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CLIMATE CHANGE RESEARCH INSTITUTE

AWARNESS AND CAPACITY BUILDING WORKSHOP

CARBON CAPTURE & UTILIZATION PLUS NET - ZERO FUTURE

(ACBCCU 2022)

WEBINAR PROCEEDINGS

4th Feb 2022

ORGANIZED BY

CLIMATE CHANGE RESEARCH INSTITUTE

Azadi Ka Amrit Mahotsav

Climate Change Research Institute

INDIA INTERNATIONAL CENTRE

Climate Change Research Institute

Awareness and Capacity Building Workshop
Carbon Capture & Utilization plus Net zero Future
(ACBCCU 2022)

Webinar Proceedings

4th February 2022

In association with

India International Center

Carbon Capture & Utilization plus Net zero Future
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Preface

Shifting seasons, changing rainfall patterns, floods and fires across the globe, all have become realities before us. In the meeting of COP 26 held in Glasgow in November 2021, world leaders have agreed to take intense climate change mitigation actions in a move towards Net zero emission targets, which translate into **Adaptation – Mitigation - CO_2 capture**. It is therefore vital to recognize Carbon Capture and Utilization (CCU) as one of the key energy technologies and understand natural and manmade carbon sinks on land and air

The Climate Change Research Institute organized a virtual workshop on "Carbon Capture and Utilization plus Net zero Future" in collaboration with the India International Centre, Delhi on 4th February 2022 having eminent speakers. The Aim of the Workshop was to sensitize researchers with the knowledge of India's NDCs, Sustainable Development Goals and Climate Action using carbon dioxide capture and utilization. Earlier, as part of *Azadi ka Amrit Mahotsva* celebration and also Youth Climate Change Action Day (which falls on 5th December), the Institute planned its 5th Awareness and Capacity Building workshop on "Role of Carbon Capture & Utilization: Towards A Sustainable Net zero Future" (ACBCCS-2021) on a Virtual Platform to be held on 7th December. The event was rescheduled on 4th February 2022.

We thank Prof. D.P. Agrawal, Chairman Governing Council, Climate Change & Research Institute (CCRI) for presiding over the event. Eminent speakers Prof. K. Palanivelu, Director, Climate Change & Disaster Management, Centre for Environmental Studies, Anna University, Chennai; Prof. Mohamed Kheireddine Aroua, Associate Dean (Research and Post Graduate Studies) and Head, Centre for Carbon Dioxide Capture and Utilization, Sunway University, Malaysia; Shri Gautam Sen, former Senior Vice President, Reliance and former Executive Director, ONGC; Dr. Abhijit Mitra, Director, Research, Techno India University, West Bengal participated in the Panel discussion. Following questions were discussed

- What are the Policy and Technical issues in implementation of CCS technology?
- What are technological complications in carbon capture process and how can we improve on the same?
- How student can get involved in Carbon capture and storage/ carbon capture and utilization?
- Employment generation in CCS technology - scope for geologists and engineers?

The workshop recommendations and key messages are contained in this report.

Dr. (Mrs.) Malti Goel
Chief Executive and President
Climate Change Research Institute

Meet the Panelists

Chair:
Prof. D.P. Agrawal, Chairman, Governing Council, Climate Change & Research Institute (CCRI) and former Chairman, UPSC

Keynote Speaker:
Prof. K. Palanivelu, Director, Climate Change & Disaster Management, Centre for Environmental Studies, Anna University, Chennai

Guest Speaker:
Prof. Mohamed Kheireddine Aroua, Associate Dean (Research and Post Graduate Studies) and Head, Centre for Carbon Dioxide Capture and Utilization, Sunway University, Malaysia

Speakers:
Shri Gautam Sen, former Senior Vice President, Reliance and former Executive Director, ONGC; and Dr. Abhijit Mitra, Director, Research, Techno India University, West Bengal and former Head, Dept. of Marine Science, University of Calcutta, Kolkata

Moderator:
Dr. (Smt) Malti Goel, President, CCRI and former Adviser, DST, Govt. of India

Date & Time:	**Friday, 4 February 2022 at 3:30 pm – 5:30 pm**
Registration link:	https://zoom.us/webinar/register/WN_uQXb6_6JRjOHwJ2lKDj8dQ
IIC Website:	https://iicdelhi.in/

Climate Change Research Institute

Carbon Capture & Utilization plus Net zero Future

(ACBCCU 2022)

4th Feb 2022

Webinar Recommendations

India adopted *Panchmrit* Action plan in COP26 to achieve Net zero emissions by 2070. The COP26 is seen as a journey to advance carbon capture, utilization and sequestration (CCUS) technology. The CCUS is not one technology but a set of technologies in multi-disciplinary fields. Even with most ambitious targets India has for RE; action for CCUS is becoming critical. The processes for some are well known; but their scaling up is highly challenging.

With this in view the webinar provided the following **Key Messages** for the CCUS technology acceleration.

(i) The CCUS should be recognized as a vital technology for achieving the Net zero targets. Application of: Digital techniques for optimization and Innovation in materials used for CO_2 capture would have important roles in making it cost-effective.

(ii) There has to be Climate Action from the governments, corporates and academia to advance CCUS technology, namely;

- Governments should announce CCUS acceleration Technology Projects policy and provide fiscal incentives, increase investment to address climate change concerns and introduce standards for large emitting sources.
- Corporate sector to make accelerated transition to climate action by adopting science based targets (SBTi) by committing to Net zero across all industries.
- Academia to invest in collaborative research, to build teams with common goals for CO_2 capture and to see that captured CO_2 can be used as a raw material, to synthesize and to produce chemicals and fuels.

(iii) Finally, India should design a Science, Technology and Innovation roadmap of the next 25 years with targeted increased investment in R&D, application of CCUS in energy sectors and a solution to achieve Net zero targets.

Carbon Capture & Utilization plus Net zero Future
(ACBCCU 2022)

4th February 2022

Welcome Address

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

1. Prof. D.P. Agrawal, Chairman, Governing Council CCRI chaired the Panel Discussion. He extended warm welcome to all and said that a very important topic carbon capture and utilization plus Net zero future has been chosen today. He said our Institute has recently contributed a book 'Climate Change and Green Chemistry of CO_2 Sequestration' in which Foreword was given by former Minister Mr. Suresh Prabhu. He writes "*according to the International Energy Agency, carbon capture and utilization CO_2 sequestration is a technology set of options that can significantly reduce fossil fuel emissions*." Yet we know there is a great challenge in its applications and if you have to achieve Net zero, then the challenges are much more. The Paris Agreement 2015 signed by 196 countries implied to limit global warming to 2 degrees centigrade by the end of 21st century. In the COP26 meeting held in UK in 2021 it was suggested that the temperature rise has to be limited to 1.5 degrees. Many countries have committed to reach Net zero by 2050. Therefore today's deliberation should be a direction at the policy level, direction at the technology level and a suggestion to what are the likely options are available to India.

2. Application of Science & Technology will lead to new industrial products. The economic development should go on despite the target of reduction in emissions for bringing carbon footprints to the Net zero. At the policy level, Government of India has given emphasis to use clean energy such as from wind, from sea and from solar. Solar energy has given some hope that the targets to achieve bulk of electricity production could be met using our own resources. Other options are improving energy efficiency and adopting carbon capture & storage to our fossil fuel based plants. In addition the government might take some fiscal measures. In fact, in many countries fiscal measures have been utilized in approaching Net zero, which means that governments are for companies which have Net zero carbon footprints. Government of India is planning fiscal measures in the policy for people to change from fossil fuel driven vehicles to electrical vehicles. In general, belief is that another 10 to 15 years down the line in India, the electrical vehicles share will become something like 50%. Electrical charging infrastructure for vehicles is one of the bottlenecks. Through some states are doing much better by creating infrastructure facilities for vehicle charging. The policy must focus that more and more renewable energy would be used for battery charging in the form of electricity rather than using electricity based on the fossil fuels.

3. For understanding the dynamics of the climate change, computer simulations play vital role. India has made significant progress and computing power using cloud computing to

simulate the interactions among planetary activities leads to understand future impacts of climate change. Summarizing, he said that a lot of behavioral change is required in the population to save energy, and in judicious use of clean energy. That would mean producing less wastage, utilizing even the wastage to produce energy and lesser footprint during the production process. This one day deliberation on such a crucial subject at the time, when we are celebrating the *Azadi ka Amrit Mohotsav* of the country, should go a long way, because the eminent speakers are going to cover the technology and other issues. Once again, I welcome all the speakers, all the guests and all the participants.

Thank you very much.

Background and Moderator's Remarks

Dr. (Mrs.) Malti Goel, Chief Executive, Climate Change Research Institute (CCRI) and Emeritus Scientist, MST

1. Dr. (Mrs.) Malti Goel profusely thanked Chairman Prof D. P. Agrawal for a very inspiring address and setting the tone of the workshop. She extended hearty welcome to all distinguished speakers, the participants from different organizations and the eminent members of the India international center for joining us.

2. We are honored that eminent panelists Prof K. Palanivelu from Anna University, Shri Gautam Sen from Ex-ONGC & Reliance, Professor Abhijit Mitra from Calcutta University and are highly acclaimed in carbon capture research. I am extremely thankful to Guest Speaker Prof. Mohamed Kheireddine Aroua from Sunway University in Malaysia for joining with us. I had the honor to visit his Center at the Sunway University about two years ago, to participate and conduct a CCU workshop in the first Euro Asia Conference on CO_2 Caption and Utilization held in Malaysia.

