

# “Geologic carbon storage pathways”



Presented by

---

**Vikram Vishal**

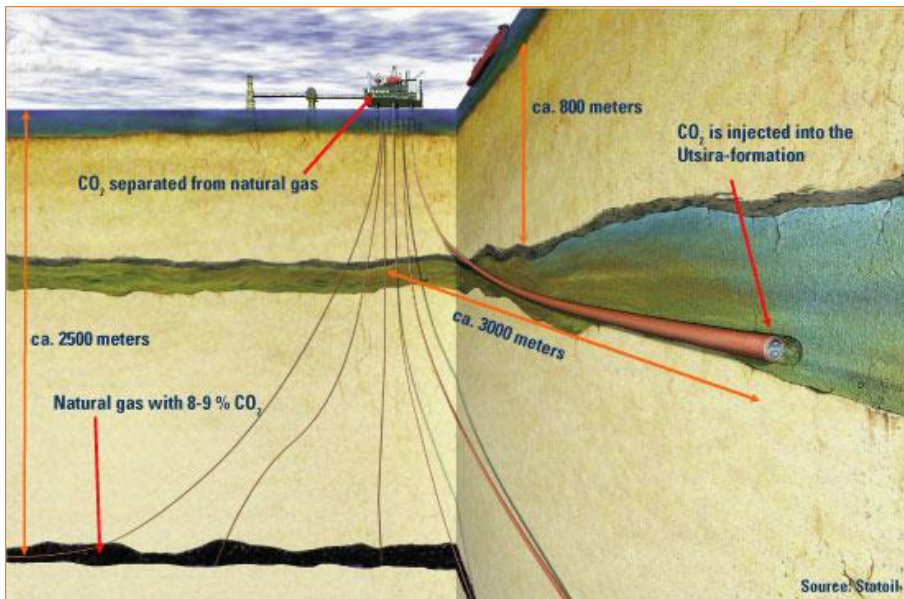


**Convener**

**National Centre of Excellence in Carbon Capture and Utilization  
Associate Professor, Earth Sciences, and IDP-Climate Studies  
Indian Institute of Technology Bombay, Mumbai**

# CCUS is the Way

Storage of CO<sub>2</sub> from anthropogenic sources into deep lithological units for geologically significant periods of time.



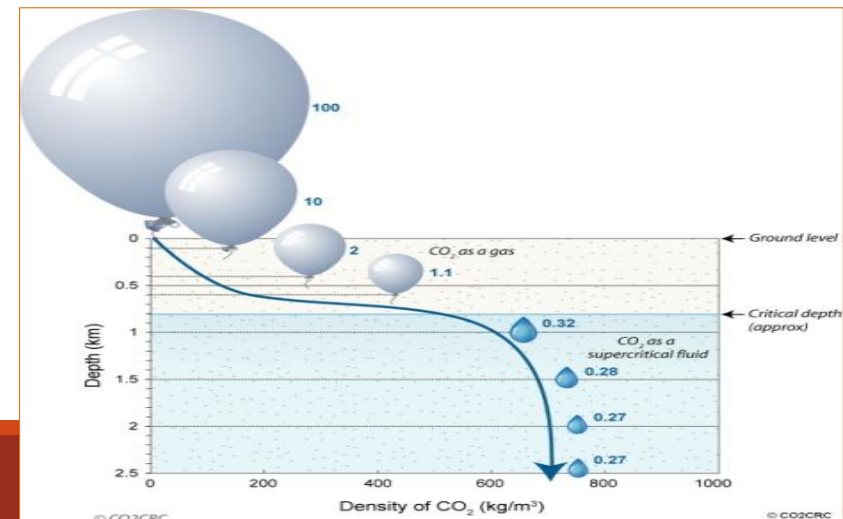
Global Warming

Carbon Sequestration

Gas Trapping Mechanism

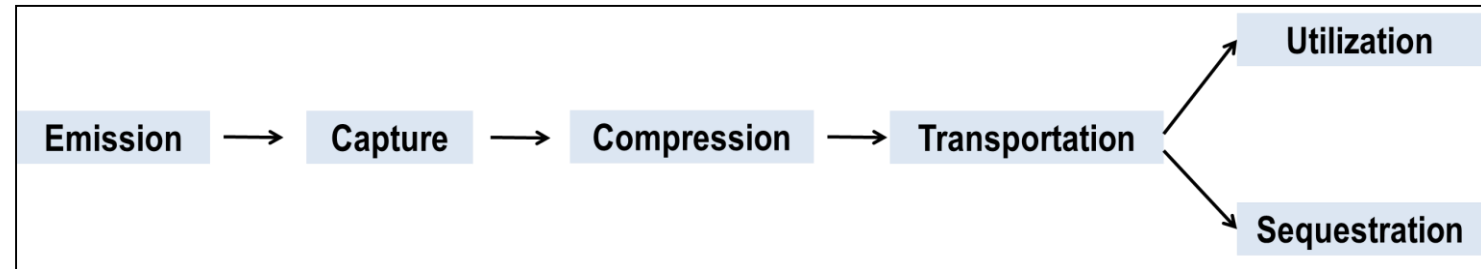
Permeability, Strength, Storage Potential

Storage Vs. Enhanced Gas Recovery



# Role of CCS in 21<sup>st</sup> Century World

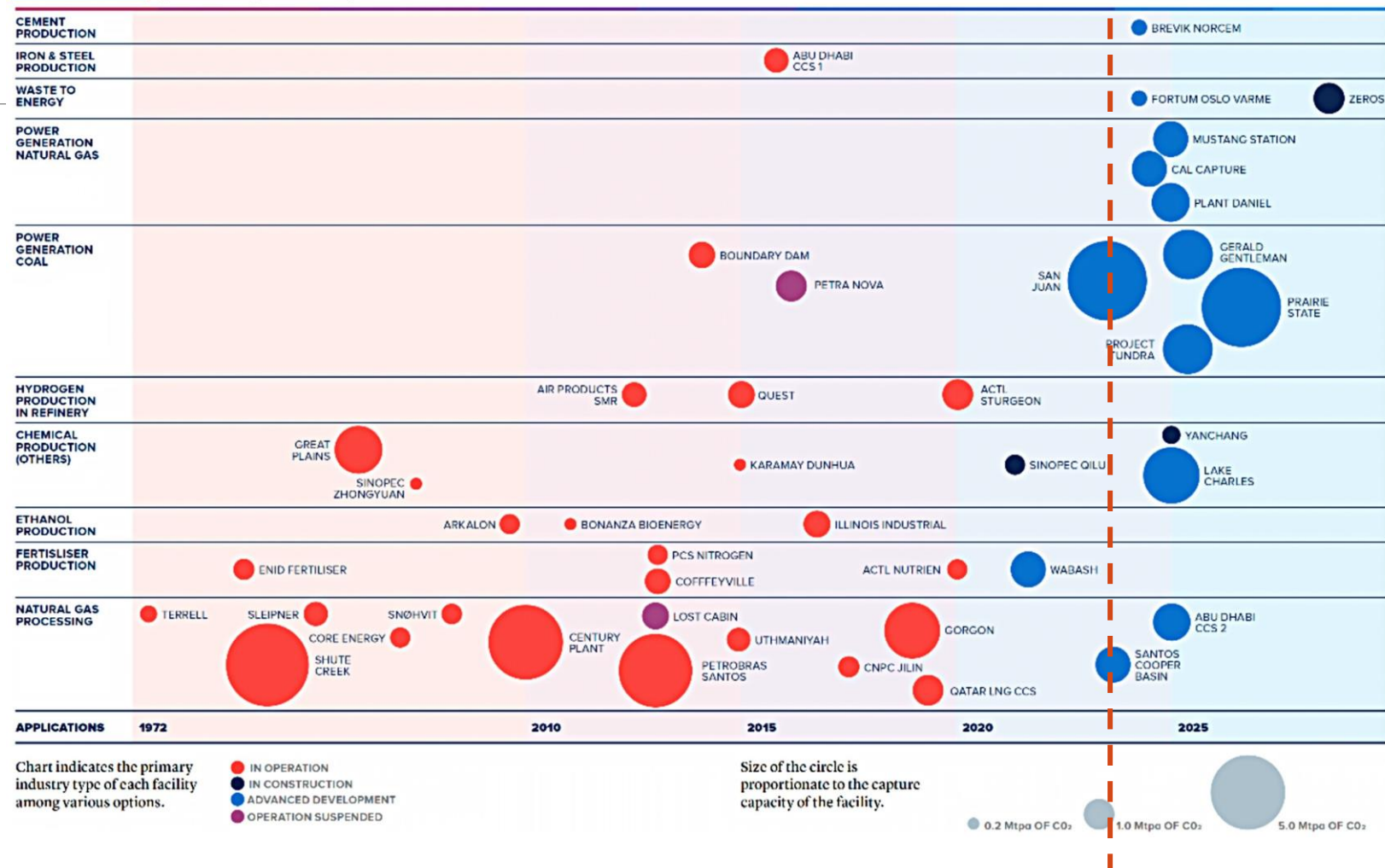
- One of the 14 Grand Challenges of the 21<sup>st</sup> century
- Five of the 17 Sustainable Development Goals: climate action; clean energy; industry, innovation and infrastructure; responsible consumption and production; partnerships to achieve the goals.
- IPCC assessment includes CCS as a key mitigation portfolio. No CCS ~ cost rise by 138%
- **CCS is a non-avoidable strategy towards climate change mitigation**



| Myths  | Reality  |
|--|--|
| CO <sub>2</sub> storage is not happening... it is an untested/unproven technology”       | <b>300+ MMT CO<sub>2</sub> already stored</b> in geological formations over the world  |
| “There is not enough storage space to store enough CO <sub>2</sub> to make a difference” | <b>Upto 27519 gigatons of CO<sub>2</sub></b> can be sequestered spanning over 600 basins worldwide. Can last 10000 years with <b>2.3 GT CO<sub>2</sub></b> stored every year (IPCC)                                    |
| “The CO <sub>2</sub> will leak”  | Caprocks will prevent leakage. Detailed monitoring of the reservoirs are done pre and post injection for <b>up to 10 years</b> . Risk reduces with each series of injection and close monitoring (Benson et al., 2007) |
| “Is there specific regulation in place?”   | Each country is coming up with their own. Tax benefits has encouraged industries to opt for storage. Paris Agreement and COP25 has encouraged govts to come up with policy for CCUS.                                   |
| “Who is responsible for the CO <sub>2</sub> once it is stored underground?”              | Operator through project lifecycle, regulator after completion. Policies being developed to allocate roles.  |

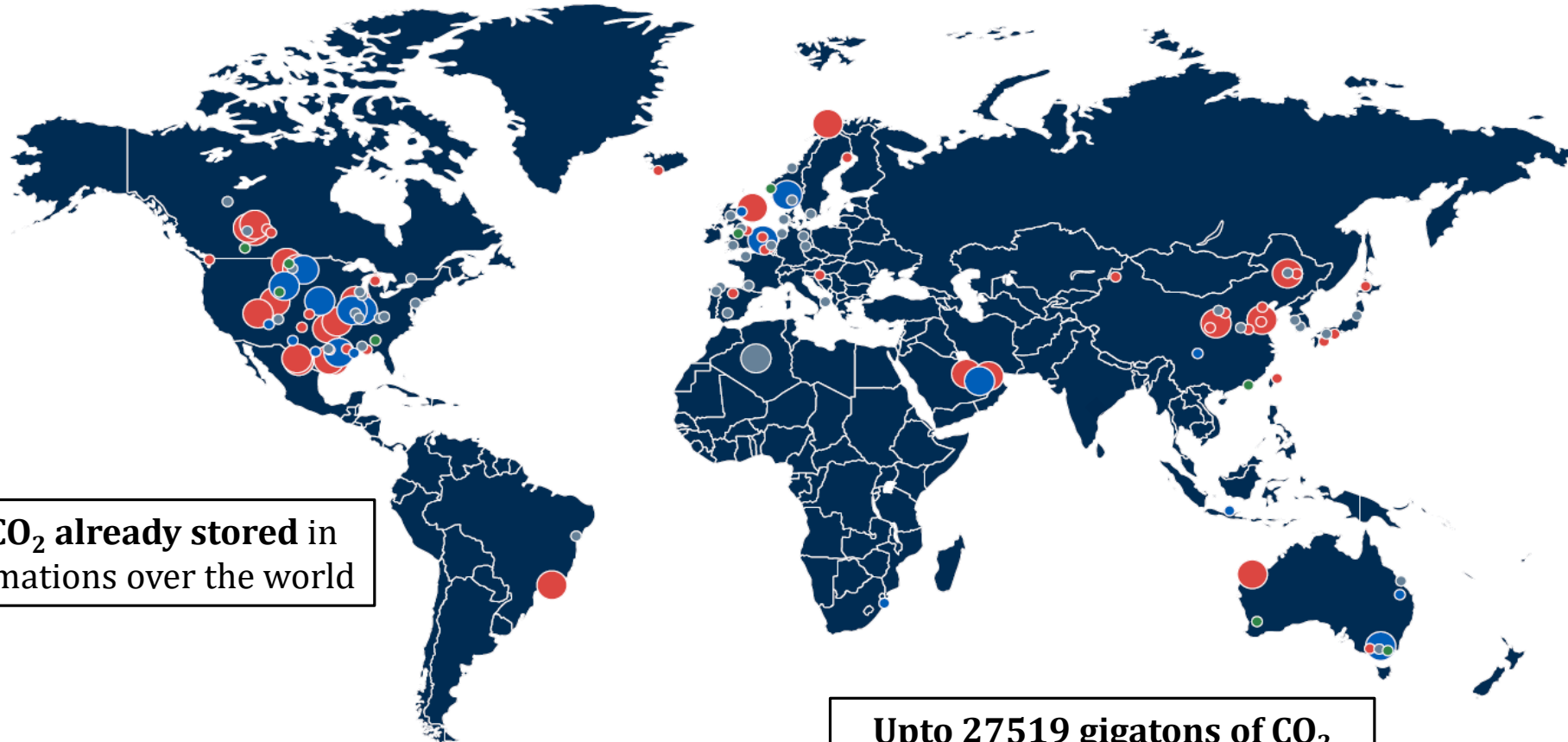
# Worldwide status: CCUS

Project information is captured and shared publicly by the Global Carbon CCS Institute in its [CO2RE database](#) (GCCSI, 2021)





