Effective utilization of Carbon dioxide from Thermal Power Plants Exhausts: Adapting Bio-Carbon Capture Storage & Utilization Technology

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Key Words / Points

- ***Climate Justice*** - Addresses Climate Reward/Penalty
- ***Carbon dioxide Mitigation*** - Developing economies with major reliance on coal based thermal power, the best option is Carbon Capture & Storage(CCS).
- ***Carbon dioxide Level in the Atmosphere*** - 410 ppm, quite alarming and is the cause of Climate Change.
- **CCS** to be renamed as **CCUS** (Carbon Capture Uses and Storage) with focus on Industrial use of CO_2.
- ***COP 23 Bonn ,Germany Outcome-*** Climate finance for developing economies; Reducing fossil fuel emissions; Keep the atmospheric temp. rise to below 2 ^{o}C; and Enhance role of renewable energy.

(COP - Committee of parties on Climate Change)

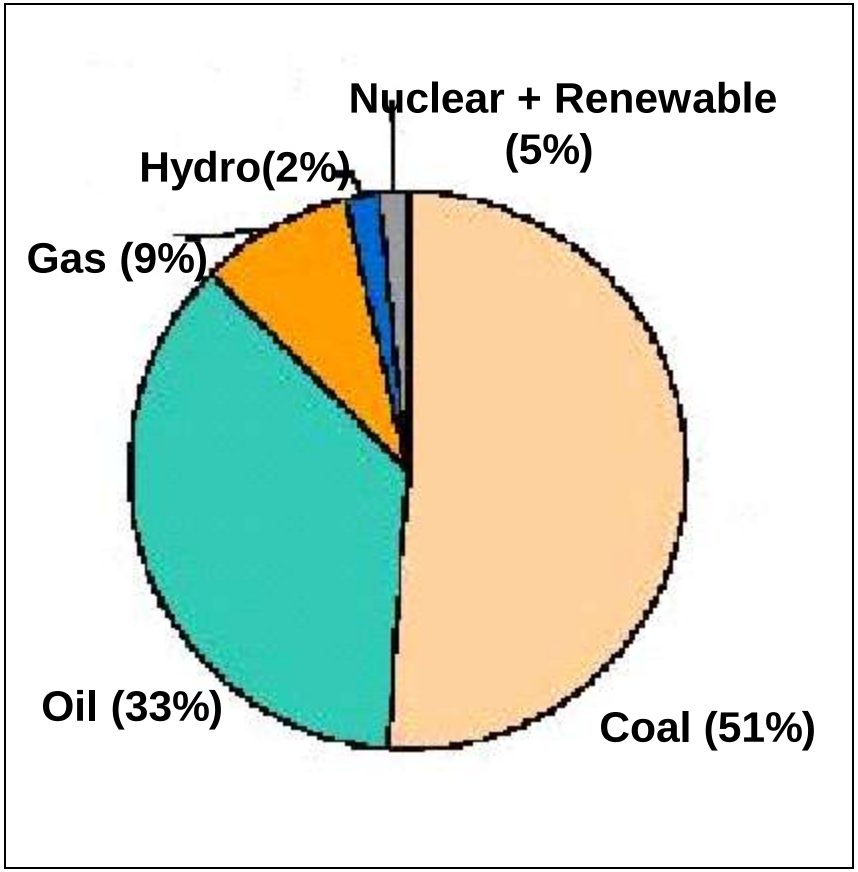
Focus of my Talk ?

Carbon Capture Utilization & Storage (CCUS)