3. The Climate Change Research Institute is a distinguished institute in the field on Environment and Climate Change. The organization is engaged in creating awareness and understanding of climate change and providing education to address local concerns of climate change for developing human resources by adopting the practices of science, technology and innovation. The awareness and capacity building workshop in CO_2 sequestration research and technology is our flagship area and this is fifth in the series. Our associates, the India International Center is a premier organization engaged in the dissemination of specialized cultural, social, intellectual and scientific deliberations, and exchange of new knowledge.

3. Today's theme **Carbon Capture & Utilization plus Net zer**o is very topical. It is important for Climate Action, i.e., achieving SDG13 and many other Sustainable Development Goals (SDGs). Climate change, shifting seasons, changing rainfall patterns, floods and fires across

the globe, all have become realities before us, demanding accelerated climate control actions, says IPCC 6th report. Looking at the current global status of CCUS, there are 26 large scale projects in operation, sequestering 40 Mt of CO_2 per annum. This gives us an idea of scale of operation needed for climate change action, which demands CO_2 sequestration of terra tons. Terra reminds us of the International Solar Alliance, which has a target of achieving 1000 terra watts (TW) solar energy capacity addition by 2030.

4. India as a nation is striving for Green Growth and Climate Justice. In updated NDCs in COP26, more ambitious targets for renewable energy are stated. India's Net zero targets of 2070 translates into achieving a balance in emissions and sinks. **Energy security** and **Economic productivity** are two big challenges to achieve Net zero targets in all sectors of economy. Application of CCUS on large-scale is yet arguable. There is also a debate about CCS vs CCU, especially in the power sector. While the CCS treats CO_2 as waste and CO_2 storage options include soil, minerals, wetlands, coastal regions etc., the CCU is an approach for making use of captured CO_2 in value added products. Scenario of CO_2 utilization can be very wide, as follows.

i. Catalytic reduction of CO_2 leads to value added chemicals.
ii. Catalytic hydrogenation of CO_2 leads to fuels
iii. Enhanced oil recovery (EOR) in which CO_2 is injected into an existing oil well to increase pressure and reduce the viscosity of the oil. IEA has estimated that for every barrel of oil produced, there is net CO_2 storage on 0.19MT.
iv. CO_2 curing of concrete, conversion into minerals and rocks
v. Uptake of CO_2 from the atmosphere or other sources by microalgae biomass
vi. Mineralization of CO_2 from flue gas or other sources like industrial waste materials
vii. Ocean Sequestration options
viii. Growth of woody biomass via afforestation, reforestation
ix. Injection of CO_2 from flue gas into coal seams – ECBM

5. Undoubtedly the CCUS remains a technology with multiple options and deep challenges, both in storage and utilization. It is not one technology but a set of technologies. Processes are known for some, their scaling up is highly challenging. Application of digital techniques and innovation in materials would have important roles in scaling up in cost-effective manner.

With this I invite Keynote Speaker Prof Palanivelu and Guest Speakers to comment on technology, status and challenges in CCU applications. Thank you very much!

Keynote Speaker

Prof. K. Palanivelu, Director, Centre for Climate Change & Disaster Management, Centre for Environmental Studies, Anna University, Chennai

1. Prof. K. Palanivelu greatly appreciated the initiative of the Institute to organize this webinar on an important topic. Decarbonization or carbon Net zero is a *mantra* that has

emerged out of recently concluded IPCC conferences. How we can move about this and achieve something for the global society? In his presentation on "CO_2 Utilization from Large Scale Stationary Sources", he said globally records show that the rate at which carbon dioxide increases is going up and the current concentration of carbon dioxide is about 417 ppm. Among the various sources of carbon dioxide, 73% comes from electricity generation in the power sector. Industrial sectors also contribute especially steel and other heavy industries. From stationary sources like thermal power plants, steel, aluminum industries, considerable amount of carbon dioxide emissions into the atmosphere can be reduced using CCUS.

2. India, ranked seventh in terms of carbon dioxide emission, but in terms of per capita emission of 1.7 tons per head and ranking is also above 150. We can adopt carbon mitigation and become a climate resilient society by managing situation arising out of this warming. He described in detail the processes for CO_2 capture from the flue gas, which mostly consist of carbon dioxide and nitrogen. One of the benchmark currently employed is *Absorption* using monoethanolamine. The slight warming can liberate the carbon dioxide, which again could be utilized for various benefits. Another possibility is *Cryogenic separation*; liquid carbon dioxide captured can be used for various purposes. An emerging technique for carbon dioxide capture is *Membrane separation*; it can capture carbon dioxide selectively leaving nitrogen. The captured carbon dioxide could be used to get various value added products, pharmaceutical chemicals, various drugs, chemicals and drinks, food materials, fertilizers and all kind of carbonates including inorganic organic carbonates, enhanced oil gas recovery and polycarbonate polymers. Definitely, carbon dioxide utilization is one of the important solutions. The technology level varies for different technologies, whether it is a lab-scale or a pilot scale or a demonstration. The commercial viability for the compound converted into useful material is also to be assessed. He has published original research in many premier Journals like J. of Membrane Separation, J. of CO_2 Utilization and J. of Cleaner Production.

3. For climate change mitigation, India is focusing on renewable energy and increasing the green cover by capturing naturally carbon dioxide. Still reaching Net zero is not possible without the use of carbon dioxide capture and utilization. Fossil fuel burning will continue. Some standard has to be introduced where large scale emissions of carbon dioxide from thermal power stations, cement industry, steel industry etc. are taken care off. The EPA, USA have introduced standard that any industry if they emit about 25,000 tons per year, they have to adopt CO_2 capture process. In the end he suggested it is desirable that all countries including India have some standard for large-scale emitting sources of capture carbon dioxide. Much more initiatives are needed across the globe to achieve Net zero carbon targets.

Thank you very much!

(Note – The full presentation of Dr Palanivelu can be seen on p. 16 onwards)

Guest Speakers

Prof. Mohamed Kheireddine Aroua, Associate Dean (Research and Postgraduate Studies) and Head, CCDCU, Sunway University, Malaysia

1. Prof. Mohamed Kheireddine Aroua from Sunway University in Malaysia conveyed his thanks for the invitation to this workshop and said that he will share the work on green solvent for CO_2 capture being carried out at our university. As the cost of CO_2 capture is one of the issues, the challenge lies in its application at large scale. Therefore we are looking at new sources of solvent, which are from renewable, that may in the long-term be more sustainable and can provide a better choice to the existing or the benchmark technology.

2. At the Sunway University he is Associate Dean for Research and Postgraduate Studies and heading the Center for Carbon Dioxide Capture and Utilization and leading the research cluster on the material research, smart science and engineering. He is also attached to the Department of Engineering and University of Leicester, UK. The Sunway University is private nonprofit university having about 8000 students, 72 academic programs, seven academic schools and 17 research centers. Sunway City is near Kuala Lumpur, one of the smart cities in Malaysia. He welcomed all to visit his center at the Sunway University. The School of Engineering and Technology is one of the biggest schools in the University. It has 1000 students with nine academic programs to academic departments, five research centers and groups. He said we are producing nearly more than 300 publications per year, which is equivalent to more than seven per academic person in the school, in a year. At the Center of for Carbon Dioxide Capture & Utilization started in January 2018, his focus is on CO_2 capture and utilization research.

3. The CO_2 is a gas that is emitted from fossil fuel burning plants. It affects our environment and specially the climate on earth. Climate change is a grand challenge facing humanity and life on earth. To address this challenge development of new processes to capture CO_2 and utilizing this gas is our goal. He described various projects undertaken and said that a number of Sustainable Development Goals especially SDG-13, (Climate Action), SDG-7 (affordable and clean energy) and SDG-9 (innovation and industrial innovation) for business opportunities and by creating new processes for CO_2 utilization are also addressed. To integrate the CO_2 capture and its utilization, it's a big challenge facing the researchers so as to reduce the cost of CO_2 capture. Teams are being built in partnership with others, hoping that in the next two or three decades, the captured CO_2 can be used as a raw material, to synthesize and to produce chemicals and fuels. The first Rural-Asian network is currently being established. A short video of the CCDCU, Sunway University was shown. He introduced his team of scientists.

4. Coming to the main topic he said to develop a green solvent from renewable resources, chemical absorption is one of the technologies that have been used for a long time. It is used in 95% of the processes to remove CO_2 from natural gas or from other process gases.

This technology has been there for decades. Despite being fully established, there are still many issues. He explained the parameters of the design developed for low cost solvents. In power plants in the current technology for CO_2 captured from flue gas or from the atmosphere, the regeneration is very costly and overall process is not economical. To avoid regeneration, the MIT group is working on integrating the capture CO_2 directly with utilization using electro-chemical techniques. He described the ways to minimize the cost of regeneration and options to arrive at a cost similar to MEA, which has a benchmark for CO_2 capture. Glycerol could be added to replace MEA partly, and because glycerol is generated from renewable energy sources it forms a green solvent. However, an ideal green solvent is a challenging task. We need to focus on solvent derived from renewable resources for long-term sustainability and we should also consider solvent blends. He said we could identify some area of mutual interest, where we can also establish some collaboration.
Thank you.