# Worldwide status



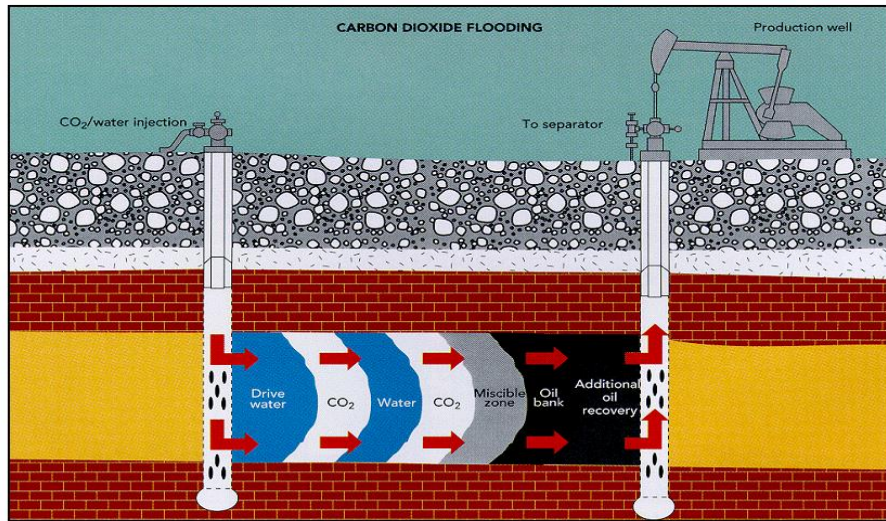
300+ MMT CO<sub>2</sub> already stored in geological formations over the world

- |   |   |
|---|---|
| <span style="color: red;">●</span> LARGE SCALE CCS FACILITIES IN OPERATION & CONSTRUCTION | <span style="color: red;">●</span> PILOT & DEMONSTRATION SCALE FACILITY IN OPERATION & CONSTRUCTION |
| <span style="color: blue;">●</span> LARGE SCALE CCS FACILITIES IN ADVANCED DEVELOPMENT    | <span style="color: blue;">●</span> PILOT & DEMONSTRATION SCALE FACILITY IN ADVANCED DEVELOPMENT    |
| <span style="color: grey;">●</span> LARGE SCALE CCS FACILITIES COMPLETED                  | <span style="color: grey;">●</span> PILOT & DEMONSTRATION SCALE FACILITY COMPLETED                  |
|   | <span style="color: green;">●</span> TEST CENTRE  |
- LARGE SCALE = >400,000 TONNES OF CO<sub>2</sub> CAPTURED PER ANNUM

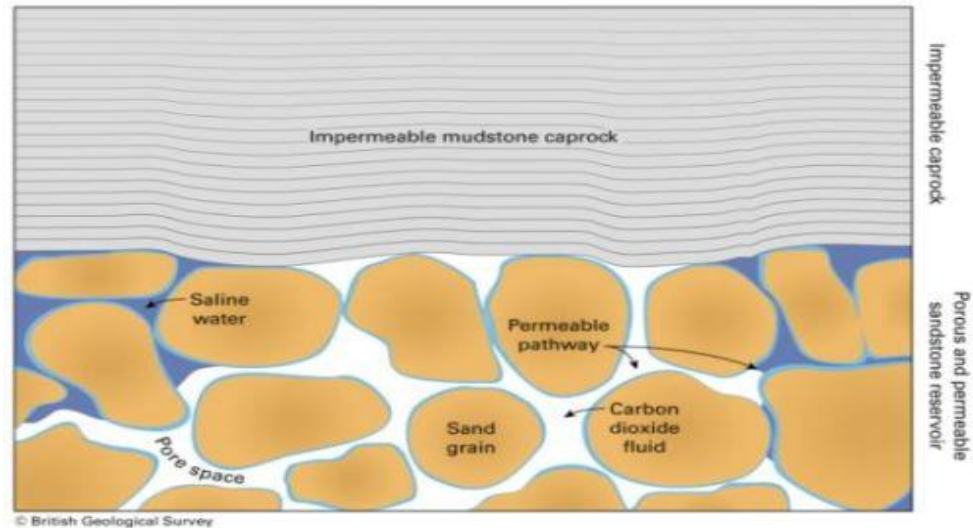
Upto 27519 gigatons of CO<sub>2</sub> can be sequestrated spanning over 600 basins worldwide. Can last 10000 years with **2.3 GT CO<sub>2</sub>** stored every year (IPCC)

*Source: GCCSI Report, 2020*

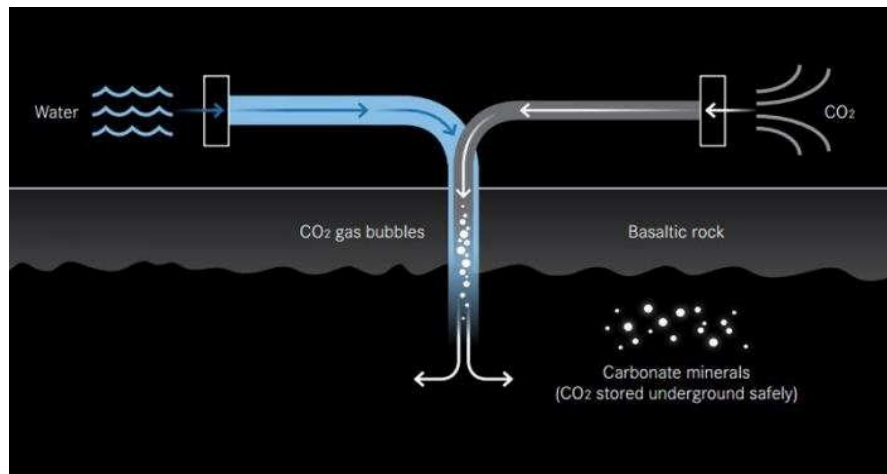
# Geological Diversity in India



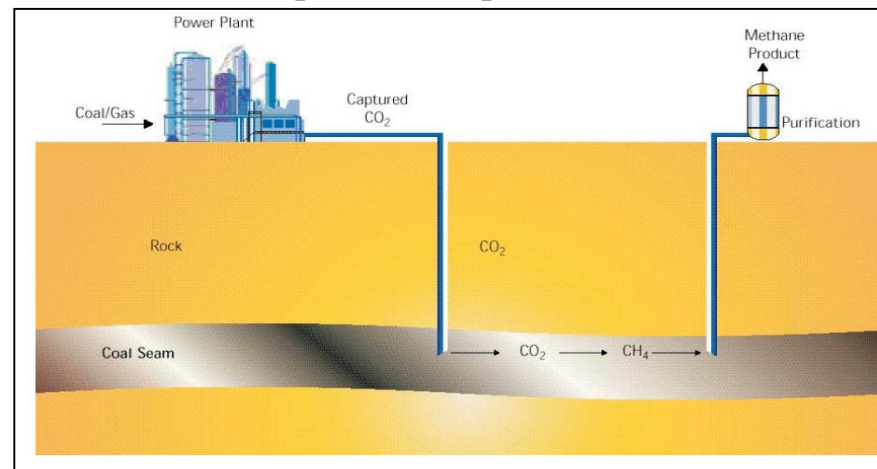
Depleted Oil and Gas Reservoirs



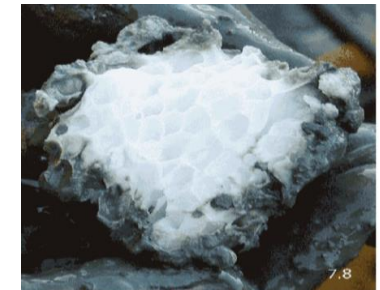
Deep Saline Aquifers



Basalts



Enhanced Coalbed Methane Recovery (ECBM)



Methane hydrate recovery (?)

# Status of CCS in India

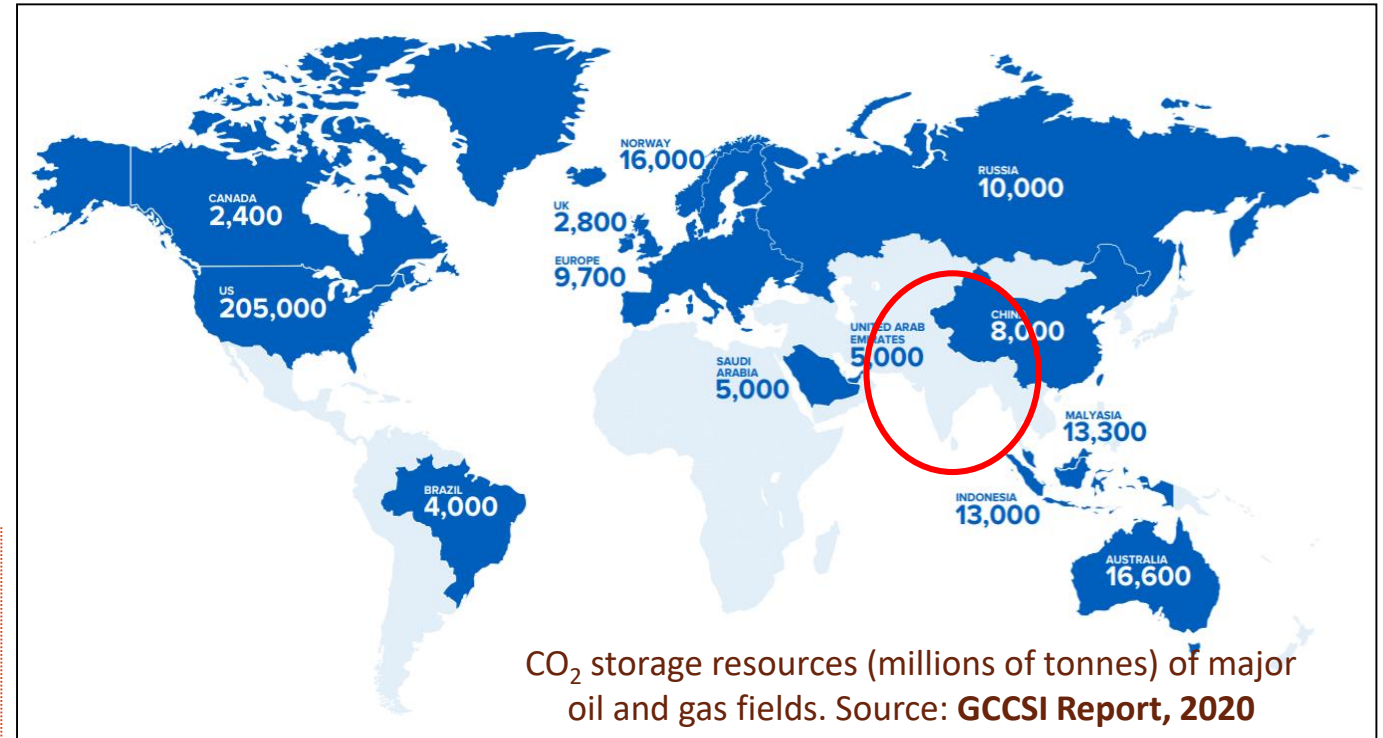
- ONGC – IOCL: CO<sub>2</sub> capture from Koyali refinery for CO<sub>2</sub>-EOR in Gandhar field, Gujarat (MoU/Studies)
- OIL – IOCL: CO<sub>2</sub> capture from the flue-gas stacks of hydrogen generation unit and gas turbine power plant at Digboi refinery for EOR in Nahorkatiya and Dikom oil fields in Assam (MoU/Studies)
- Essar O&G E&PL: Feasibility assessment of pilot scale CO<sub>2</sub> enhanced coalbed methane recovery
- MoP&NG, 2018 framework for incentivizing EOR/IOR, which includes CO<sub>2</sub> enhanced petroleum recovery

