm3n*. The unit cell consists of 46 water molecules forming eight (two pentagonal

dodecahedron 5^{12} & six tetrakaidecahedron $5^{12}6^{2}$) cages. The ideal amount of CO_2 in hydrates is 29.83 wt% (6.66 mmol. g^{-1}) when all the cages are filled, while it is 24.17 wt% (5.50 mmol. g^{-1}) when only $5^{12}6^{2}$ cages are filled. We present our experimental results on CO_2 hydrates, in particular to illustrate rapid and higher retention capacity in different silica (SiO_2) adsorbents saturated with H_2O.

CARBON DIOXIDE STORAGE AND ENHANCED OIL RECOVERY

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Extended Abstract

Anthropogenic source of carbon dioxide has altered the natural carbon cycle making carbon sequestration a necessity. Carbon dioxide can be either stored in Saline aquifers or in depleted Oil and gas fields. There is an additional advantage if we store it in oil fields for injecting high pressure carbon dioxide enhances recovery factor making the project commercially viable. Enhanced coal based methane is another area where injected carbon dioxide can increase methane production for coal seams have a higher affinity for carbon dioxide as compared to Methane. In India enhanced coal based methane has a great potential for our power plants are mostly coal based and located close to coal mines. Yet Gujarat, Assam and now Rajasthan are areas where enhanced Oil recovery can be highly successful with the abundant presence of depleted oil fields.

In this presentation case studies on successful implementation of storing high pressure super critical liquid carbon dioxide in old oil fields as well as insaline aquifers in USA and Canada have been discussed at length. Besides commercial advantage, geology of old fields are much better known and are therefore preferred sites for storing high pressure super critical liquid carbon dioxide and the very fact that these reservoirs have been habitats for oil speaks volumes about the sealing capacity of such reservoirs. Saline aquifers though ubiqtous and has a much larger storage capacity needs detail seismic studies to ensure that what is injected does not leak out. Miscible carbon dioxide under super critical condition interacts with reservoir oil reduces viscocity, interfacial tension and therefore increases mobility. This results in higher recovery factor and the additional oil pays the cost of the enhanced recovery project. Even if the oil is such that carbon dioxide injected is immiscible injected carbon dioxide can alter the petrophysical properties of the host rock increasing mobility. Heavier oil fields are surely a great candidate for this tertiary recovery.

Monitoring the injected carbon dioxide is extremely important. Time lapse seismic surveys in three dimension, and its processing and pre- stack inversion along with rock physics studies can lead to quantative interpretation of the volumes of carbon dioxide actually sequestered .Time lapse Shear wave studies can indicate if the elastic properties of the host rock has been altered by injected carbondioxide, and this needs to be factored in quantative interpretation.Similarly time lapse amplitude variation with offset can in principle also describe the effect of injected carbon dioxide on the fluids as well as the host rock for a quantative interpretation of the volume of carbon dioxide sequestered and if there is any change in time .Since the changes with time often are

small, exact repeatability of the survey is necessary to ensure the sanctity of the studies .This can only be verified at the non-reservoir and usually changes at the reservoir level are taken which is above the changes at the non-reservoir level , and the latter is usually termed as noise .Downhole seismic and saturation logs in time lapse mode needs to be acquired besides time lapse survey to provide hard data at the well forinterwell interpolation seismic forreservoir description.

It can therefore be concluded that enhanced oil recovery through carbon sequestration is a commercially viable technology especially for power plants located in Gujarat, Assam and Rajasthan.Quantative interpretation of the volume of high pressure supercritical liquid carbon dioxide injected is essential in time lapse manner to ensure that stored carbon dioxide does not leak back to the atmosphere.

About Author

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Sh Gautam Sen joined Oil and Natural Gas Commission (as was then called in 1976) as a Graduate Trainee after completing his Masters in Physics from Delhi University. He joined as a Geophysicist and gradually moved into Oil and Gas exploration. He rose to the level of Executive Director in Jan 2003. He joined RIL as SR VP Geoscience in Dec 2007.