Shri Gautam Sen, Ex-Sr. VP Reliance and Ex-Executive Director, ONGC

1. Shri Gautam Sen, at the outset said that he would respond to three questions, which include Feasibility of Carbon Capture and storage/carbon capture and utilization; Technological complications in Carbon Capture; and Employment generation in CCS for geologists and engineers He said that the three critical issues in acceptance of visibility of carbon capture and storage we are facing are (i) Technological complications, (ii) Cost of carbon capture and (iii) Employment generation. To get zero emissions and negative emissions scenario, the feasibility issue is not there anymore. About 1.37 gigatons of emission was added in 2021, which was only 0.2 gigatons in 1850. One can capture carbon dioxide from a point source or directly in the atmosphere and in the oceans. The cost of capturing carbon dioxide from a point source which has 10 to 15% concentration is estimated to be between 30 – 100 USD. But direct air capture (DAC) costs are much higher than that, it can go up to 1000 USD. At the same time one can have vertical gardens for CO_2 sequestration in cities and that would not cost much.

2. The CO_2 capturing machines are energy intensive. Also the water requirement is very high. In DAC one can build small modular systems but we may need as many as 20 million machines by 2100. He described Adsorption process and said that Temperature swing adsorption and Moisture swing adsorption are being developed. Temperature swing absorption is preferred because water requirement is less and carbon dioxide is emitted at a lower temperature.

3. For point source carbon capture; post combustion, pre combustion or oxy fuel combustion are the options. The CO_2 can be sequestered in oceans at different depths. There is lot of scope for capturing carbon from oceans. Phytoplankton capture of carbon dioxide is becoming more capable of absorbing carbon dioxide. One can increase the productivity of phytoplankton by adding iron filings. In Iceland, mineralization of rocks has been studied with captured carbon dioxide. IIT Bombay has predicted that in India, the

basalt rocks can absorb few gigatons of carbon dioxide. Enhanced oil recovery and enhanced coal based methane have been tried in India. The saline aquifers absorb CO_2 but need to be periodically monitored.

4. He concluded by saying that Geologists have an important role in storage. The employment is generated and engineers will have to champion the entire project, starting from machine building to capture and also utilization.

Thank you very much.

(Note – The presentation of Shri Gautam Sen can be seen at p. 25 onwards)

Dr. Abhijit Mitra, Director Research, Techno India University, West Bengal, Faculty Member and former Head, Department of Marine Science, University of Calcutta, Kolkata

1. Dr. Abhijit Mitra, joined from Calcutta. At the outset he said that CO_2 capture in coastal areas is a very eco-friendly approach, which takes care of the biodiversity of the environment pollution, as well as the emissions by sequestration. In very remote islands of Sundarban in the lower stretch of the river Ganges, which have mangrove vegetation in the Bay of Bengal, it is actually the 'blue carbon', the carbon present in the coastal vegetation and in the coastal soil. They are great potential reservoir of the carbon. He pointed out that in Sundarbans area, an expansion of the liquid is seen as 3.14 millimeter per year due to rise of the temperature, much more than the global average of 2.50 millimeter per year.

2. The CO_2 level$_s$ in all the three seasons pre-Monsoon, Monsoon or post- Monsoon, has crossed 400 ppm. There is no industry there, but road towards the Sundarban has every day about 1,33,000 to 1,50,000 cars plying. One liter of diesel contributes 2.64 kg of carbon dioxide, and one liter of petrol contributes about 2.3 - 2.5 kg of the carbon dioxide. Potential sinks of carbon dioxide have been destroyed by fish landing stations, by tourism resorts, by urbanization and also by setting up a large number of fish culture farms.

3. In Sundarbans there are 34 varieties of mangroves, but we have pointed out only 5-6 varieties which can absorb maximum amount of carbon dioxide. Sundarbans is divided into three parts, western, central and eastern; for the difference in the salinity. The western sector is getting the fresh water from the glaciers of the Himalayan region. It is a continuous linkage of several ecosystems. So one has to study a long stretch and collaborate with different disciplines together. We have done a number of studies, published with CSIR and with the World Bank on carbon sequestration. Crash courses involving the students and the research scholars at different times of the year are being taken.

Thank you very much.

Interactive Session

Q1. Can you please give me an instance with regards to research on how will the economy and sustainability will go hand in hand for developing country? - **Prenna Goel** (prerna.goel@terisas.ac.in)

Prof. D. P. Agrawal said that he already touched upon this issue in his address. Yes it can be done. We have abundance of coal and fossil fuels and therefore technology was designed to produce electricity economically to meet energy needs of people. But if you look at the case of solar energy, the clean energy share is increasing, it is here that the development is economically sustainable occurs. Lot of new industry is expected to come up by doing things differently. Both economy and ecology would improve.

Dr. (Mrs.) Malti Goel added that the concept of circular economy is now emerging in a big way in all aspects of life and carbon capture & utilization is one of the multi - disciplinary technologies cutting across all the sectors. The CCUS development could lead to the growth of economy and sustainability in the long run. While solar energy has great potential, there are issues about the land constraints and there can be issues in carbon capture and utilization about the cost.

Q2. How carbon capture technology can be used for mitigating GHG from dairy farming, particularly when carbon dioxide emission from live animals is not considered as emission as per IPCC? **- Bhupendra Ponda** (bphondba@nddb.coop)

Shri Gautam Sen replied to this and said that in my presentation I have tried to answer the first question and have covered feasibility of carbon capture and storage/carbon capture, utilization and its technological complications. The question here is how carbon capture technology can be used for mitigating greenhouse gas from dairy farming. Basically the point is that in dairy farming, you produce methane primarily, and methane capturing and methane solutions are entirely different. Though it is a greenhouse gas but the processes are entirely different from CO_2. So we cannot mix up and there has to be another session for it.

Q3. How can we as a student contribute to research in development of carbon capture technologies to give significant inputs to implementation part? - **Lovish Raheja** (lovishraheja26@gmail.com)

Q4. What capture technology India is working on and advance has been made? **- Deepak Pental (**dpental@gmail.com)

Q5. Which institutions in India providing research opportunities for students on CCUS R&D? - **Prenna Goel (**prerna.goel@terisas.ac.in)

Prof. K. Palanivelu in response to these questions said that in capture technologies the *Absorption* is a mature technology. Industrially, it is being applied in developed countries. Though it uses a standard benchmark solvent, many scientists are still working to improve the capture of carbon dioxide ability as well as regeneration to reduce the cost. There is a lot of scope still to work on this. Among the various technologies like *Absorption, Adsorption*, *Membrane*; while Absorption is more established, others are in the development stage and not reached the industrial scale. In utilization an Indian venture Carbon Solutions Inc has demonstrated cost-effective CO_2 capture with the sodium hydroxide as a solvent and converting straight into sodium by-carbonate soda. Working on carbon dioxide both for capture as well as its utilization aspects, many institutions in the country including IITs and CSIR laboratories are engaged in the lab-scale studies, trying to develop technology.

For students' contribution in development of carbon capture technology, definitely there is a lot of scope. Still many studies have to be conducted especially to address the environmental concerns with industry participation. To reduce the cost of capture, to improve the yield of the value-added products & fuels including methane, methanol etc. attention should be paid so that a considerable amount of conversion is taking place for the beneficial use.

Q6. I would like to ask Prof. M K Aroua, is there any research being done on the improvement of membrane technology? If yes, what kind of materials can be possible? - **Prenna Goel** (prerna.goel@terisas.ac.in)

Prof. M.K. Aroua observed that currently the cost of capture especially from the atmosphere is still very, very high. But any technology, when it starts is very expensive. It doesn't mean that it remains expensive, continuing innovation is the way forward. One example I always give to my students is about the membrane technology. The membrane technology 40 years ago was so expensive that people thought it could not be applied. Now it is everywhere, like in water treatment and various chemical processes. In application of CCU its use will remove the regeneration cost and it may become cost-effective with proper integration of the materials. There is a lot of work going on and in the next few decades we will see that the CO_2 is captured and at the same time utilized in a profitable manner. The area of CO_2 capture is not only for climate action or climate change, but also for creating life on other planets. A few months ago, they managed to produce oxygen from CO_2 in the Mars Atmosphere.

Remarks

Really enjoyed Dr. Abhijit Mitra's talk on blue carbon, how can we stop 'development' projects destroying our blue carbon sinks - Asha Gopinathan (dendron.15@gmail.com)

Concluding Remarks

1. **Dr. (Mrs.) Malti Goel** thanked all distinguished speakers and the Chairperson. The webinar began with insightful remarks of Chairman Prof. D. P. Agrawal in his Inaugural address. He said India has adopted Panchamrit Action Plan in COP26. He opined that fiscal incentives from the government and behavioural changes by the population are vital for Climate Action.

2. We have had views from scientists, engineers and academicians on carbon capture, utilization and sequestration (CCUS). India's *Panchmrit* Action plan in COP26 is as below.

- To raise the non-fossil fuel based energy capacity to 500 GW by 2030.
- By 2030, 50% of the country's energy requirements would be met using renewable energy sources.
- To reduce the total projected carbon emissions by one billion tonnes between now and the year 2030.
- The carbon intensity of the economy would be reduced to 45% by 2030.
- The country would achieve Net zero emissions by the year 2070.

3. The following is the brief summary of deliberations.

The CCUS is not one technology but a set of technologies in multi-disciplinary fields. The CO_2 capture cost continues to be high. The processes are known for some, but their scaling up is highly challenging.