## IEA Outlook 2021

- **Lithium-ion batteries.** India becomes the world's largest market for batteries in the STEPS, IVC and SDS. Supply chains for lithium and cobalt are concentrated outside
- **CCUS.** India's CO<sub>2</sub> storage potential has not yet been properly mapped. Given the important role likely to be played by CCUS in a variety of sectors in India, if CO<sub>2</sub> can be securely stored, there is a strong case for defining the potential and understanding how its geographic distribution might influence future investments in industry and power.
- **Hydrogen.** India has the potential to close the cost gap between hydrogen from electrolysis and natural gas more quickly than many other countries due to its

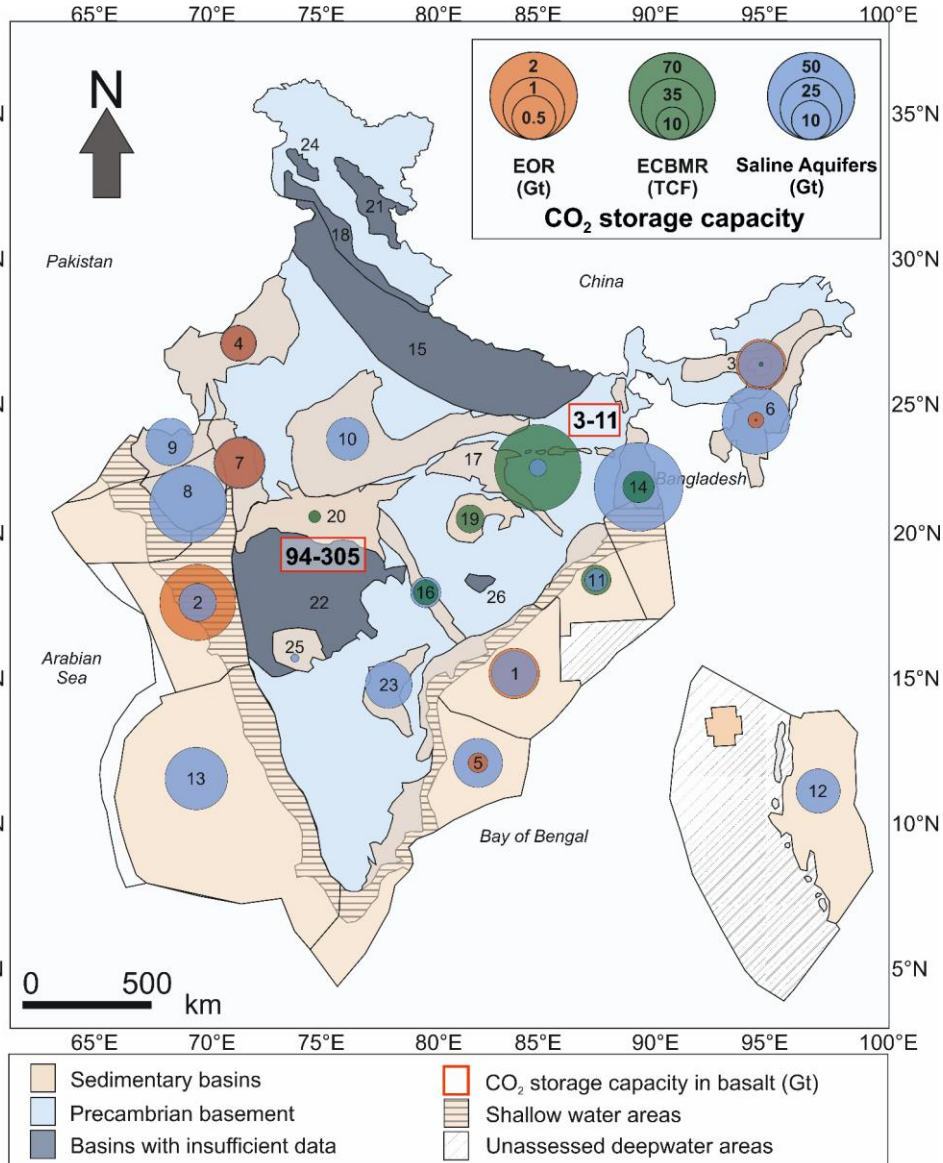
### Ongoing CCU PROJECTS at various stages

- 200 TPD CO<sub>2</sub> capture plant at Tuticorin for soda ash
- 5TPD CO<sub>2</sub> capture from blast furnace of Tata Steel
- 20TPD CO<sub>2</sub> capture plant by NTPC

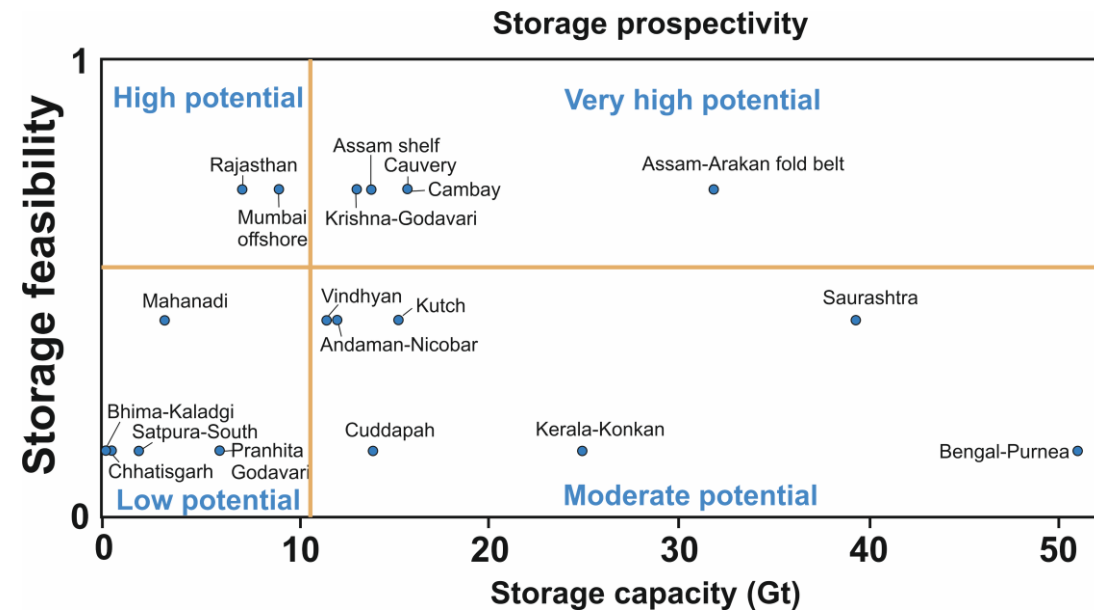
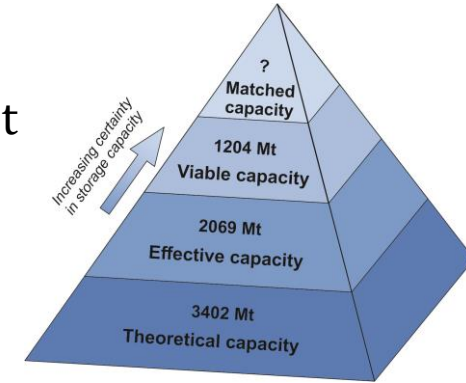




# CO<sub>2</sub> Storage Potential in India



- Enhanced oil recovery: 3.4 Gt
  - Enhanced coalbed methane recovery: 3.7 Gt
  - On-shore/Off-shore saline aquifers: 291 Gt
  - Basalt Formations: 97 – 316 Gt
- Total: 395 – 614 Gt**



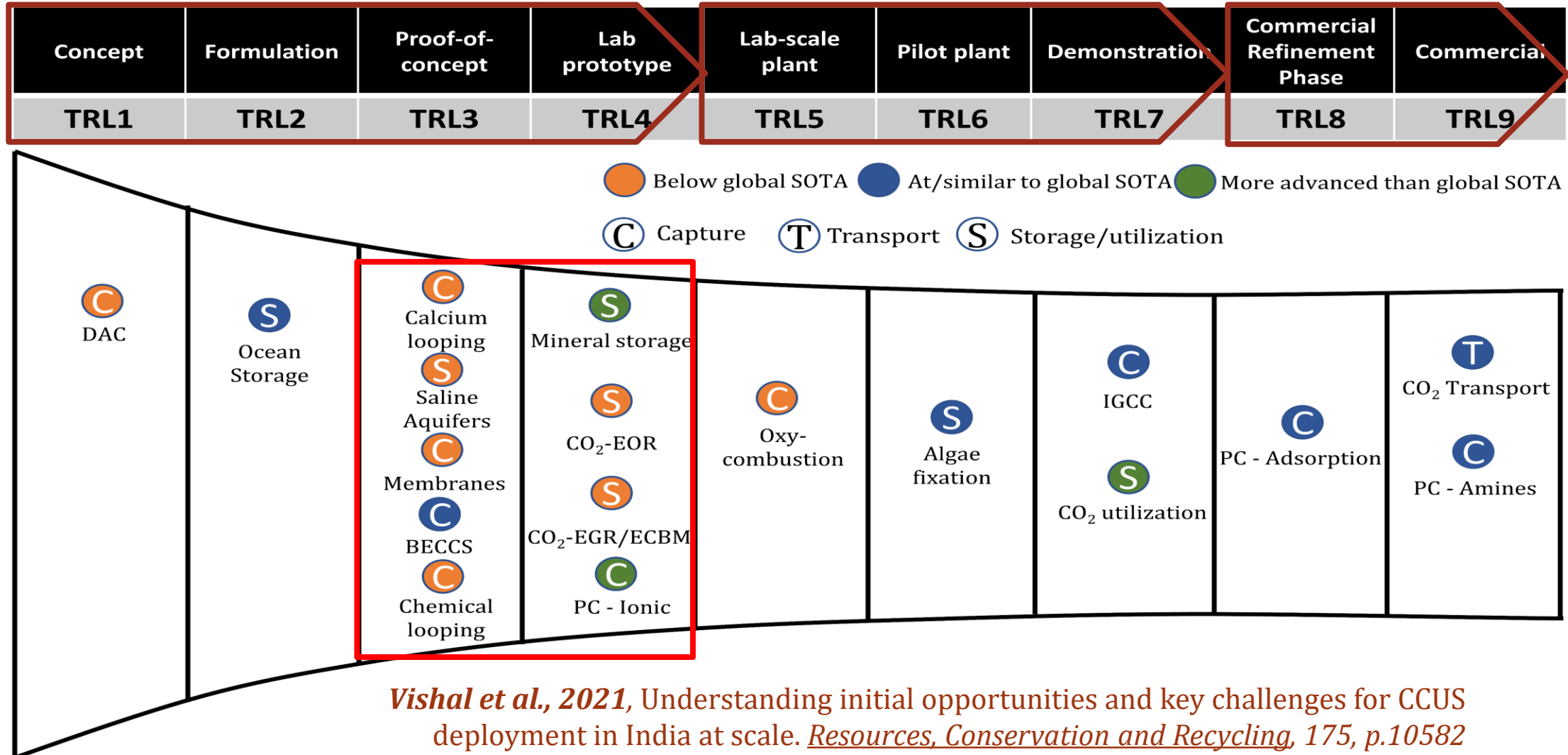
*Vishal et al., 2021, A systematic capacity assessment and classification of geologic CO<sub>2</sub> storage systems in India. International Journal of Greenhouse Gas Control, Vol. 111, p.103458.*

# Technology Readiness Levels - India

## ACADEMIA

## COOPERATION

## INDUSTRY



# CO<sub>2</sub> CAPTURE PILOT : Feasibility Studies

netra

1. Pre-Feasibility studies for 60,000 tonnes per annum CO<sub>2</sub> capture
2. Feasibility and engineering for CO<sub>2</sub> conversion to green chemicals
3. Feasibility for large scale CO<sub>2</sub> capture for enhanced oil recovery