He superannuated from RIL and became a consultant in Oil and Gas Exploration and after an 18 months stint with Sahara, he is now presently advising the upstream group of HPCL. His interests are in usage of Seismicity to find and produce new Oil and Gas.

He has published large number of papers and abstracts in journals, and wrote many industry reports. Was conferred the National Mineral Award for Geophysics in 2000 and was a recipient of National Science Talent Scholarship in 1969.

ENHANCEMENT IN NEED, FEASIBILITY AND CAPACITY BUILDING WITH OUTCOMES OF CARBON SEQUESTRATION PILOT PLANT OF NALCO AS AN ACCELERATED CARBON SINK FOR FLUE GAS

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Extended Abstract

Coal will remain the main source of electric power for the foreseeable future in India. It's imperative that we find ways to use our abundant coal resources in an environmentally sensitive manner to affordably provide the growing demands for energy. Technologies that could curb CO_2 emissions, while burning fossil fuels to allow coal to be burned in a more carbon neutral way, are attracting significant attention. Though chemical and physical routes to capture CO_2 from stack emissions exists, the cost of utilizing these technologies would result in a significant increase in the cost of power. Photosynthesis has long been recognized as a natural carbon sink, to capture anthropogenic carbon dioxide and microalgae are among the fastest growing photosynthetic organisms, having carbon fixation rates a magnitude higher than those of land plants. Microalgae utilize CO_2 at extended concentrations, therefore posses a great potential for using waste CO_2 from a coal-fired power plant to generate biomass that can be further processed into value-added products like bio-fuel, feed, fertilizer, and chemicals. India's first algae based carbon sequestration project undertaken by commercial public sector establishment - NALCO, India, having a goal to initiate aggressive carbon capture and sequestration for coal-generated electricity in Odisha using flue-gas injected open cultivation pond system; have demonstrated accelerated CO_2 sequestration ability while withstanding the high CO_2 concentrations and potentially toxic SOx and NOx gases. The outcomes shape the needs for future efforts on benchmarking the feasibilities and enhance capacity building for a low carbon growth strategy for coal based power plants.

About Author

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Dr. Ranjan R Pradhan (Technology Expert for Algae based Carbon Sequestration in India) is Head, Department of Chemical Engineering at C. V. Raman College of Engineering, Bhubaneswar, Odisha. Prof. Pradhan is partner of M/s Indocan Technology Solutions, He has been offering his expertise and services in Carbon Sequestration, biotechnology processes and process automatons & has been instrumental in development and establishment of micro-algae based carbon sequestration system as a forward integration for thermal power plants. His extensive research during his post doctoral work at University Guelph, Canada and various industrial pilot plant trials for mass cultivation bacterial systems, biotransformation have resulted in development of various industrial processes and products. He has conducted various international and national level workshops, seminars and conferences in the related technical disciplines in Cuttack.

LOW CARBON GROWTH STRATEGY FOR INDIA BASED ON OXY-COMBUSTION CARBON CAPTURE AND CO_2 UTILIZATION FOR ENHANCED COAL BED METHANE [ECBM] RECOVERY

Thomas Weber, Jupiter Oxygen Corporation

Extended Abstract

According to the International Energy Agency's World Energy Outlook 2014, India, China, and the United States, account for 70% of global coal use today. India's coal demand doubled over the ten years to 2012. India is overtaking the European Union to become the world's third-largest coal market. The power sector currently accounts for 70% of total India coal use. IEA's projections until 2040 show that energy growth in emerging economies, like China, India and Indonesia will rely primarily on coal resources.

The 21st century needs sustainable business strategies that provide an increasing energy supply while supporting climate protection and social development goals. Transformational technologies, such as carbon capture, and storage (CCS) will need to play a key role.