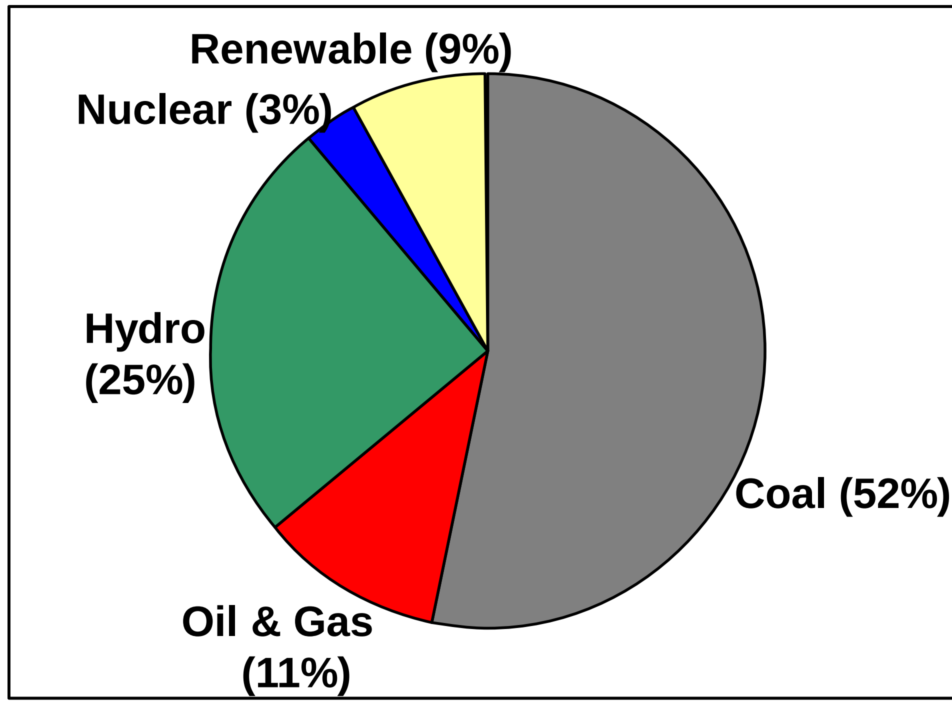
- A Global R& D initiative for capture, storage & utilization of CO2 to mitigate climate change. The key option are Geological Carbon Capture & Storage and BIO - CCUS.
- ***Carbon Capture Uses (CCU) -***

Develop new uses of captured CO2 for Pharma, Cement and Refrigeration Industry etc.