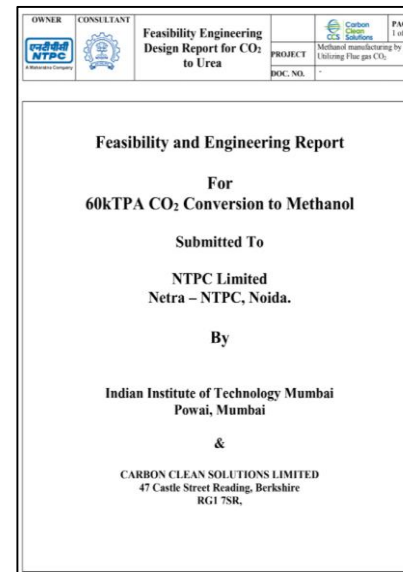
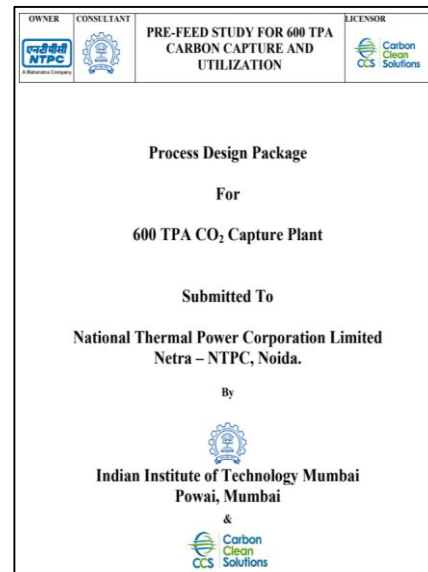


NTPC Energy Technology Research Alliance

## PROJECT PROPOSAL

1. PROJECT TITLE : Feasibility and Engineering Design for Zero Carbon Emissions - CO<sub>2</sub> capture from coal fired plant and its utilisation into green products

2. PROJECT INITIATOR : Prof. Vikram Vishal, IIT Bombay

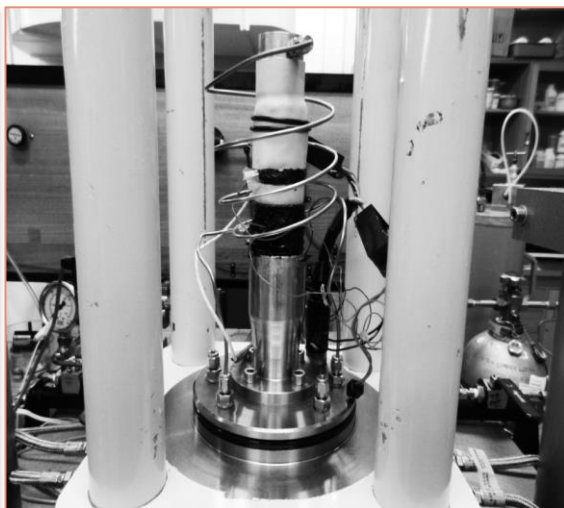




# Multi-Scale Investigation: Regional to Core to Pore Scale



Collection of samples



Create sub-surface in lab



Rock sample composition and characteristic analysis: EPMA and XRF



Low Pressure Gas Adsorption setup



Gas Permeameter



Deformation Test



2

Pulse Decay Permeameter

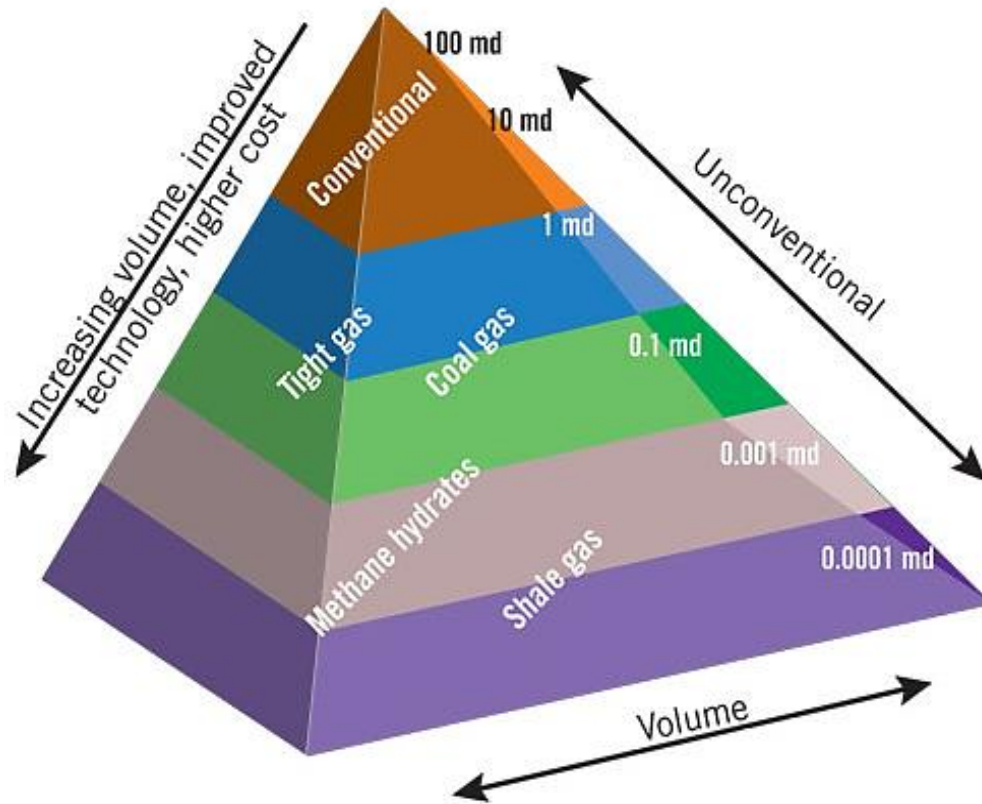


# CO<sub>2</sub> flow-storage-deformation - state-of-art laboratories

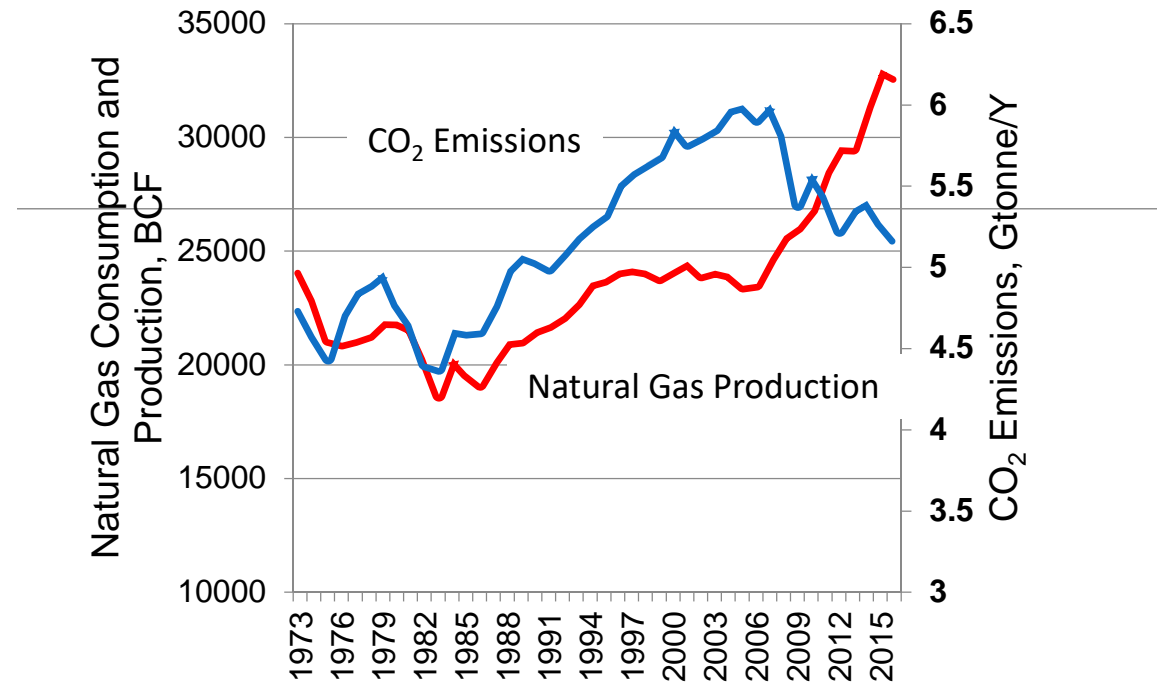




# Opportunities & Challenges in Unconventional Reservoirs

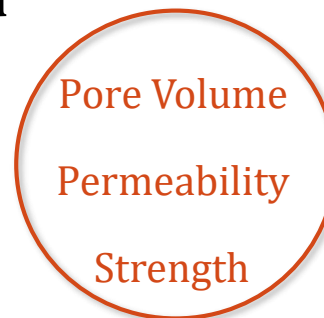


The Resource Pyramid  
(Holditch, 2006)



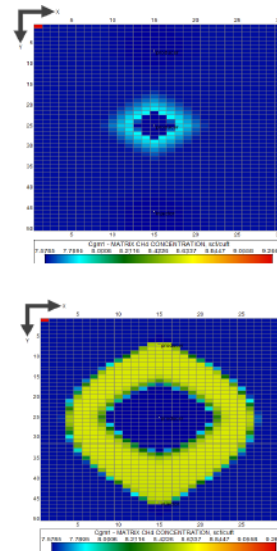
## Reservoirs less understood

- How much pore space?
- What ease of extraction?
- System integrity?

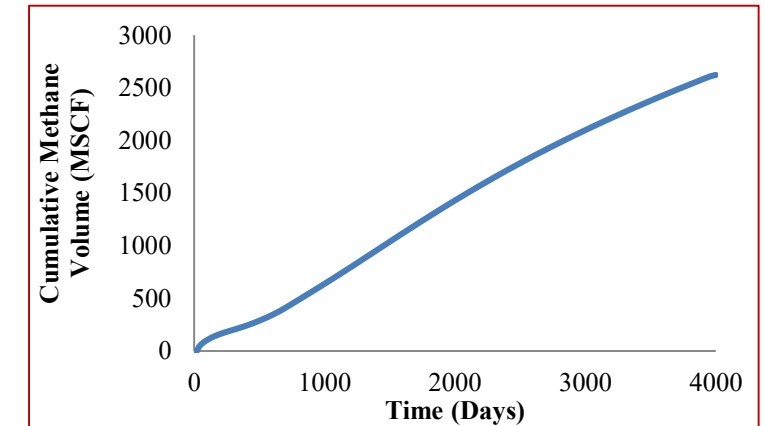
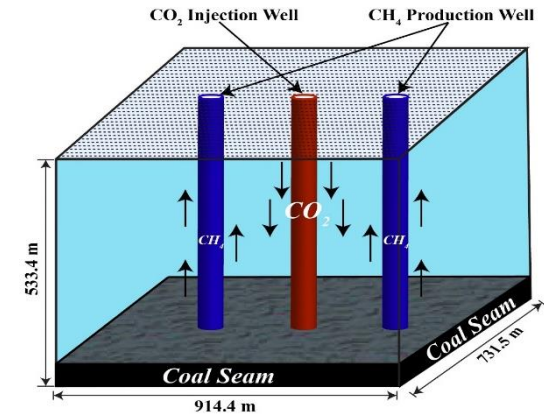


# ECBMR and Coal Seam CO<sub>2</sub> Sequestration

1. Deformation of coal with injection of CO<sub>2</sub>
2. Role of injected fluid phase in deep sub-surface conditions
3. Enhancing CH<sub>4</sub> production with injection of CO<sub>2</sub>



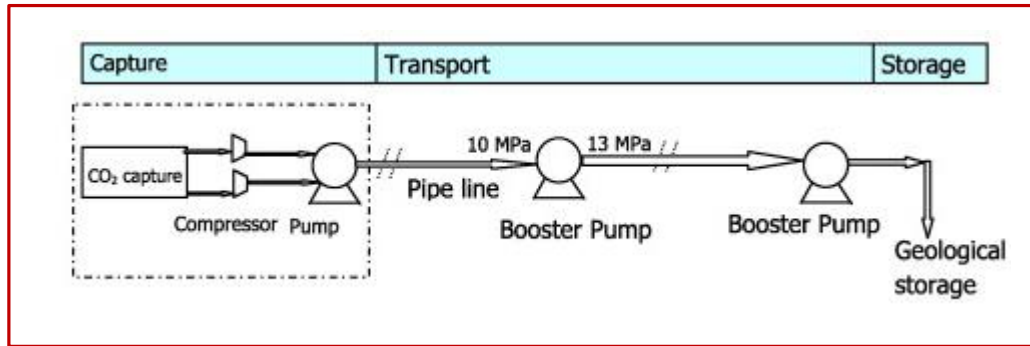
Matrix Methane Concentration  
(after 30 days and 600 days)



Chandra D. and Vishal V., 2020, J Nat Gas Sci Engg, Art. 103453  
Vishal V. et al., 2019, Energy and Fuels, Vol. 33(6), pp. 4835-4848.  
Vishal V. et al., 2018, Energy, Vol. 159, pp. 1185-1194  
Vishal et al., 2013, Energy, Vol. 49, pp. 384-394  
Vishal et al., 2013, Int J Coal Geol., Vol. 105 pp. 36-47.