Carbon capture and storage, including CO_2 utilization (CCSU), offer a solution to manage the reality of massive global fossil energy consumption even beyond 2040. CO_2 utilization options within CCS projects can attract business groups and industry to engage in real scale application and demonstration of CCSU projects that will drive down overall costs, making those technologies affordable in emerging economies. Beneficial utilization of CO_2, creating a revenue stream from captured CO_2, can be realized through enhanced oil recovery, enhanced coal bed methane recovery, the algal biomass industry, and others. Significant potential for enhanced coal bed methane recovery has been identified in India.

Oxy-combustion based carbon capture technologies in conjunction with CO_2 utilization for enhanced coal bed methane recovery offer economic solutions to substantially mitigate CO_2 emissions. Co-benefits from applying those technologies to coal fired power plants will be air pollutant control and permanent CO_2 storage.

Jupiter Oxygen's unique technologies can be a critical part of strategic alliances for the financing and management of successful complex carbon capture, utilization and storage projects. Jupiter Oxygen's focus is to identify favorable economic and resource conditions for profitable large scale CCSU demonstration projects. Jupiter Oxygen is engaged in demonstration project activities in the U.S., Mexico, China, and India.

The presentation will be structured as follows:

1. Introduction: Jupiter Oxygen's technology development (short movie clip)
2. CO_2 utilization: Key for cost effective carbon capture & storage projects
3. Business opportunity: Enhanced coal bed methane (ECBM) recovery
4. CCSU demonstration: Importance of site selection and project synergies
5. Industry engagement: Getting the coal, oil and gas industry involved

About Author

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Thomas Weber works directly with the CEO and the executive management team to expand Jupiter Oxygen's clean energy business and project development in the U.S. and internationally. Thomas represents Jupiter Oxygen with the Business Council for Sustainable Energy (Board of Directors), as well as the Global CCS Institute, and the Carbon Sequestration Leadership Forum. He regularly participates as a business delegate at the United Nations' Climate Change conferences.

Before joining Jupiter Oxygen USA in 2004, he had sixteen years of experience in interdisciplinary project management in German companies, with 10 years at a construction firm, including as CEO.

About Jupiter Oxygen Corporation

Jupiter Oxygen Corporation (JOC), a privately held Illinois company, has developed technologies for industrial energy efficiency and cost effective carbon capture from fossil fuel power plants. Jupiter Oxygen's expertise is based on its continued research, development and everyday use of oxy-combustion. Experiments on and the development of the patented oxy-combustion process began in the mid-1990s as a way to cut fuel costs and lower emissions at Jupiter Aluminum Corporation an aluminum recycling and coil manufacturing plant. Jupiter's technology has been in use at Jupiter Aluminum since 1997.

Based on cooperative research and development agreements [CRADA], as well as supported by federal grants, Jupiter Oxygen worked a decade with experts from the National Energy Technology Laboratory (NETL) of the U.S. Department of Energy (DOE) to develop cost effective carbon capture solutions, obtaining several patents on the joint technology development. The work's focus had been on retrofitting existing coal fired boilers, achieving technology readiness for a demonstration project, allowing for the scale-up of the technology.

JOC's high flame temperature oxy-combustion technology, combined with NETL's Integrated Pollutant Removal system, enables the capture of more than 95% of CO2, and the elimination of key pollutants (NOx, SOx, PM, mercury). Key end product is salable and pipeline ready CO2. The technology had been implemented at Jupiter Oxygen's 15 MWth boiler test facility and research center south of Chicago. Furthermore, Jupiter Oxygen and NETL developed a new boiler design based on high flame temperature oxy-combustion, which can serve the CO2 utilization industries in the near future.

In May, 2011, Xinjiang Guanghui New Energy Co. Ltd, and Jupiter Oxygen Corporation, announced their Strategic Alliance Agreement to market Jupiter's patented high flame temperature oxy-combustion technology, and the carbon capture system, in China.

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