India's Energy Scenario



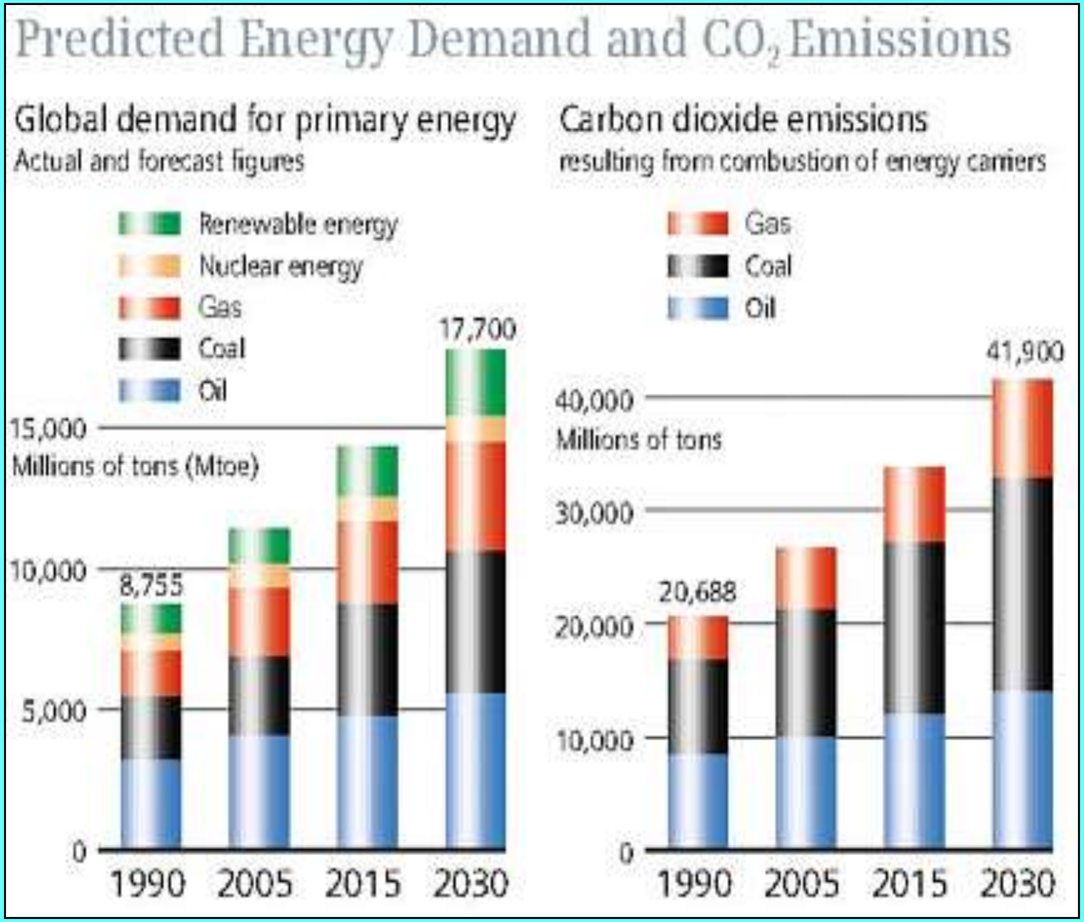
India's Power Scenario



India's Energy Scenario is mostly driven by conventional Fossil Fuels

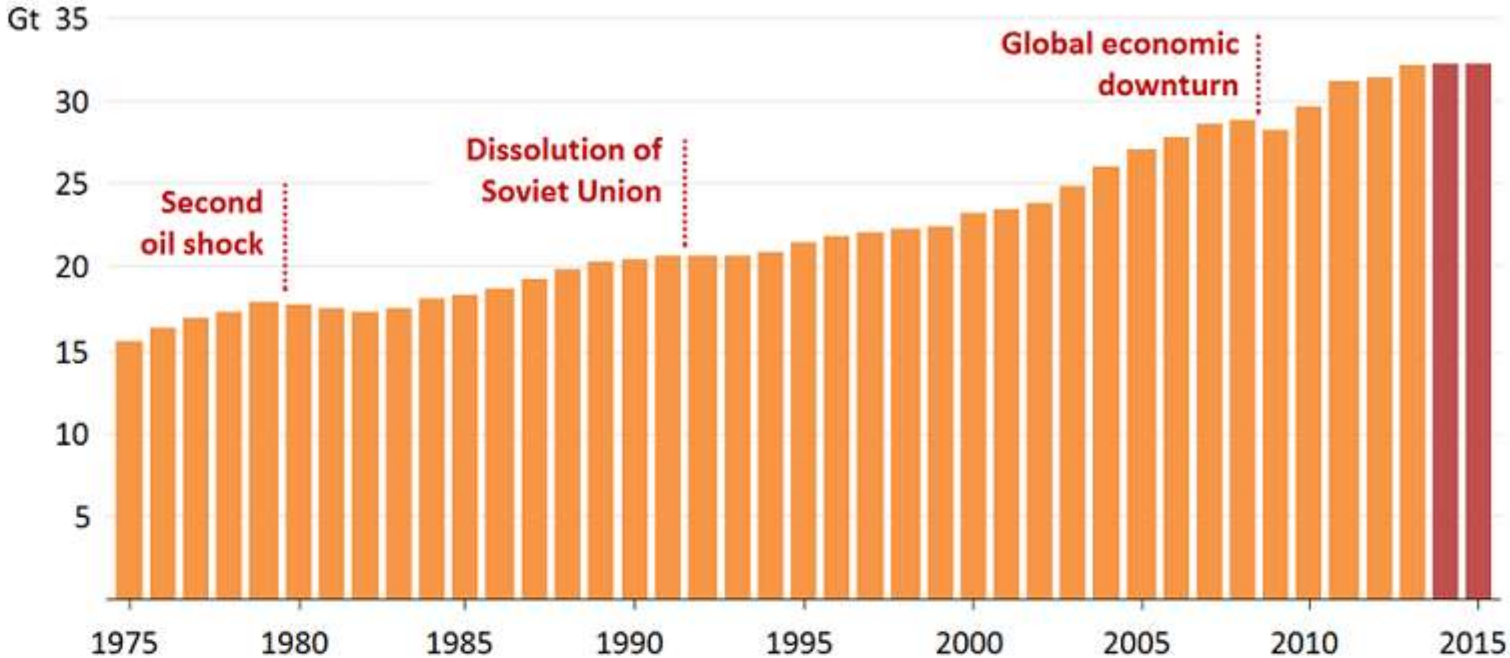
Source: Planning Commission of India

Global energy scenario



Data is based on the International Energy Agency's "Business as usual" scenario.
Clear political and technical measures are necessary to reduce CO_2 emissions
Source: IEA 2011. 1 Mtoe = 1 million tons oil equivalent = 41.868 PJ