Key Messages emerged for advancing CCUS technology are; as follows:

(i) The CCUS is a vital technology for achieving the Net zero targets. Application of digital techniques and innovation in materials would have important roles in making CO_2 capture cost-effective.

(ii) There has to be Climate Action from the governments, corporates and academia all of them, so as to accelerated CCUS technology development.

a. **Governments** should announce CCUS acceleration Technology Projects policy and provide fiscal incentives, increase investment to address climate change concerns and introduce standards for large emitting sources.
b. **Corporate sector** to make accelerated transition to climate action by adopting science based targets (SBTi) by committing to Net zero across all industries.
c. **Academia** to invest in collaborative research, to build teams with common goals for CO_2 capture and to see that captured CO_2 can be used as a raw material, to synthesize and to produce chemicals and fuels.

(iii) We have almost 50 years from now to reach Net zero mission targets of 2070. It is imperative for India to have a roadmap for next 25 years as an interim action. India began a CO_2 sequestration national research programme in 2006-2007 in the Ministry of Science & Technology in association with Ministry of Power. The capabilities existed in a large number of academic institutions, R&D laboratories and industrial units under the umbrella of DST, CSIR and stakeholder ministries. We need an integrated effort on the policy side. For the advancement of CCUS technology, increased investment in R&D and a 'Science, Technology and Innovation Roadmap' for the next 25 years' with solutions to achieve Net zero targets, should be the goal.

Annexure 1

Presentation by Dr. K. Palanivelu

Keynote Lecture
CO_2 Utilization from Large Scale Stationary Sources

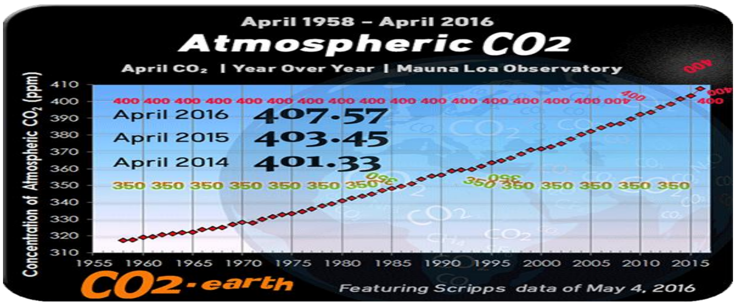
Webinar On
Role of Carbon Capture Utilization: Towards A SustainableNet zero Future
Organized By
Climate Change Research Institute, New Delhi
4-2-2022

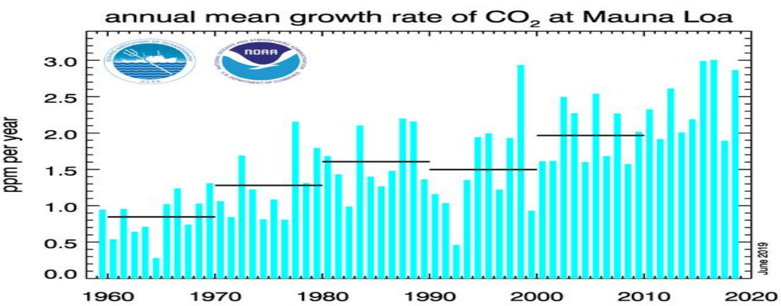
Dr. K. Palanivelu
Professor
Centre for Environmental Studies
Anna University, Chennai
kpvelu@gmail.com

- Earth is getting warmer
- The Climate is changing faster than ever before -Developmental issues
- We live in the age of CC-extreme weather

Events like excess rain (flood), storms, heat waves, Increase in diseases, etc

Nov. 30, 2020 414.43 ppm
Nov. 30, 2021: **416.54 ppm (1 Year Change 2.11 ppm (0.51%)**

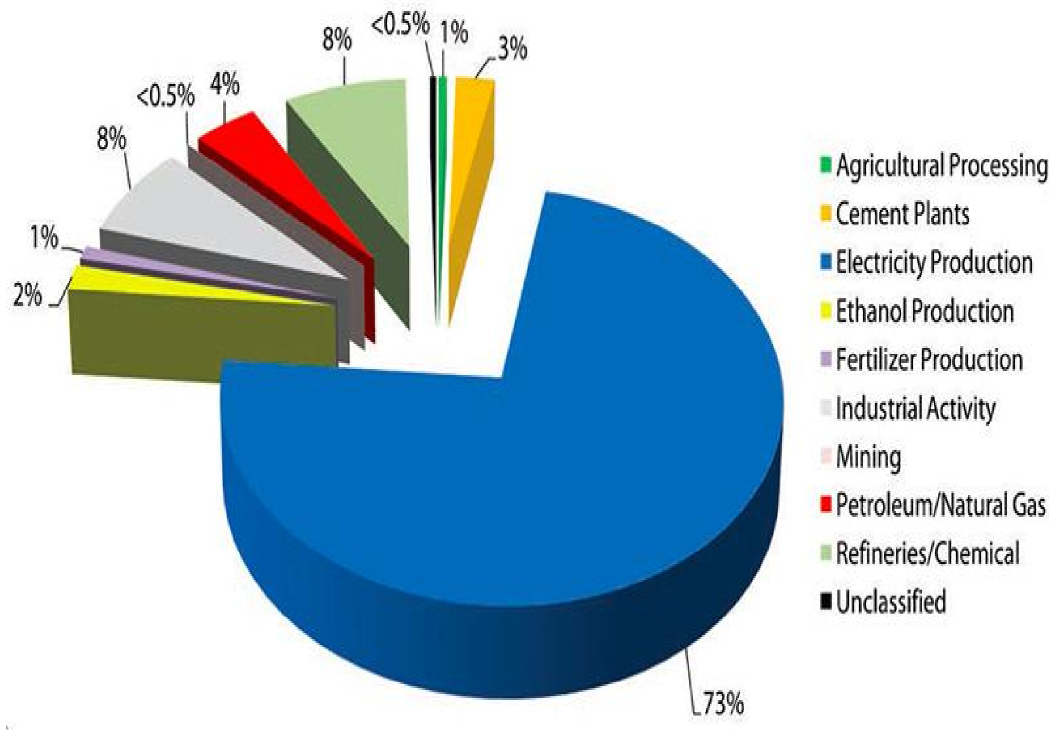




CO_2: Carbon dioxide

- A naturally occurring gas that is also a byproduct of the combustion of fossil fuels, biomass, other industrial processes, and land-use changes.
- CO_2 is the principal anthropogenic greenhouse gas (~ 60%)responsible for global warming
- It is the reference gas against which other greenhouse gases are measured; therefore, it has a global warming potential of 1

Stationary Sources of CO_2



Typical flue gas composition from power plants

Gas	Pulv. coal combustion flue gas	Waste incinerat flue gas	Coal gasification fuel gas §	Coal-fired IGCC flue gas	Natural gas Groningen	Gas-fired CC flue gas
O_2 %V	~ 6	7 - 14		~ 12		~14
N_2	~ 76	balance	~4 / ~1	~ 66	~14	~76
CO_2	~11	6 - 12	~4 / ~13	~ 7	~1	~ 3
H_2O	~ 6	10 - 18	~4 / ~1	~ 14		~ 6
CO		0.001-0.06	~58/~40			
H_2			~30/~29			
Ar	~ 1	~ 1	~ 1	~ 1	~1	
SO_2 ppm w		200 -1500		10 - 200		
H_2S			1000-4000			
NOx	500 - 800	200 - 500		10 - 100		10 - 300
NH_3			300 - 800			
HCN			40 - 150			
HCl		400 - 3000	500 - 600			
HF		2 - 100	150 - 250			
CH_4					~ 81	
HC		< 0.002			~ 4	
Hg, Cd, other heavy metals: 0.001:0.2 ppm, dust 0.02-20 ppm,						

CO_2 emissions…

- From 1750 to 2011 CO_2 emissions are
  - ✓ Fossil fuel combustion & Cement production = 180 GtC
  - ✓ Deforestation & other land use change = 375 GtC
- Cumulative emissions = 555 GtC

From that 155 GtC is taken up by ocean & 160 GtC have accumulated in natural terrestrial ecosystems, remaining will remains in atmosphere. (Ref : IPCC-AR5, 2013)

GHG Emissions

Country	Annual GHG Emissions in 2005 including LULUCF				
	$MtCO_2e^2$	global ranking	% of global total	per capita	per capita ranking
Brazil	2,840.5	4	6.6%	15.3	19
China	7,194.8	1	16.7%	5.5	94
India	1,865.0	7	4.3%	1.7	152
Indonesia	2,035.5	5	4.7%	9	58
Mexico	671.0	11	1.6%	6.3	82
South Africa*	422.6	23	0.98%	9	59
Russia	1,997.6	6	4.6%	14	23

Responding

- Mitigation- refers to efforts to cut or prevent the emission of greenhouse gases - limiting the magnitude of future warming. It may also encompass attempts to remove greenhouse gases from the atmosphere.