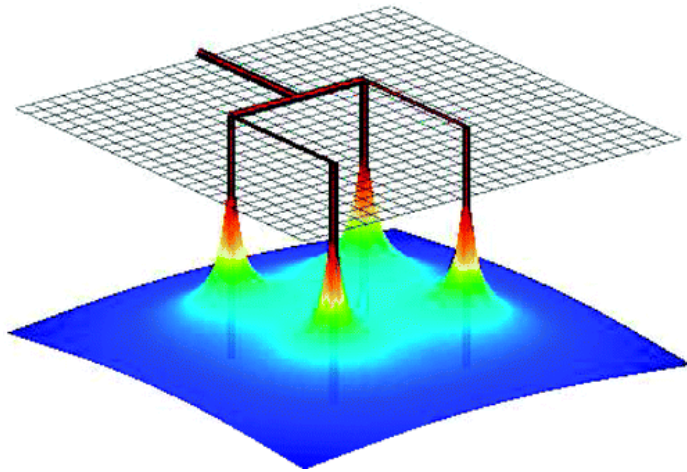
Vishal V., 2017, Fuel, Vol 192, pp. 201-207  
Vishal V., 2017, Journal of CO<sub>2</sub> Utilization, Vol 17, pp. 235-242  
Vishal V. et al., 2015, Fuel, Vol 139, pp. 51-58  
Vishal V. et al., 2015, J Nat Gas Sci Engg, Vol 22, pp. 428-436  
Vishal V. et al, 2013, Engineering Geology, Vol 167, pp. 148-156

# System Analysis of CO<sub>2</sub> capture, transport and storage

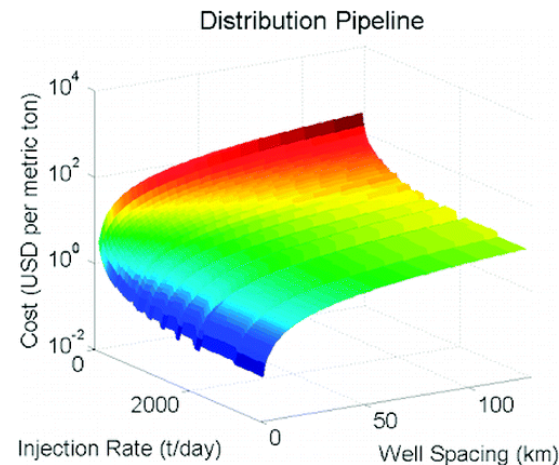


## System Analysis

- Key to analyse the whole chain of CO<sub>2</sub> capture technologies, transportation and storage & Utilization (CCUS)
- Refineries have several units that emit CO<sub>2</sub>, including steam methane reformers, catalytic crackers and combined heat and power units.
- Low-carbon hydrogen: Steam methane reforming can be coupled with CCS to enable a near-emissions free hydrogen production from methane
- Techno-economic analysis of CCUS: Holistic approach is required to implement CCUS
- Life cycle assessment (LCA) of CCUS: To avoid shifting of environmental burdens
- Transportation systems: Transportation cost depends upon well spacing and injection rate



CO<sub>2</sub> transportation and injection



Cost of distribution pipeline network as a function of well spacing and injection rate. The cost varies over several orders of magnitude



# Safety and Environment

Cap Rock Integrity

Effects of CO<sub>2</sub> sequestration on chemical and physical properties of rocks

CO<sub>2</sub> /Water/Rock interactions

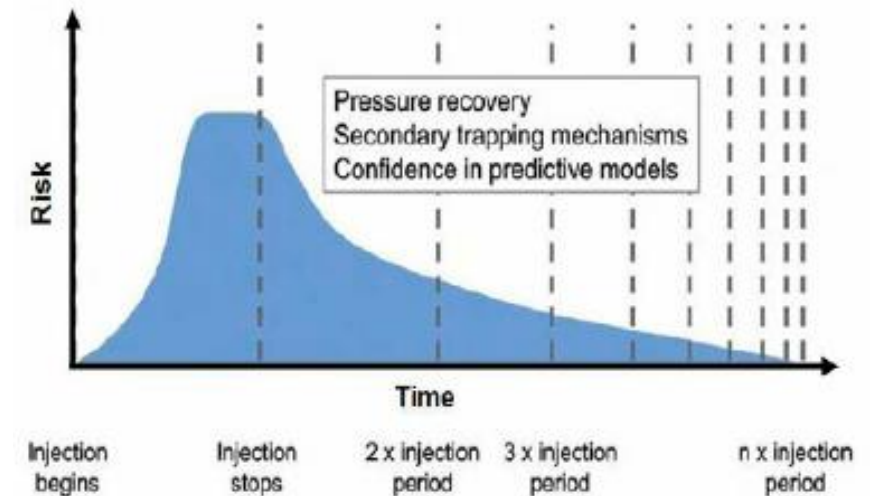
Environmentally sound technologies

MEASURING: measure the amount of CO<sub>2</sub> stored

MONITORING: maintain the storage integrity over time

VERIFICATION: ensure the stored CO<sub>2</sub> does not pose any threat to ecosystem

- Geochemical tracers, flux method, water chemistry
- Geophysical methods-Remote sensing, Lineaments
- Simulators to model sub-surface CO<sub>2</sub> plume



# National Centre of Excellence in Carbon Capture and Utilization

(Estd. 2021)



सत्यमेव जयते  
Department of Science and Technology  
Ministry of Science and Technology  
Government of India



- Nanofluid amine based solutions
- Modified membrane based CO<sub>2</sub> separation
- Aqueous solution-based CO<sub>2</sub> capture

- CO<sub>2</sub> valorization
- Methanol production
- High value organics
- CO/CH<sub>4</sub> generation

- Country-wide capacity assessment
- Source-sink matching
- Enhanced oil recovery
- Enhanced CBM recovery

- CO<sub>2</sub> transportation
- Life-cycle analysis
- Techno-economic analysis
- Bioenergy based CCS (BECCS)
- Environmental Impact Assessment



Carbon Capture



CO<sub>2</sub> utilization

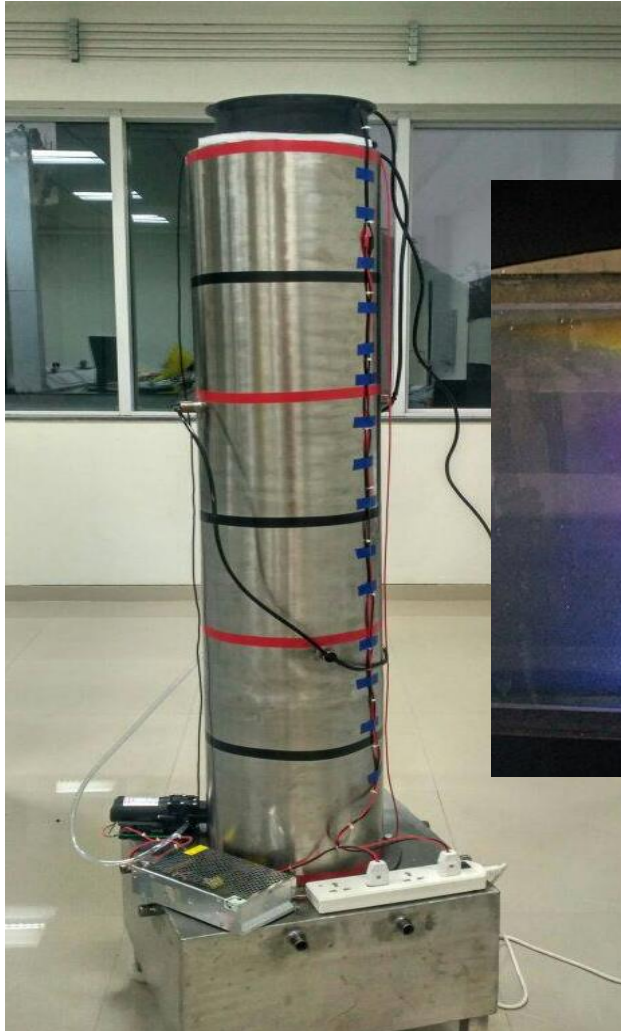


CO<sub>2</sub> sequestration

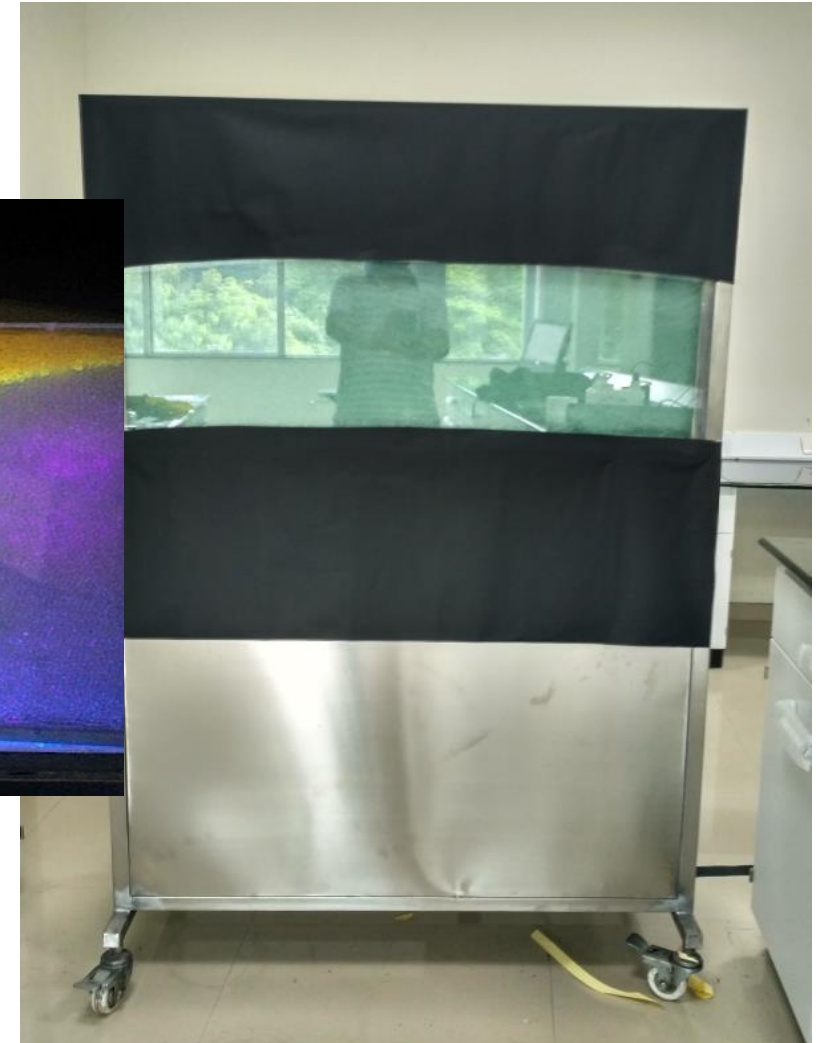
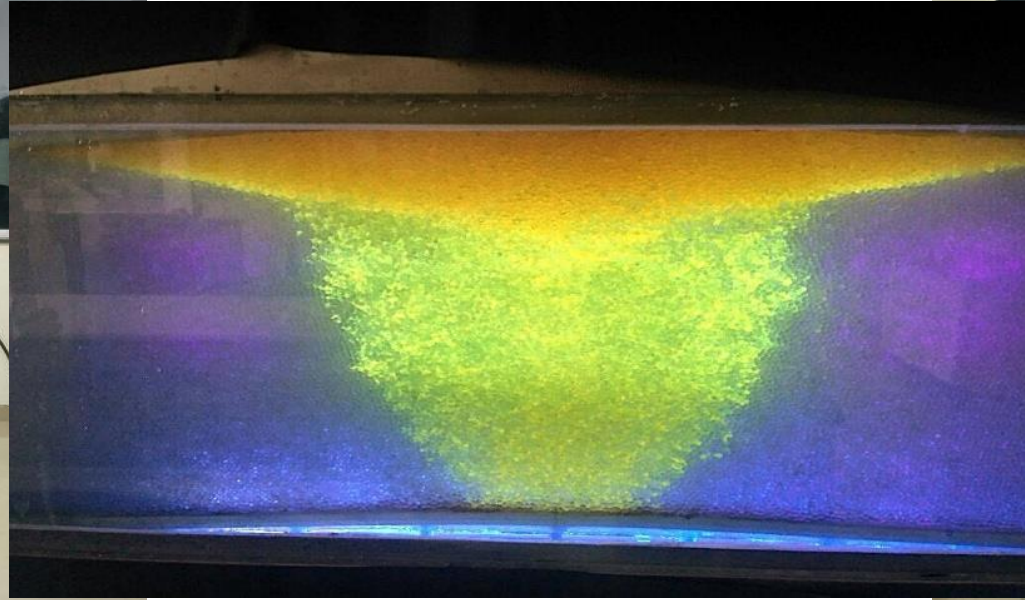