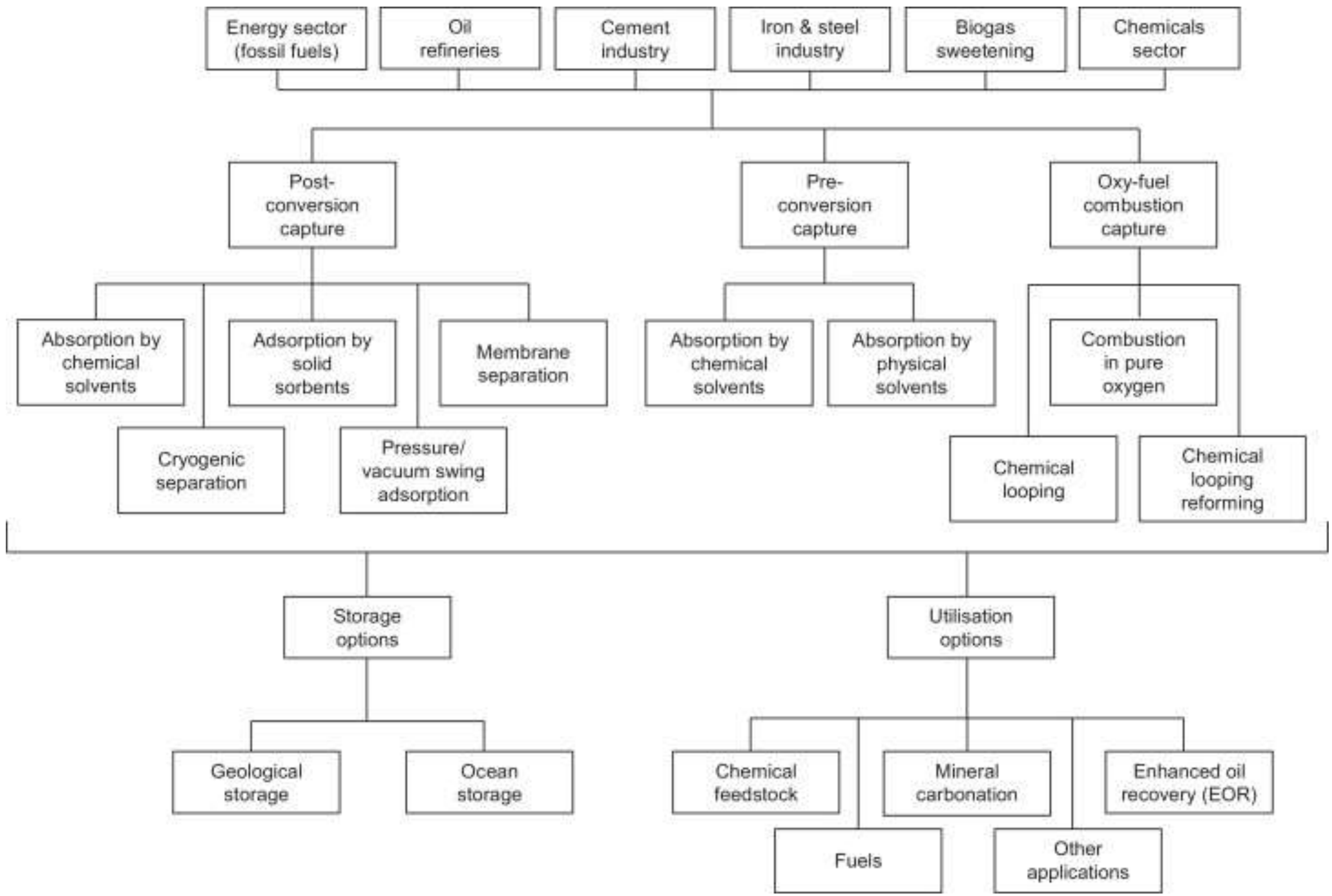
Global energy-related CO_2 emissions



IEA analysis for 2015 shows renewables surged, led by wind, and improvements in energy efficiency were key to keeping emissions flat for a second year in a row