Globally by all countries- low carbon society AVOIDING THE UNMANAGEABLE

- Adaptation-refers to the actions taken to manage the unavoidable impacts of climate change

Regional- climate resilient society MANAGING THE UNAVOIDABLE

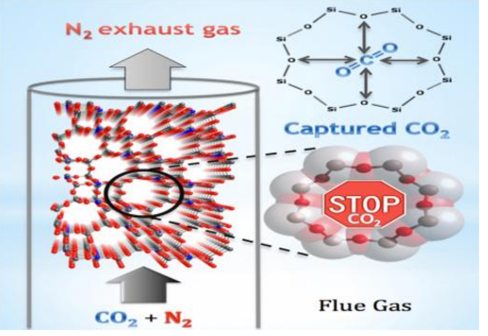
Reducing CO_2 emissions

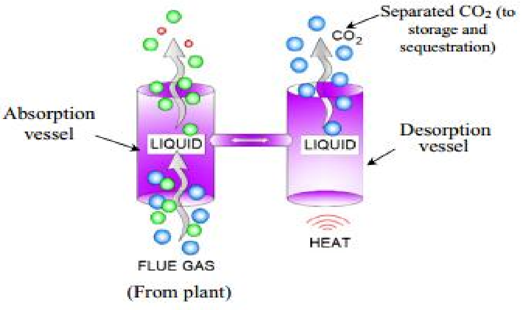
- Identifying the most efficient path to reducing atmospheric CO_2 is the subject of much research and debate

Most solutions being considered fall into one of three categories:

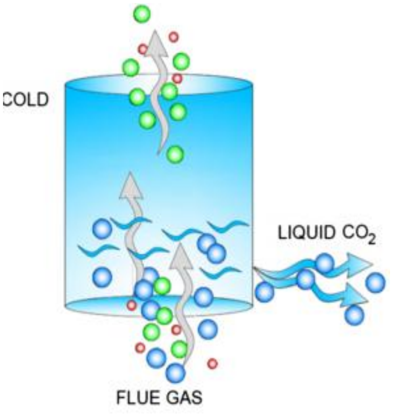
- Eliminating CO_2 emissions at their source by replacing CO_2-intensive processes with alternatives (*e.g.*, replacing fossil-fuel-based electricity generation with a low-carbon-based alternative)
- Mitigating CO_2 emissions from existing facilities and processes using carbon capture, conversion, utilization, and/or sequestration
- Actively removing carbon from the biosphere.
- Each general approach has its merits and drawbacks

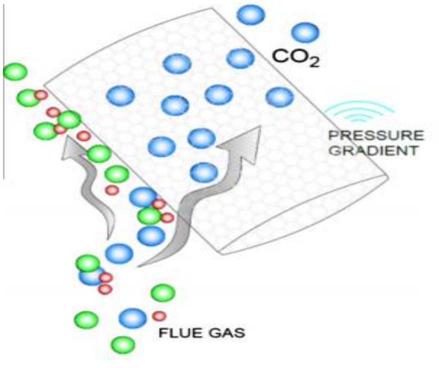
CAPTURE OF CO_2





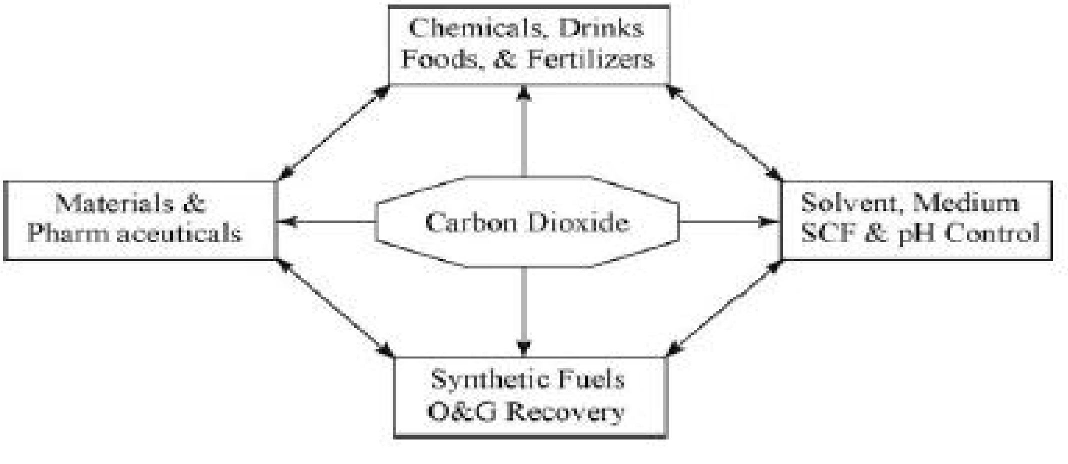
Adsorption **Adsorption**



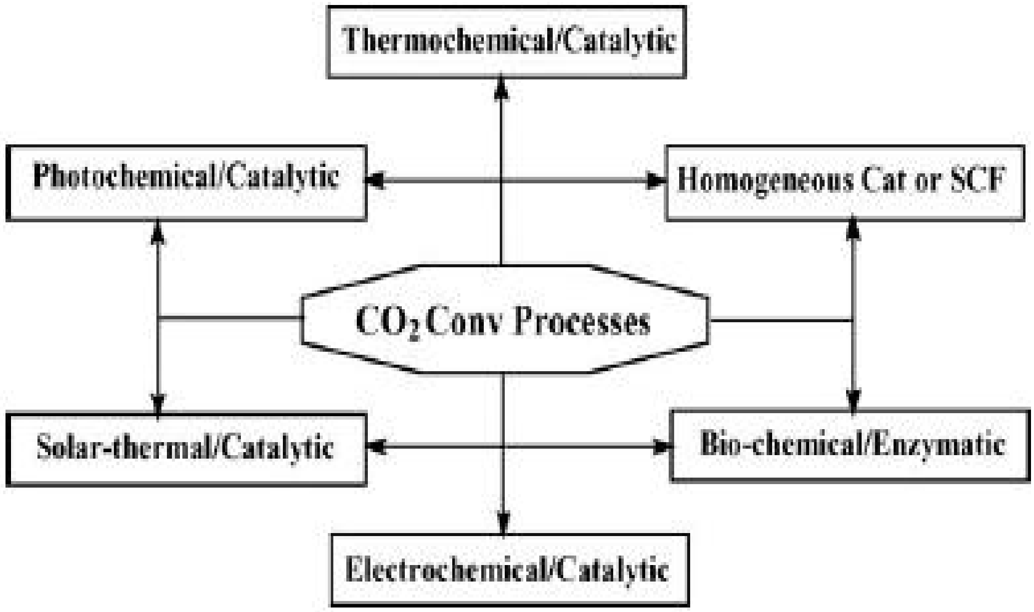


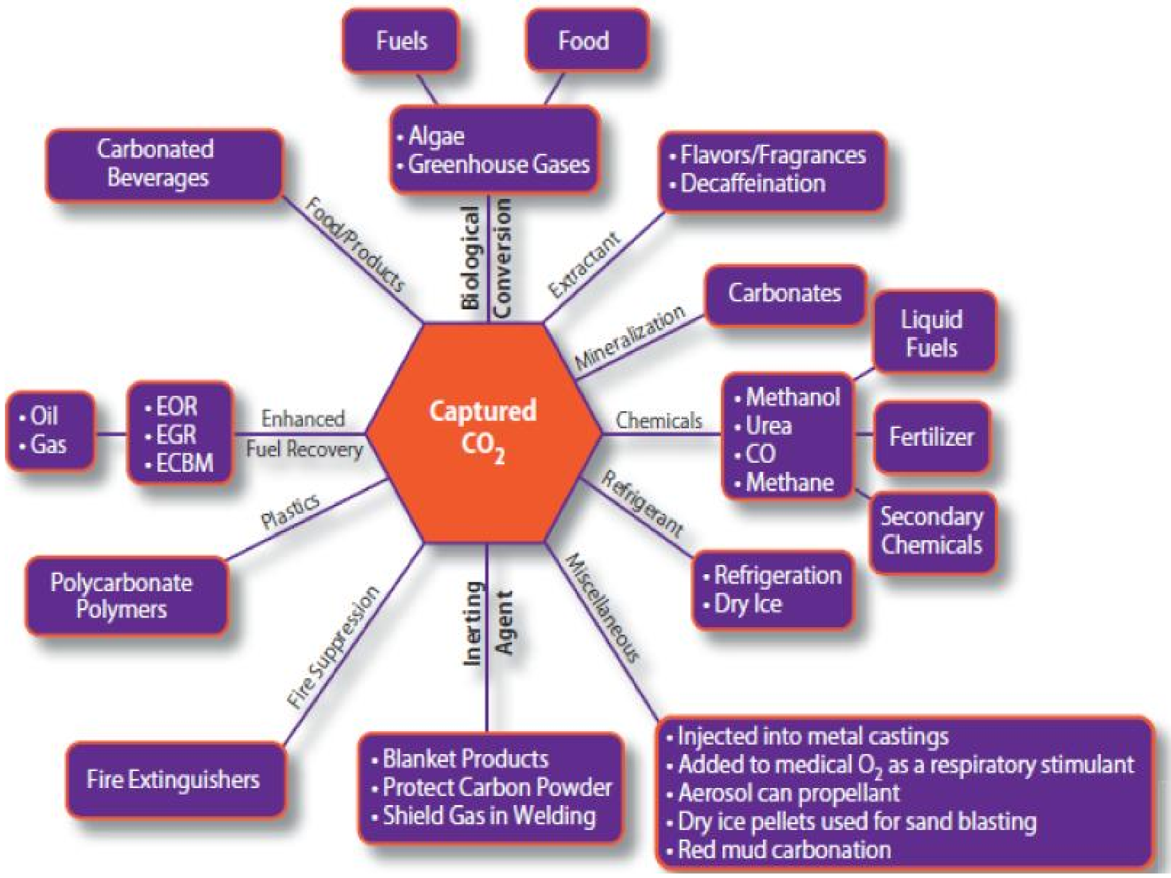
Cryogenic separation **Membrane separation**