Cross-cutting systems

# S&T Communication: CCS



**Carbon Capture Model**



**Carbon Storage Model**

Showcase for explaining the principles of CCS

# CCUS Capacity Building and Roadmap for INDIA

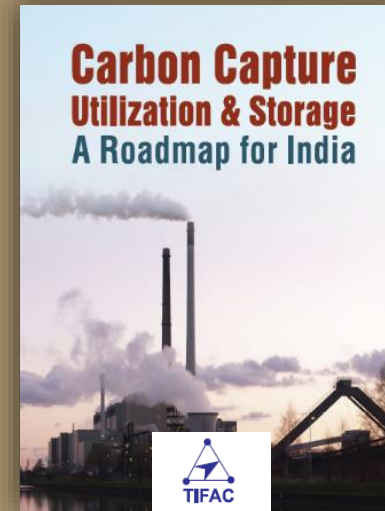
## CCUS Mumbai - 2016



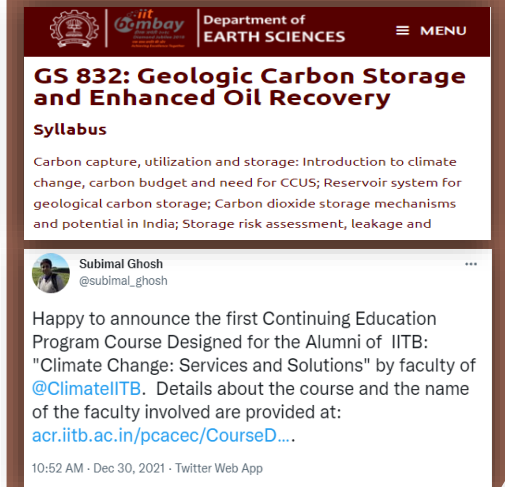
## CCUS Mumbai - 2018



## DST Roadmap - 2018



## CCUS in Curriculum - 2022

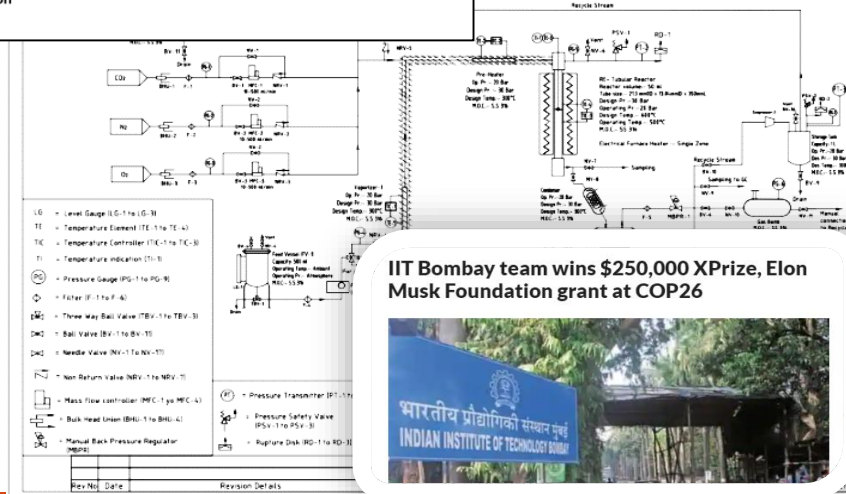
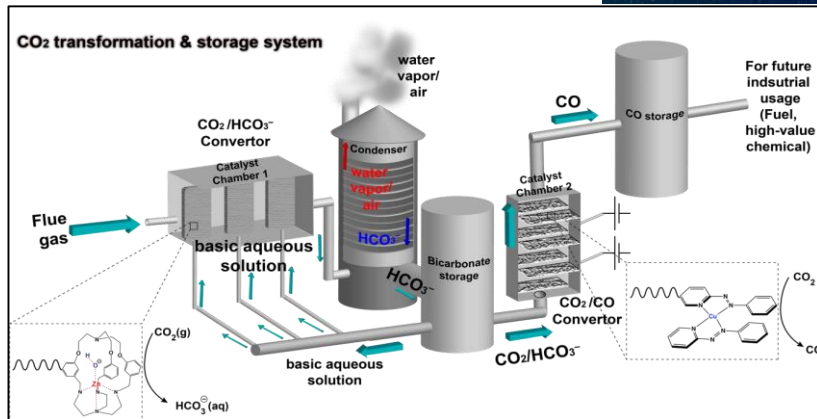




# India in Global CCUS competitions

## CCS X-Prize – 2021 for demonstration of CO<sub>2</sub> removal

A trimodular CO<sub>2</sub> capture, conversion and storage system

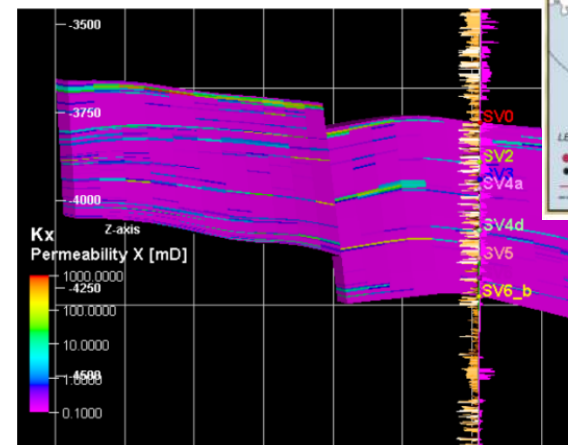
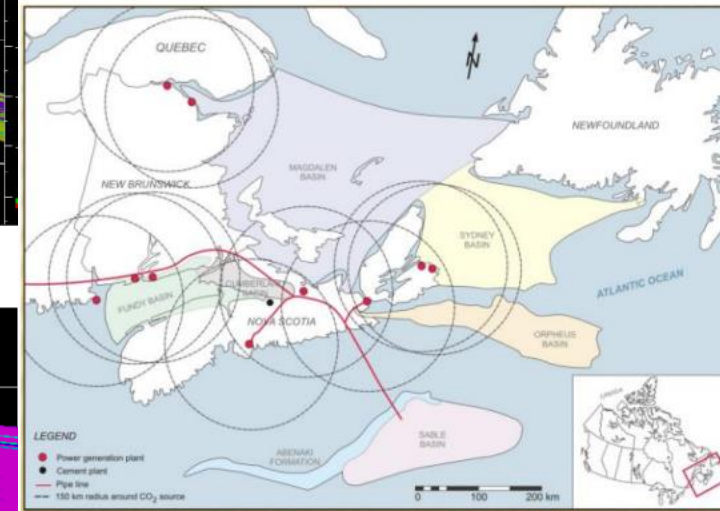
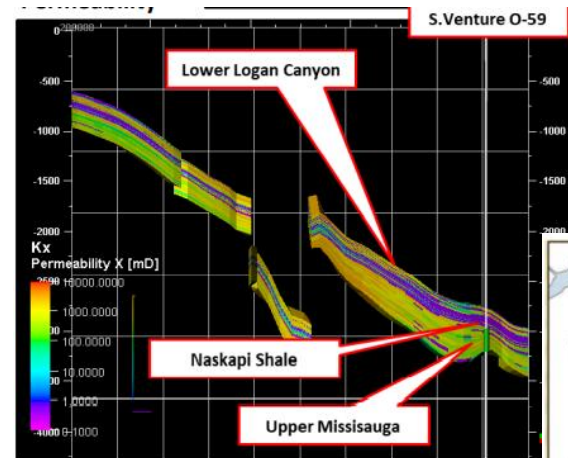


IIT Bombay team wins \$250,000 XPrize, Elon Musk Foundation grant at COP26



## Minus CO<sub>2</sub> – 2022 on Quantitative assessment of the CO<sub>2</sub>

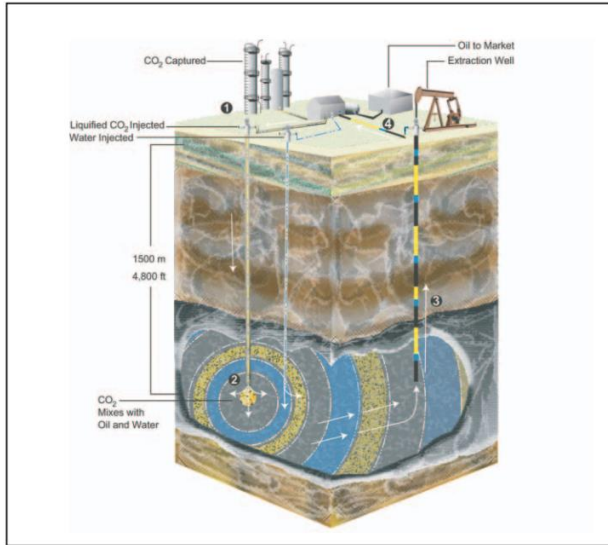
Storage potential of the Scotian Shelf



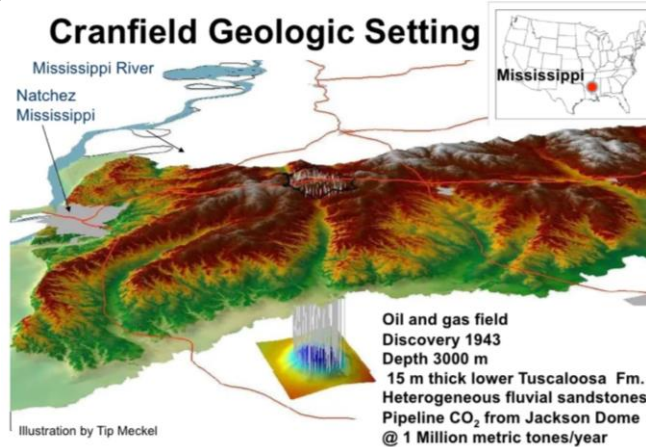
Team: Firdush Hussain, Sonal Janagal, Arpita Chakraborty, Sushmita Mastud, Rhythm Shah  
Mentors: Profs. Bharath, Sudipta and Vishal

# CO<sub>2</sub> Storage Projects

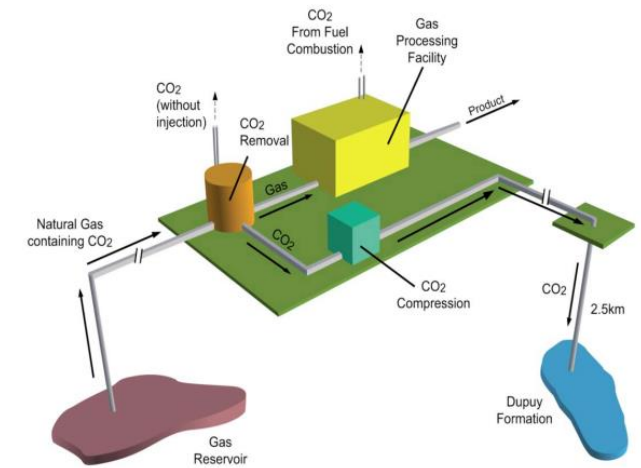
## Weyburn-Midale (>30 Mt)



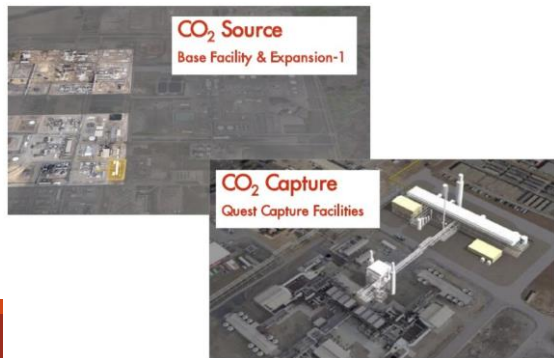
## Cranfield, USA (>5 Mt)



## Gorgon, Australia (5 Mt)



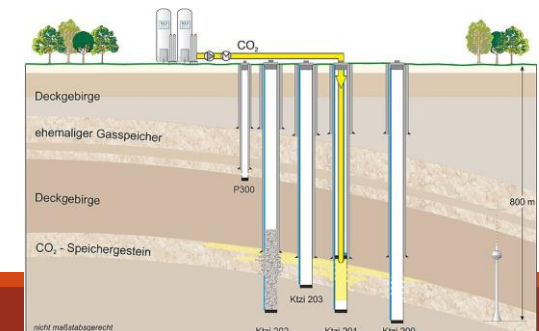
## Quest, Canada (5 Mt)