From the International Energy Agency

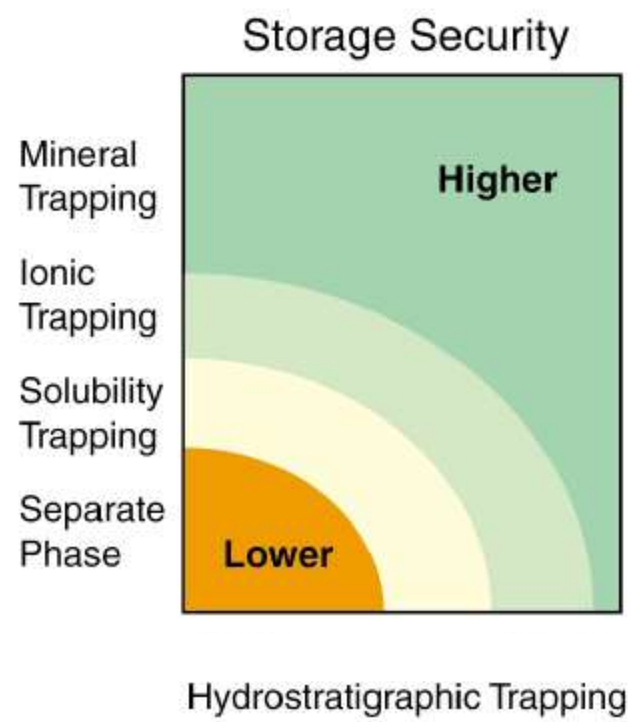
CCS and CCU options



Geological Carbon Capture and Storage

The CO_2 captured can be stored in

- Deep underground formations
- Depleted oil and gas reservoirs
- Coal beds
- Gas Hydrates
- Deep brine- filled formations



Physical and geochemical processes that enhance storage security

Industrially generated CO_2 is pumped into deep under ground formations and dissolves in the native formation fluids. Some of the dissolved CO_2 would chemically react and become part of solid mineral/ coal matrix. Once dissolved or reacted to form minerals, CO_2 is no longer buoyant and would not rise to the ground surface.

CO_2 Trapping Mechanisms

I Hydrodynamic Trapping

- **Closed Stratigraphic Trapping**

II Geochemical

- **Solubility Traps**
- **Ionic Traps**
- **Mineral Traps**

Solubility Trapping

CO_2 (gaseous) + H_2O → H_2CO_3 (aqueous)

Ionic Trapping

H_2CO_3 (aqueous) + OH^- → HCO_3^- (aqueous)

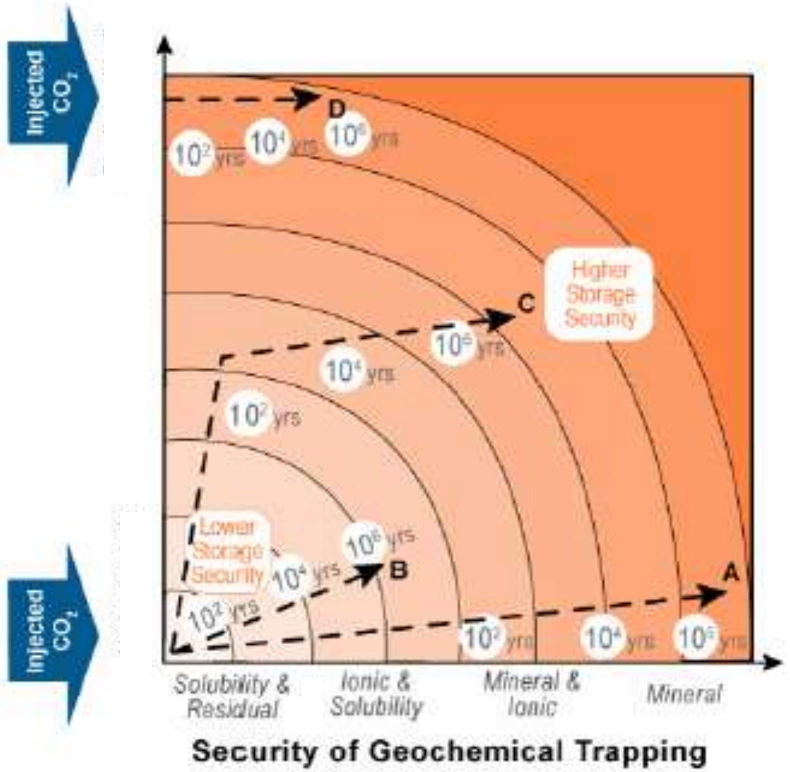
HCO_3^- (aqueous) + OH^- → H_2CO_3 (aqueous)