The existing and emerging application areas of CO_2-conversion and utilization



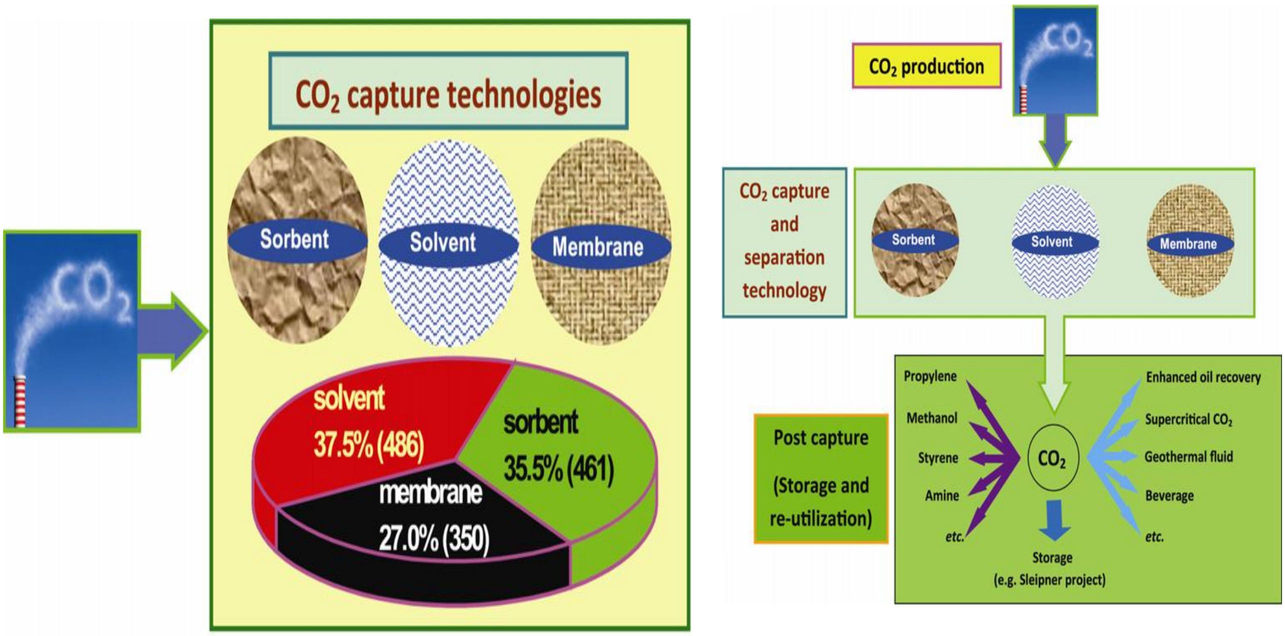
<u>Scope of chemical processes for CO_2 conversion</u>





Criterion	Methanol production	(Carbonate) mineralisation	Polymerisation	Formic acid	Urea
Technology maturity	😮	🙂	😮	😮	🙂
Scale-up potential	😮	🙂	🙂	🙂	😮
Commercial viability	😮	🙂	😮	☹️	😮
CO2 abatement potential	☹️	🙂	🙂	☹️	☹️

Patent status in 2013



Carbon capture patents rise for fifth year running

- As countries aims to mitigate reliance on fossil fuels
- Global patents registered for carbon capture and storage have risen 22 per cent, increasing for the fifth year running
- The number of patents registered has increased from 167 in 2019-20 to 203 in 2020-21
- Just 62 carbon capture and storage (CCS) patents five years ago
- The surge in registration has been driven by China, which was responsible for 81 per cent of global patents last year
- The country is the world's largest emitter of carbon emissions and is responsible for over half of the world's coal power generation

Circular Carbon Economy

- While renewable technologies are part of the solution towards climate mitigation, holistic whole system solutions are required long-term due to the continued reliance on fossil fuels
- The **Circular Carbon Economy** employs a technology-neutral whole systems approach to achieve energy market stability, responsible and inclusive economic growth, and sustainable development goals
- The four **R'**s of the Circular Carbon Economy include:
  1. Reduce: using all carbon mitigation options and fuels with a reduced carbon footprint
  2. Reuse: carbon capture and utilisation without chemically altering carbon
  3. Recycle: create new value-add products by chemically altering carbon
  4. Remove: carbon capture utilisation storage (CCUS), direct air capture, and natural sinks

Challenges in CO_2 utilization

- Costs of CO_2 capture, separation, purification, and transportation to user site.
- Energy requirements of CO_2 chemical conversion (plus source and cost of H_2 and/or other co-reactants if involved).
- Market size limitations, little investment-incentives and lack of industrial commitments for enhancing CO_2-based chemicals.
- Lack of socio-economical driving forces for enhanced CO_2 utilization

INDIA'S ACTION PLAN TO REDUCE CO_2 EMISSIONS

1. Reduce emission intensity by 33 to 35 per cent by 2030 compared to 2005 levels

HOW:

- Introduce new, more efficient, cleaner technologies in thermal power generation
- Reduce emissions from transport sector
- Promote energy efficiency, mainly in industry, transport, buildings, appliances
- Develop climate resilient infrastructure
- Pursue Zero Effect, Zero Defect policy under Make in India programme

2. Produce 40 per cent of electricity from non-fossil fuel based energy resources by 2030

HOW:

- Install 175 GW of solar, wind and biomass electricity by 2022, scale it up in following years
- Aggressively pursue hydropower development
- Achieve target of 63 GW of installed nuclear power capacity by 2032

3. Create additional carbon sink of 2.5 to 3 billion tonnes of carbon dioxide equivalent by 2030 through additional forest and tree cover

HOW:

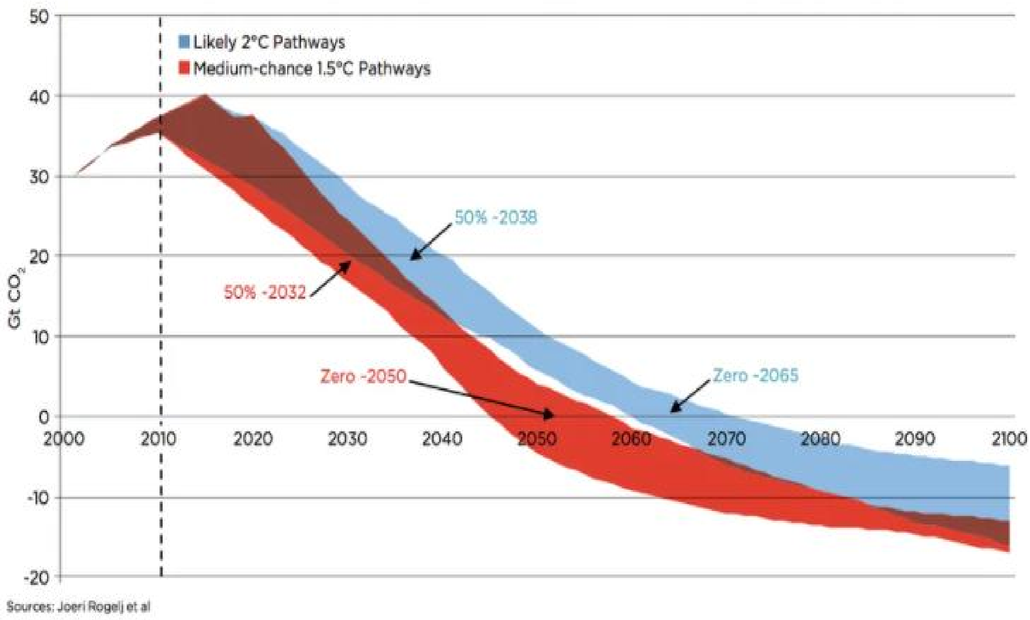
- Full implementation of Green India Mission, other afforestation programmes
- Develop 140,000 km long tree line on both sides of national highways

Conclusions

- Burning fossil fuels won't end soon
- Some limit(Standard) has to be introduced for stationary sources(large emitting)
- Harmful carbon emissions can end soon with the help of **CCU-Carbon to value (Pollutant to Product)**, possible with startup support from Govt.

Annexure 2

Presentation by Shri Gautam Sen



1.5 and 2 degree emission scenarios; everything after emissions dip under zero at mid-century is negative emissions. | OCI

Carbon Capture

- Carbon concentration has gone upto 417 ppm; while 350 ppm is considered safe.
- Effects of Global warming is clear and India s fragile Himalayan ecology and long coast lines , along with the plains provide the recipe for extreme weather, flooding , drought
- Global carbon emissions are rising from existing fossil fuel.
- 37 GT emission est in 2021 (0.2 Gt in 1850)
- It is no longer a feasibility issue, it has to be done to mitigate climate disaster.

Carbon capture (contd.)