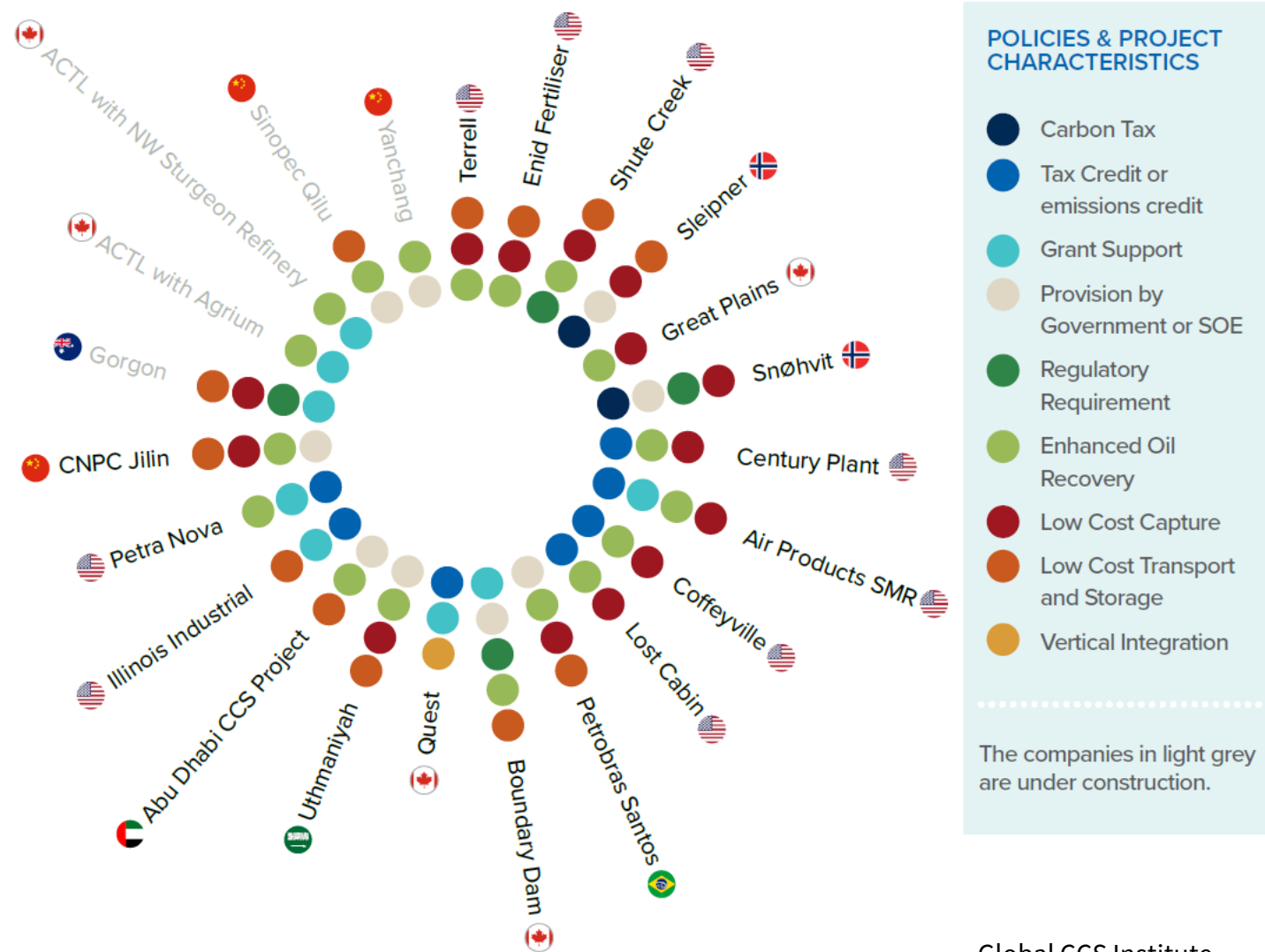
## Petra Nova, USA (4 Mt)



## Ketzin, Germany (67 Kt)



# Funding and clustering: Policies driving CCUS



Global CCS Institute



# Road Ahead

Tremendous efforts for reduction of CO<sub>2</sub> emissions required.

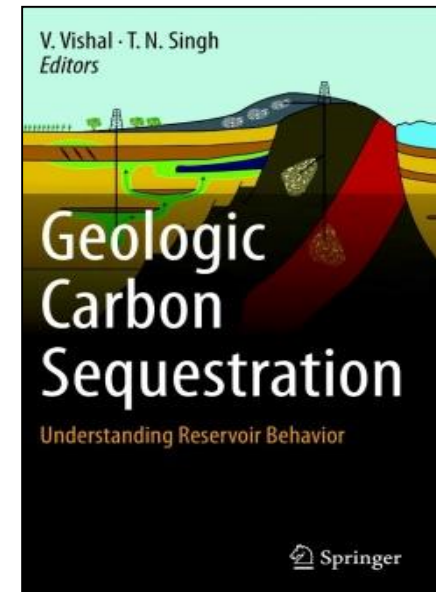
CCUS is a key mitigation strategy.

India to account for ~20% of global industrial CCS by 2060 – IEA.

Accelerated R&D, collaborative efforts, international and industrial engagements, capacity building, policy support, funding required.

**Although the problem of CO<sub>2</sub> emissions is global, the solution for each reservoir is unique.**

|   | 1.5 C | 2 C |
|---|-------|-----|
| Cumulative CO <sub>2</sub> removal (Gt) | 680   | 490 |
| CO <sub>2</sub> removal/yr (Gt)         | ~9    | ~6  |



# SELECT PUBLICATIONS

# CO<sub>2</sub> Utilization-Storage : ECBMR/ EOR / Saline Aquifer



A systematic capacity assessment and classification of geologic CO<sub>2</sub> storage systems in India

Vikram Vishal <sup>a,b,\*</sup>, Yashvardhan Verma <sup>a,c,d</sup>, Debanjan Chandra <sup>a</sup>, Dhananjayan Ashok <sup>a</sup>



Simulation of CO<sub>2</sub> enhanced coalbed methane recovery in Jharia coalfields, India

Vikram Vishal <sup>a,b,\*</sup>, Bankim Mahanta <sup>a,b,d</sup>, S.P. Pradhan <sup>c</sup>, T.N. Singh <sup>a</sup>, P.G. Ranjith <sup>b</sup>



Full Length Article  
Saturation time dependency of liquid and supercritical CO<sub>2</sub> permeability of bituminous coals: Implications for carbon storage

Vikram Vishal <sup>a,\*</sup>



In-situ disposal of CO<sub>2</sub>: Liquid and supercritical CO<sub>2</sub> permeability in coal at multiple down-hole stress conditions

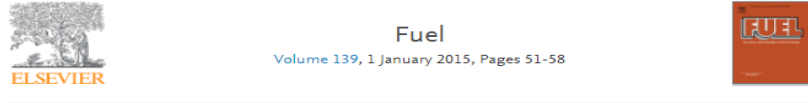
Vikram Vishal <sup>a,\*</sup>



Full length article

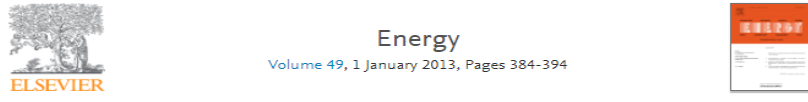
Understanding initial opportunities and key challenges for CCUS deployment in India at scale

Vikram Vishal <sup>a,b,1,\*</sup>, Debanjan Chandra <sup>a</sup>, Udayan Singh <sup>c,d</sup>, Yashvardhan Verma <sup>a,c,f</sup>



Influence of sorption time in CO<sub>2</sub>-ECBM process in Indian coals using coupled numerical simulation

V. Vishal <sup>a,b</sup>, T.N. Singh <sup>c,d</sup>, P.G. Ranjith <sup>d</sup>



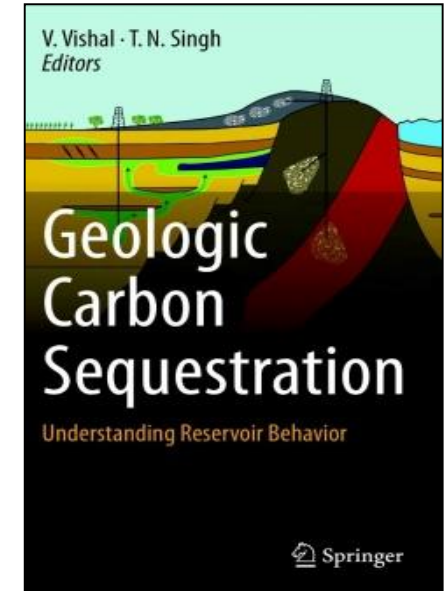
Numerical modeling of Gondwana coal seams in India as coalbed methane reservoirs substituted for carbon dioxide sequestration

V. Vishal <sup>a,b,c,d</sup>, Lokendra Singh <sup>d</sup>, S.P. Pradhan <sup>c</sup>, T.N. Singh <sup>c</sup>, P.G. Ranjith <sup>b</sup>



CO<sub>2</sub> permeability of Indian bituminous coals: Implications for carbon sequestration

V. Vishal <sup>a,b,c</sup>, P.G. Ranjith <sup>b,d</sup>, T.N. Singh <sup>c</sup>



ORIGINAL RESEARCH  
published: 01 October 2021  
doi: 10.3389/fclim.2021.720959

## Sensitivity Analysis of Geomechanical Constraints in CO<sub>2</sub> Storage to Screen Potential Sites in Deep Saline Aquifers

Yashvardhan Verma <sup>1,2,3</sup>, Vikram Vishal <sup>1,2\*</sup> and P. G. Ranjith <sup>2</sup>

<sup>1</sup> Computational and Experimental Geomechanics Laboratory, Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India, <sup>2</sup> Department of Civil Engineering, Faculty of Engineering, Monash University, Clayton, Melbourne, VIC, Australia, <sup>3</sup> IITB-Monash Research Academy, Indian Institute of Technology Bombay, Mumbai, India



# CO<sub>2</sub> capture technologies



Experimental investigation of some metal oxides for chemical looping combustion in a fluidized bed reactor

M.K. Chandel<sup>1</sup>, A. Hoteit<sup>2</sup>, A. Delebarre<sup>\*</sup>

<sup>1</sup>Department of Energetics and Environmental Engineering, Ecole des Mines de Nantes, 44307 Nantes, France



## The potential of waste-to-energy in reducing GHG emissions

Munish K Chandel, Gabriel Kwok, Robert B Jackson & Lincoln F Pratson

To cite this article: Munish K Chandel, Gabriel Kwok, Robert B Jackson & Lincoln F Pratson (2012) The potential of waste-to-energy in reducing GHG emissions, Carbon Management, 3,2, 133-144, DOI: 10.4155/cmt.12.11

To link to this article: <https://doi.org/10.4155/cmt.12.11>

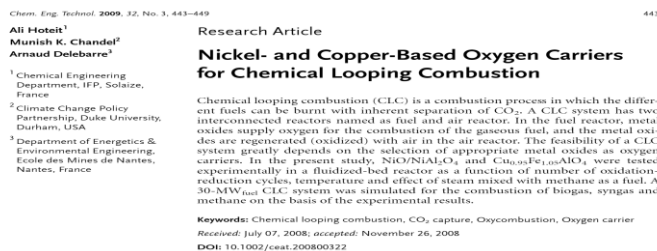


## Biogas combustion in a chemical looping fluidized bed reactor

A. Hoteit<sup>a,1</sup>, M.K. Chandel<sup>a,2</sup>, S. Durécu<sup>b</sup>, A. Delebarre<sup>a,\*</sup>

<sup>a</sup>Department of Energetics and Environmental Engineering, Ecole des Mines de Nantes, 44307 Nantes, France

<sup>b</sup>IREST - SECH Group, Research Department, Technopôle de Nancy-Brabois, BP 184, 54505 Vandœuvre les Nancy, France



## Modeling and Analysis

## Suitability of CO<sub>2</sub> capture technologies for carbon capture and storage in India

Dharmender Yadav, Munish K. Chandel✉, Pramod Kumar

First published: 08 January 2016 | <https://doi.org/10.1002/ghg.1579> | Citations: 4



## RESEARCH ARTICLE

## 200-MW chemical looping combustion based thermal power plant for clean power generation

Raman Sharma<sup>1,\*†</sup>, Munish Kumar Chandel<sup>2</sup>, Arnaud Delebarre<sup>3</sup> and Babu Alappat<sup>1</sup>

<sup>1</sup>



13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland

## Economic Implications of CO<sub>2</sub> Capture from the Existing as well as Proposed Coal-fired Power Plants in India under Various Policy Scenarios

Udayan Singh<sup>a</sup>, Anand B. Rao<sup>b,\*</sup>, Munish K. Chandel<sup>c</sup>