Mineral Trapping

$CO_3^{=}$ (aqueous) + Ca^{++} → $CaCO_3$ (solid)

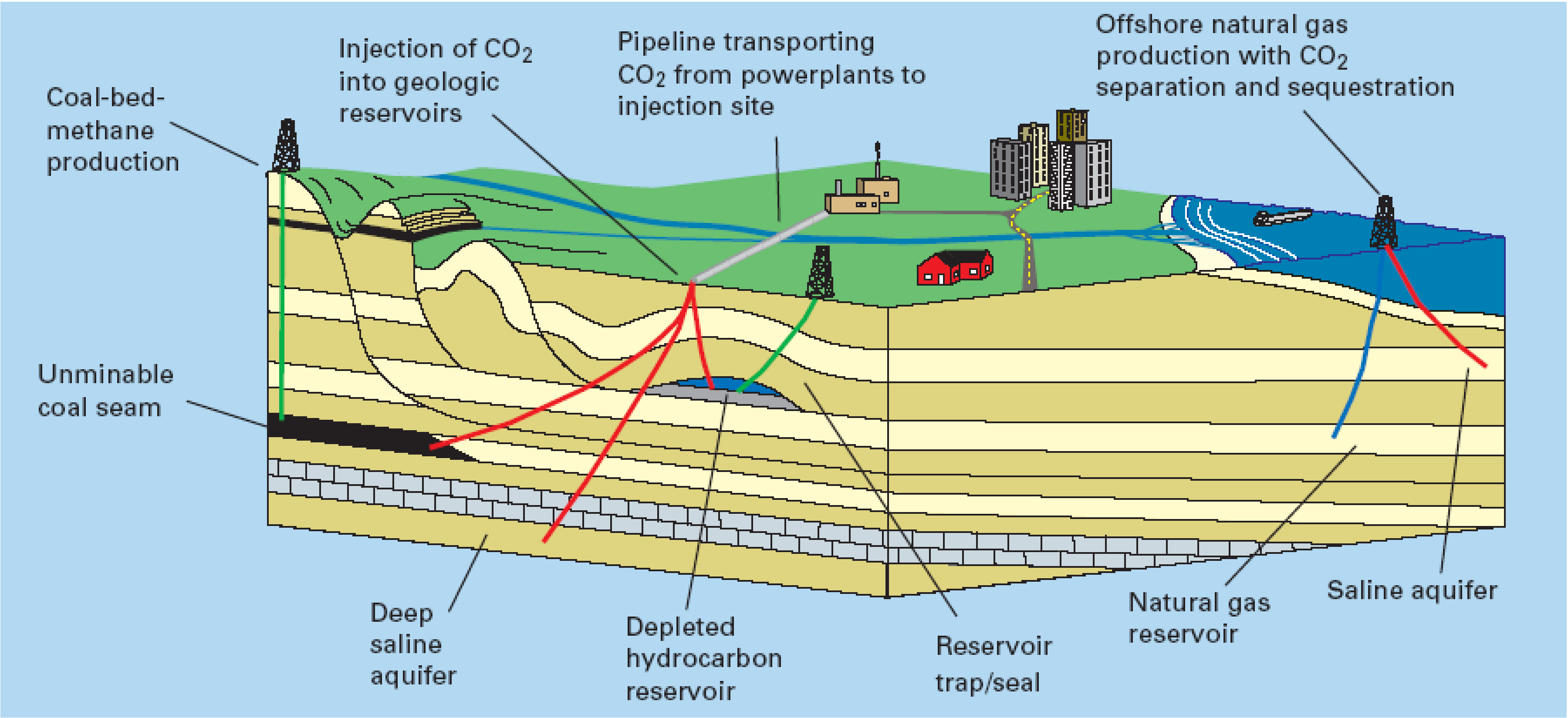
Storage Security Mechanisms and Changes Over Time