- Model used by the Intergovernmental Panel on Climate Change (IPCC) shows reaching a safe climate involves burying GT of CO_2, so-called “negative emissions.”
- Carbon dioxide is captured either at the source of generation called Point Source Carbon capture; PCC or directly in atmosphere; DAC, and in oceans.
- Once it is captured a part of it could be reused and remaining needs to be permanently stored. This whole process is termed as CCSU

DAC VS PCC

- Ambient air near power plants and industries like cement have higher concentration of carbon dioxide and therefore energy and costs requirement to capture carbon (PCC) is far less.
- Yet PCC requires Carbon capture machines tethered to CO_2 emission point sources, making the technology inflexible.
- DAC requires capturing 400 molecules of carbon dioxide in millions of molecules of nitrogen and oxygen, is the challenge.
- As per Geopart , cost varied in DAC from 20 USD to more than 1000 USD per ton CO_2 due to many uncertainties in the technology
- While the cost of capturing a ton of CO_2 from a point source stream with 10-15% CO_2 concentration was estimated to be between 30 USD to 100 USD.
- Both DAC and PCC are in addition to bio-sequestration ie capture of carbon dioxide through plants and soil.
- Vertical gardens can add to bio sequestration in cities and towns.

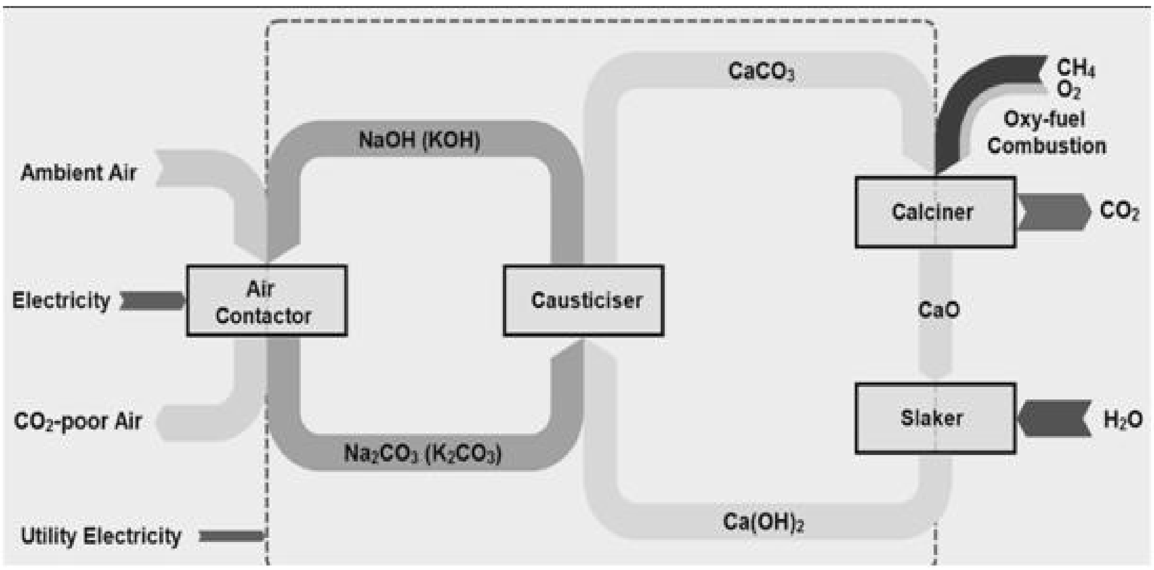
Challenges in DAC

- Direct air capture machines are energy intensive and absorption technology**,** especially, needs either huge water, or caustic chemicals to capture carbon dioxide.
- One estimate is that amine-based technology absorption needs 300 cubic KL of water to capture 3.3 giga tons of carbon dioxide a year.
- It is estimated that scrubbing 1 gigaton of carbon dioxide from the air would require around 7% of all projected U.S. energy production in 2050 and unless it is powered by low- or zero-carbon energy sources, result will not be net carbon removal
- Capturing 30 Gt CO_2 /year which is around the current global emissions – would mean building some 30,000 large-scale DAC factories, while coal-fired power stations in the world are less than 10,000 today.
- If DAC were to be carried out using small modular systems, then as many as 30 million machines will be needed by 2100.
- A DAC plant designed to capture 1 mega ton of carbon dioxide a year is estimated to cost $2.2 billion with Costs around 30 USD /ton of carbon dioxide.

Absorption

- CO_2 is captured using liquid solvents like water or alkaline solution such as sodium or potassium hydroxide, or amine-based solvents.
- Increasing the liquid gas contact area helps in increasing the efficiency.
- Absorption with a caustic solvent; CO_2 reacts with sodium hydroxide and precipitates a stable sodium carbonate.
- Sodium carbonate is mixed with calcium hydroxide in the Causticiser unit, where calcium carbonate is formed
- Sodium hydroxide is regenerated and is sent back to the contactor to start another absorption cycle.
- Calcium carbonate is heated up to around 900 °C in the Calciner unit to release CO_2 and CaO, heat demand is in the range of 1420–2250 kWh per ton of CO_2.
- CO_2 is collected and calcium oxide is mixed with water in the Slaker unit for regeneration of calcium hydroxide.
- Mono-ethanolamine is another promising liquid absorbent to capture carbon dioxide from the atmosphere

Absorption of Carbon dioxide by hydroxides



Adsorption

- Uses solid solvents like Primary Amine based solids to capture carbon dioxide from air by chemisorptions , where CO_2 molecules are held on to the solid surface by a chemical bond.
- Air is made to flow into this solid filter by a fan or blower.
- CO_2 is then desorbed from the solid sorbent by heating and creating vacuum and the process is called temperature swing adsorption
- Unlike absorption CO_2 is released at a lower temperature, though the whole process is not very efficient
- This results in a gaseous CO_2 stream that can be cooled and cycled back into the system for reuse or storage.
- Moisture swing adsorption (MSA) is another method of adsorption, in which CO_2 is released by moisturising of CO_2-rich sorbent.
- Water requirement is less than using absorbent method.

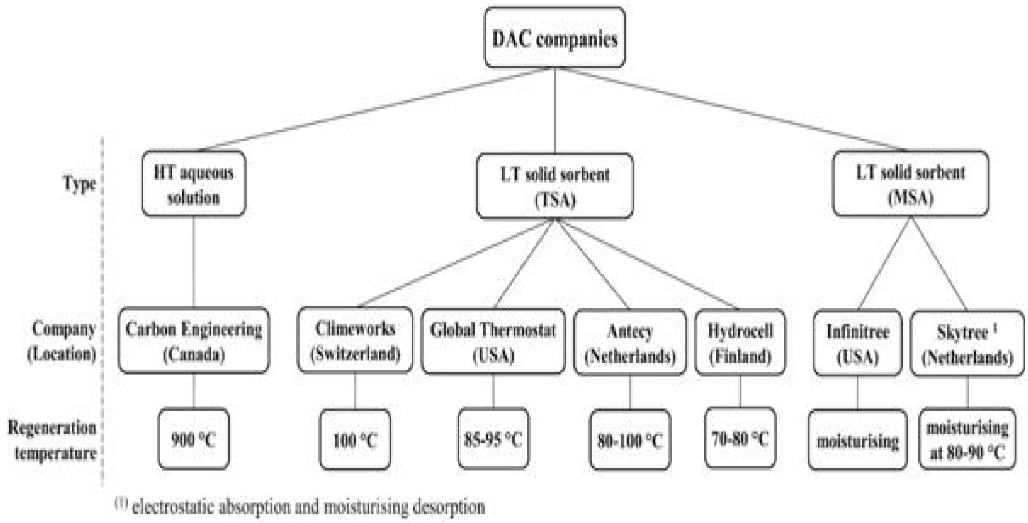


Fig. 2: Companies active in the field of CO_2 DAC

Abbreviations used: high temperature - *HT*, low temperature - *LT*, moisture swing adsorption - *MSA*, temperature swing adsorption - *TSA*. (Fasihi et al., 2019)