<sup>a</sup>Department of Mechanical Engineering, National Institute of Technology Rourkela, Rourkela 769008, INDIA

<sup>b</sup>Centre for Technology Alternatives for Rural Areas & IDP in Climate Studies, Indian Institute of Technology Bombay, Mumbai 400076, INDIA

<sup>c</sup>Centre for Environmental Science and Engineering (CESE), Indian Institute of Technology Bombay, Mumbai 400076, INDIA

## Synthetic Natural Gas (SNG): Technology, Environmental Implications, and Economics

Munish Chandel  
Eric Williams  
Climate Change Policy Partnership  
Duke University

January 2009



## Effects of Well Spacing on Geological Storage Site Distribution Costs and Surface Footprint

Jordan Eccles<sup>\*,</sup> Lincoln F. Pratson, and Munish Kumar Chandel

Nicholas School of the Environment and Earth Sciences, Division of Earth and Ocean Sciences, Duke University, Durham, North Carolina 27708, United States



## Potential economies of scale in CO<sub>2</sub> transport through use of a trunk pipeline

Munish Kumar Chandel<sup>a,\*</sup>, Lincoln F. Pratson<sup>b</sup>, Eric Williams<sup>a</sup>

<sup>a</sup>Climate Change Policy Partnership, Duke University, Durham, NC 27708, USA

<sup>b</sup>Nicholas School of the Environment, Duke University, Durham, NC 27708, USA



## The potential impacts of climate-change policy on freshwater use in thermoelectric power generation

Munish K. Chandel<sup>a,\*</sup>, Lincoln F. Pratson<sup>b</sup>, Robert B. Jackson<sup>a,\*,b,c</sup>



5th International Conference on Advances in Energy Research, ICAER 2015, 15-17 December 2015, Mumbai, India

## Prospects of Implementing CO<sub>2</sub> Capture and Sequestration (CCS) in the Proposed Supercritical Coal Power Plants in India

A R Akash<sup>a,\*</sup>, A B Rao<sup>a,b</sup>, M K Chandel<sup>c</sup>

<sup>a</sup>Centre for Technology Alternatives for Rural Areas, IIT Bombay, Mumbai 400076, India

<sup>b</sup>IDP in Climate Studies, IIT Bombay, Mumbai 400076, India

<sup>c</sup>Centre for Environmental Science & Engineering, IIT Bombay, Mumbai 400076, India

# CO<sub>2</sub> Capture and CO<sub>2</sub> Valorization

[View PDF Version](#)[Previous Article](#)[Next Article](#)

DOI: [10.1039/D1RE00035G](https://doi.org/10.1039/D1RE00035G) (Review Article) *React. Chem. Eng.*, 2021, **6**, 1152-1178

## A review on steel slag valorisation *via* mineral carbonation

Raghavendra Ragipani , Sankar Bhattacharya and Akkihebbal K. Suresh



Chemical Engineering Journal

Volume 414, 15 June 2021, 128757



## Pilot-scale testing of direct contact cooler for the removal of SO<sub>x</sub> and NO<sub>x</sub> from the flue gas of pressurized oxy-coal combustion

David Stokie <sup>a</sup>, Piyush Verma <sup>a</sup>, Benjamin M. Kumfer <sup>a</sup> , Grigoriy Yablonsky <sup>a</sup>, A.K. Suresh <sup>b</sup>, Richard L. Axelbaum <sup>a</sup>



Materials Research Bulletin

Volume 123, March 2020, 110702



## Electrochemical reduction of CO<sub>2</sub> on activated copper: Influence of surface area

Sachin D. Giri, Sanjay M. Mahajani, A.K. Suresh, A. Sarkar

## Integrated Flue Gas Purification and Latent Heat Recovery for Pressurized Oxy-Combustion

[Full Record](#)[Other Related Research](#)

TECHNICAL REPORT:

View Technical Report (1.46 MB)

<https://doi.org/10.2172/1494563>

SAVE / SHARE:

[Export Metadata](#)

[Save to My Library](#)



### Abstract

Pressurized oxy-combustion has been identified by DOE as a transformational technology for coal power with carbon capture due to the advantages that are realized when the combustion process is pressurized. The staged pressurized oxy-combustion (SPOC) process is particularly attractive as the efficiency of the process is almost 6 percentage points greater than that of first generation oxy-combustion. A critical component of the SPOC process, and potentially other pressurized combustion processes, is the Direct Contact Cooler (DCC) where the latent heat of the flue gas moisture is recovered to improve plant efficiency while simultaneously removing SO<sub>x</sub> and NO<sub>x</sub> from the flue gas, so that the FGD and de-NO<sub>x</sub> processes can be eliminated, and the cost of electricity minimized. The objective of this R&D effort was to advance the TRL of the DCC technology, which included performance testing at a 100 kW scale to validate the process and obtain key engineering data for scale-up. A collateral objective was to study the gas- and liquid-phase kinetics, and the development of a systematic chemical mechanism validated by experimental data. Experiments in a bench-scale stirred reactor provided an updated understanding of the liquid chemistry and the effects of temperature and pH. This information was used [more »](#)

Authors:

Axelbaum, Richard <sup>[1]</sup>; Stokie, David <sup>[1]</sup>; Verma, Piyush <sup>[1]</sup>; Kumfer, Benjamin <sup>[1]</sup>; Min, Yujia <sup>[1]</sup>; Zhu, Yanxuan <sup>[1]</sup>; Jun Young Shin <sup>[1]</sup>; Yablonsky Grigoriy <sup>[1]</sup>; Suresh A K <sup>[2]</sup>

[RETURN TO ISSUE](#) | [PREV](#) **ARTICLE** [NEXT](#) >

## Feasibility of Reactive Distillation for Fischer-Tropsch Synthesis

S. Srinivas, Ranjan K. Malik, and Sanjay M. Mahajani

[View Author Information](#)

**Cite this:** *Ind. Eng. Chem. Res.* 2008, **47**, 3, 889–899

Publication Date: January 15, 2008

<https://doi.org/10.1021/ie071094p>

Copyright © 2008 American Chemical Society

[RIGHTS & PERMISSIONS](#) Subscribed

Article Views

922

Altmetric

3

Citations

16

[LEARN ABOUT THESE METRICS](#)



Energy for Sustainable Development

Volume 11, Issue 4, December 2007, Pages 66-71



Articles

## Fischer-Tropsch synthesis using bio-syngas and CO<sub>2</sub>

S. Srinivas, Ranjan K. Malik, Sanjay M. Mahajani



Industrial & Engineering  
Chemistry Research

# CO<sub>2</sub> reduction and H<sub>2</sub> oxidation



Carbon

Volume 100, April 2016, Pages 632-640



Graphene oxide grafted with iridium complex as a superior heterogeneous catalyst for chemical fixation of carbon dioxide to dimethylformamide

Subodh Kumar <sup>a, 1</sup>, Pawan Kumar <sup>a, 1</sup>, Arghya Deb <sup>b</sup>, [Debabrata Maiti](#) <sup>b</sup>, Suman L. Jain <sup>a</sup>

<sup>a</sup> Chemical Sciences Division, CSIR-Indian Institute of Petroleum, Dehradun, 248005, India

<sup>b</sup> Department of Chemistry, Indian Institute of Technology-Bombay, Powai, Mumbai, 400076, India

**ASIAN JOURNAL  
OF ORGANIC CHEMISTRY**

Focus Review | Full Access

## Photoelectrocatalytic Reduction of CO<sub>2</sub> into C1 Products by Using Modified-Semiconductor-Based Catalyst Systems

Aniruddha Dey, Prof. [Debabrata Maiti](#) , Prof. Goutam Kumar Lahiri

First published: 04 July 2017 | <https://doi.org/10.1002/ajoc.201700351> | Citations: 8

**nature reviews** chemistry

Explore content ▾

Journal information ▾

Publish with us ▾

nature > nature reviews chemistry > perspectives > article

Perspective | Published: 29 August 2018

## Designing electrochemically reversible H<sub>2</sub> oxidation and production catalysts

[Arnab Dutta](#) , [Aaron M. Appel](#) & [Wendy J. Shaw](#)

*Nature Reviews Chemistry* **2**, 244–252 (2018) | [Cite this article](#)

1282 Accesses | 32 Citations | 17 Altmetric | [Metrics](#)

**ACES** Asian Chemical  
Editorial Society



# CO<sub>2</sub> Utilization



Energy

Volume 32, Issue 11, November 2007, Pages 2061-2071



## Underground coal gasification: A new clean coal utilization technique for India

Anil Khadse, Mohammed Qayyumi, Sanjay Mahajani, Preeti Aghalayam



Energy

Volume 35, Issue 6, June 2010, Pages 2374-2386



## Laboratory studies on combustion cavity growth in lignite coal blocks in the context of underground coal gasification

Sateesh Daggupati <sup>a</sup>, Ramesh N. Mandapati <sup>a</sup>, Sanjay M. Mahajani <sup>a</sup>, Anuradda Ganesh <sup>b</sup>, D.K. Mathur <sup>c</sup>, R.K. Sharma <sup>c</sup>, Preeti Aghalayam <sup>a</sup>



Journal of Membrane Science

Volume 614, 15 November 2020, 118506



## In-situ growth of zeolitic imidazolate framework-67 nanoparticles on polysulfone/graphene oxide hollow fiber membranes enhance CO<sub>2</sub>/CH<sub>4</sub> separation

Krishnamurthy Sainath <sup>a</sup> , Akshay Modi <sup>a</sup> , Jayesh Bellare <sup>a, b, c, d</sup>



Chemical Engineering Journal Advances

Volume 5, 15 March 2021, 100074



## CO<sub>2</sub>/CH<sub>4</sub> mixed gas separation using graphene oxide nanosheets embedded hollow fiber membranes: Evaluating effect of filler concentration on performance

Krishnamurthy Sainath <sup>a</sup>, Akshay Modi <sup>a, b</sup>, Jayesh Bellare <sup>a, c, d, e</sup>

INTERNATIONAL JOURNAL OF CHEMICAL  
REACTOR ENGINEERING

Volume 4

2006

Article A37

## Reactor Model for the Underground Coal Gasification (UCG) Channel

Anil N. Khadse\*

Mohammed Qayyumi<sup>†</sup>

Sanjay M. Mahajani<sup>‡</sup>

Preeti Aghalayam\*\*



Journal of Environmental Chemical Engineering

Volume 9, Issue 1, February 2021, 105041



## An improved water electrolysis and oxy-fuel combustion coupled tri-reforming process for methanol production and CO<sub>2</sub> valorization

Abhishek Dwivedi <sup>a</sup>, Ravindra Gudi <sup>a</sup> , Pratim Biswas <sup>b</sup>

# Techno-economics and life-cycle studies on CCUS



Journal of CO<sub>2</sub> Utilization

Volume 24, March 2018, Pages 376-385



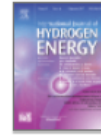
Oxy-fuel combustion based enhancement of the tri-reforming coupled methanol production process for CO<sub>2</sub> valorization

Abhishek Dwivedi <sup>a</sup>, Ravindra Gudi <sup>a</sup> , Pratim Biswas <sup>b</sup>



International Journal of Hydrogen Energy

Volume 42, Issue 36, 7 September 2017, Pages 23227-23241



An improved tri-reforming based methanol production process for enhanced CO<sub>2</sub> valorization

Abhishek Dwivedi <sup>a</sup>, Ravindra Gudi <sup>a</sup> , Pratim Biswas <sup>b</sup>



Energy Procedia

Volume 54, 2014, Pages 431-438



Cost Implications of Carbon Capture and Storage for the Coal Power Plants in India ☆

Anand B. Rao <sup>a</sup> , Piyush Kumar <sup>b</sup>



Energy Procedia

Volume 90, December 2016, Pages 326-335



Techno-Economic Assessment of Carbon Mitigation Options for Existing Coal-fired Power Plants in India ☆

Udayan Singh <sup>a</sup>, Anand B. Rao <sup>b, c</sup> 



Energy Procedia

Volume 114, July 2017, Pages 7638-7650



Economic Implications of CO<sub>2</sub> Capture from the Existing as Well as Proposed Coal-fired Power Plants in India under Various Policy Scenarios ☆

Udayan Singh <sup>a</sup>, Anand B. Rao <sup>b</sup> , Munish K. Chandel <sup>c</sup>



Energy Procedia

Volume 114, July 2017, Pages 7492-7503



Relevance of Carbon Capture & Sequestration in India's Energy Mix to Achieve the Reduction in Emission Intensity by 2030 as per INDCs ☆

A.R. Akash <sup>a</sup> , Anand B. Rao <sup>a, b</sup>, Munish K. Chandel <sup>c</sup>

**Thank you for the opportunity  
and for your kind attention**