Point Source Carbon Capture; PCC

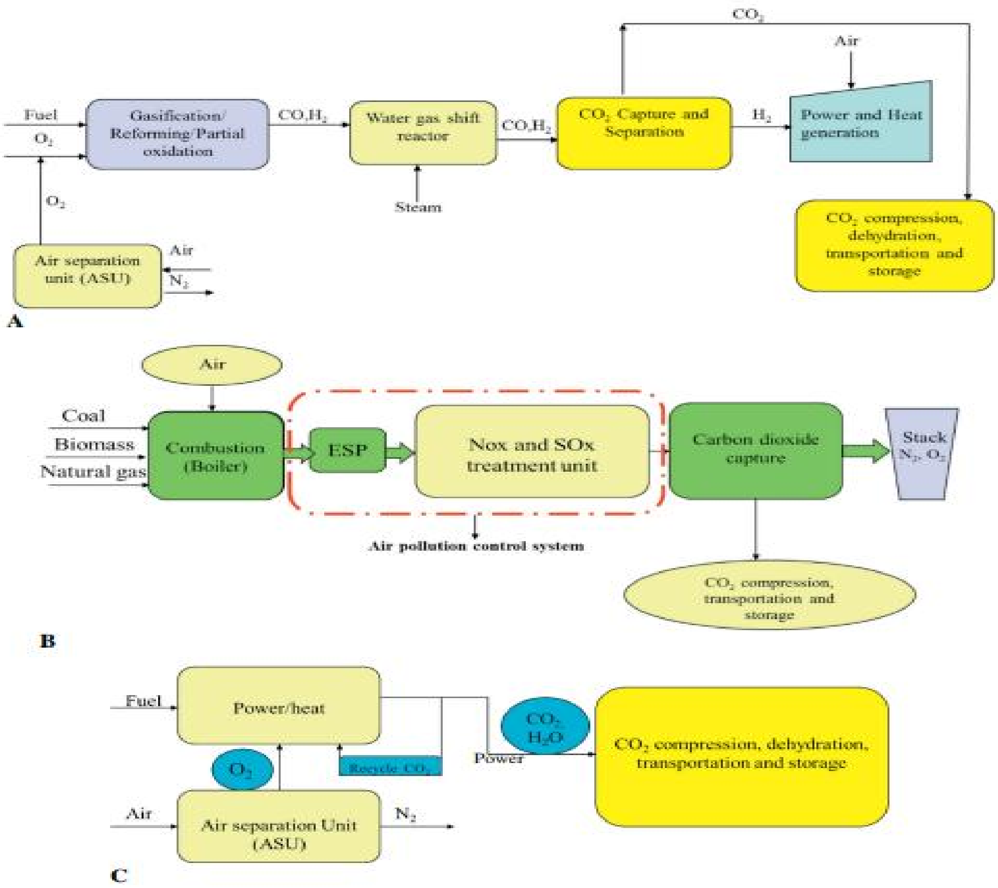
- A fossil fuel power plant generates power by combustion of fossil fuel generating heat, that turns water into steam which turns a turbine connected to an electricity generator.
- **Post-combustion**
- The burning of fossil fuels produces flue gases, which include CO_2, water vapor, nitrogen and sulfur dioxide. The flue gases are passed through a electrostatic precipitator (ESP), so that majority of large particulate matter is removed.
- Carbon dioxide is then captured using liquid amine scrubbing systems to remove CO_2 by bubbling the gas through water that contains 20–50% amine.
- This strongly binds to CO_2 but not other molecules and the liquid water-amine-CO_2 solution is then heated to release CO_2.
- The liquid amine-water is recycled back to the absorber to trap more CO_2.
- Alternately activated carbon usually charcoal with fine pores increasing the surface area or membrane separation (polymer or ceramic based material) are applied to treat the flue gas in order to remove the CO_2 from the flue gas.

PCC (contd.)

- Can be retrofitted for existing plants has higher thermal efficiency for conversion to electricity.
- Has great potential for reduction of carbon dioxide in short term
- **Pre-combustion**
- Carbon is trapped and removed from fossil fuels before the combustion process ends.
- Fossil fuel is partially oxidized, and then steam is injected resulting in a synthesis gas, or syngas, a mixture loaded with H2 and CO_2.
- It's easy to isolate, capture and sequester the CO_2 from that mix.
- Carbon dioxide is captured at high pressure but this plant can not be retro fitted to existing plants

PCC (contd.)

- O**xy-fuel combustion**,
- Fossil fuel is burnt using pure oxygen. This results in a flue gas whose two main components are CO_2 and water. It is possible to separate out the CO_2 by compressing and cooling the water
- The process allows the production of a very high purity CO_2 stream.
- Easier to purify the stream once trace contaminants has been removed.
- High capital cost requirement largely because of the need for huge amount of electric power required for the separation of oxygen from air.
- There is a substantial reduction in the emission of NOx during the oxy-fuel combustion process ,and this technology can be retro fitted to existing power plants
- Risk and safety issues related to oxygen management and its effect on the boiler.



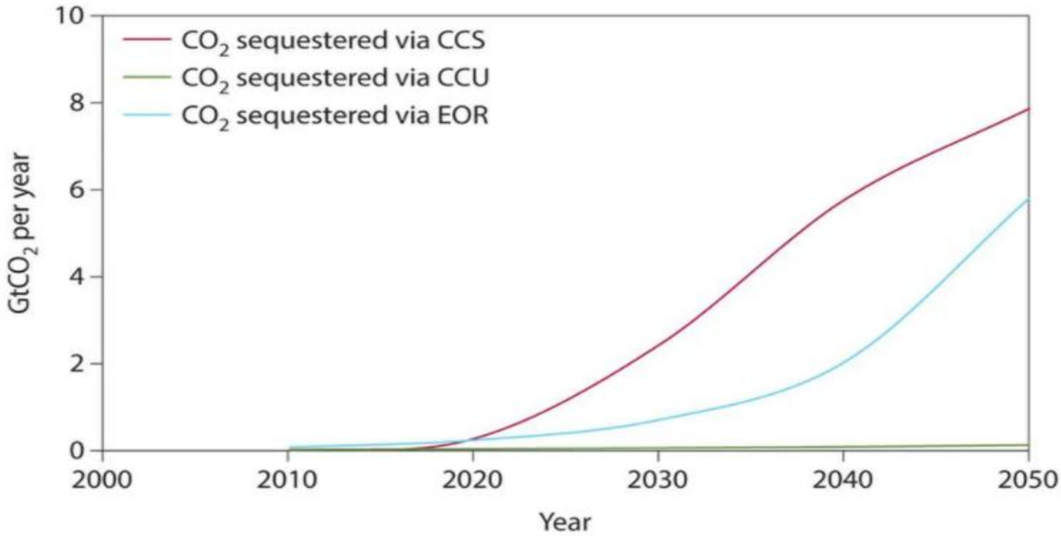
- (A) Pre-combustion CO_2 capture technology, (B) post-combustion CO_2 capture technology, (C) oxy-fuel CO_2 capture

Carbon capture in oceans

- Extracting CO_2 from seawater is akin to direct air capture.
- By reducing CO_2 concentration in the ocean, the water draws in more carbon from air to regain balance.
- Seawater is a more concentrated solution of CO_2 than the ambient air, which means less work is required to separate it out.
- But seawater is also considerably heavier than air, which means more work is required to move it through the system.
- Addition of 0.4% CaO increases CO_2 absorption of seawater by 79.25 %
- Phytoplankton can capture CO_2. When plants die they go to bottom of sea thus sequestering CO_2. Phytoplankton growth can be enhanced by seeding it with iron filings. When phytoplankton sinks, the bacteria that decompose them may also affect distribution of nitrogen and oxygen in water.
- In place of iron filings, use of biogenic iron dust nanoparticles (Sahara desert, volcanoes) is now suggested for Phytoplankton growth. More research would be needed to know whether it offers significant CO_2 removal potential.

Carbon utilization and storage

- It involves pulling CO_2 out of the air and then using it in place of hydrocarbons in energy and industrial processes, effectively recycling it.
- The total "mitigation challenge" is roughly 800 gigatons of CO_2 by 2050 to stay within 2 deg.
- Most models used by the IPCC show CCS accounting for approximately 14 to 20 percent of that challenge.
- Apart from enhanced oil recovery (EOR), other CCU technologies can permanently sequester only 3.86 GT of CO_2 by 2050. CCU can however reduce emission.
- Geological storage is possibly the only way to bury and sequester the massive amounts of CO_2 that will need to be buried and sequestered by 2050, either in saline aquifers, old oil and gas fields, coal seams or within basalts. Leakages in saline aquifers may need monitoring.
- In a recent publication in International journal of greenhouse journal, researchers of IIT Mumbai claimed that India can store 400 GT of CO_2.



Mineralization

- Occurs naturally; weathering of silicates and rocks rich in Calcium or Magnesium.
- During ex-situ carbon mineralization solid reactants are reacted with fluid or gas rich in carbon dioxide, at the site of carbon-dioxide capture. Alkaline Industrial wastes can also be used.
- In in -situ carbon mineralization carbon-dioxide rich fluids are circulated within basalts as inter-trappean at depths for a permanent storage.
- Current technology requires 1.6 to 3.7 tonnes of rock to fix one tonne of CO_2. Since the reaction is exothermic, it produces energy that can be recycled back to source the reactor.
- The kinetics of this process is slower than adsorption and absorption processes.
- There is currently no large-scale implementation of mineral carbonation.

Conclusions

- India faces a double whammy, need to develop, only has coal reserves, the dirtiest fuel.
- Large scale Biosequestration and capturing carbon, using PCC and storing carbon in basalts, old oil and gas fields if available as EOR or otherwise, and subsequently follow it up with DAC as R and D in urban area.
- Geologists will be involved in storage while engineers have to champion the entire project.

Carbon Capture & Utilization plus Net zero Future
(ACBCCU 2022)

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India International Centre in collaboration with **Climate Change Research Institute**
present a webinar on

Workshop on
Carbon Capture and Utilization plus Net-Zero Future

Chair: Prof. D.P. Agrawal
Chairman, Governing Council, Climate Change & Research Institute (CCRI) and former Chairman, UPSC

Keynote Speaker: Prof. K. Palanivelu, Director
Climate Change & Disaster Management, Centre for Environmental Studies, Anna University, Chennai

Guest Speaker: Prof. Mohamed Kheireddine Aroua
Associate Dean (Research and Post Graduate Studies) and Head, Centre for Carbon Dioxide Capture and Utilization, Sunway University, Malaysia

Speakers:
Shri Gautam Sen
Former Senior Vice President, Reliance and former Executive Director, ONGC; and

Dr. Abhijit Mitra
Director, Research, Techno India University, West Bengal and former Head, Dept. of Marine Science, University of Calcutta, Kolkata

Moderator: Dr. (Smt) Malti Goel
President, CCRI and former Adviser, DST, Govt. of India

On Friday, 4 February 2022 from 15:30 hrs onwards

Registration Link: https://zoom.us/webinar/register/WN_uQXb6_6JRjOHwJ2lKDj8dQ

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