- When the CO_2 is injected, it forms a bubble around the injection well, displacing the mobile water laterally and vertically within the injection horizon.
- The interactions between the water and CO_2 phase allow geochemical trapping mechanisms to take effect.
- Over time, CO_2 that is not immobilized by residual CO_2 trapping can react with in situ fluid to form carbonic acid i.e., H_2CO_3 called solubility trapping that dominates from tens to hundreds of years.
- Dissolved CO_2 can eventually react with reservoir minerals if an appropriate mineralogy is encountered to form carbon-bearing ionic species i.e., HCO_3^- and CO_3^{2-} called ionic trapping which dominates from hundreds to thousands of years.
- Further breakdown of these minerals could precipitate new carbonate minerals that would fix injected CO_2 in its most secure state i.e., mineral trapping which dominates over thousands to millions of years.



Storage expressed as a combination of physical and geochemical trapping. The level of security is proportional to distance from the origin. Dashed lines are examples of million-year pathways

Source: IPCC Report



Potential CO_2 storage reservoirs and products. Red lines indicate CO_2 being pumped into the reservoirs for sequestration, green lines indicate enhanced recovery of fossil fuels caused by CO_2 sequestration, and the blue line indicates conventional recovery of fossil fuels.

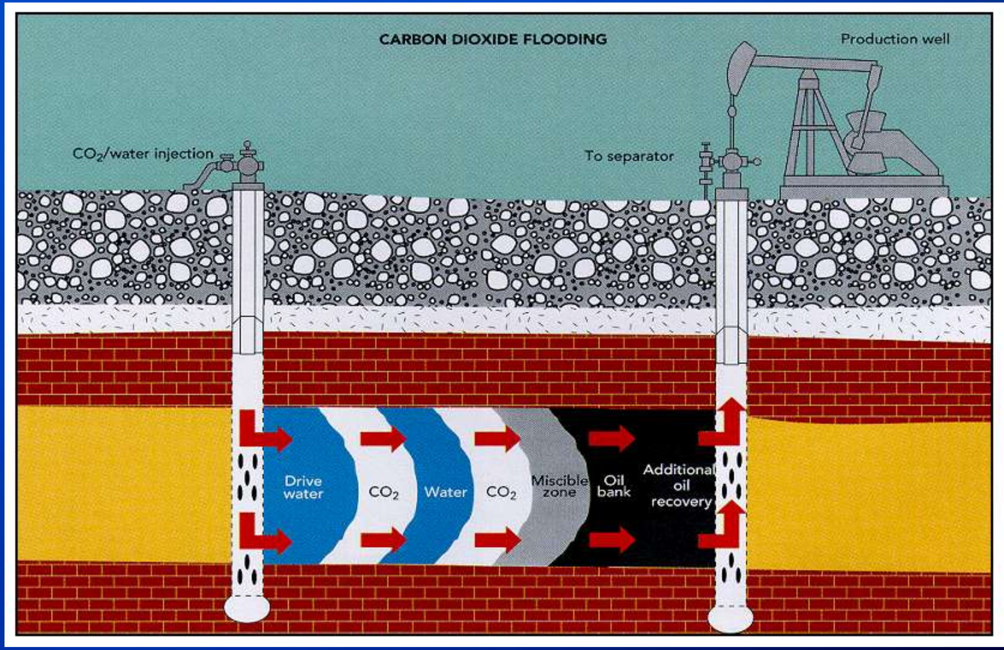
CO_2 storage in depleted oil/gas reservoirs can enhance production of oil/gas.

Enhanced Oil Recovery (EOR) can be either miscible or immiscible depending primarily on the pressure of the injection gas into the reservoir.

Miscible phase: **CO_2-EOR, the CO_2 mixes with the crude oil causing it to swell and reduce its viscosity, whilst also increasing or maintaining reservoir pressure. The combination of these processes enables more of the crude oil in the reservoir to flow freely to the production wells from which it can be recovered.**

Immiscible phase: **CO_2-EOR, the CO_2 is used to re-pressure the reservoir and as a sweep gas, to move the oil towards the production well.**

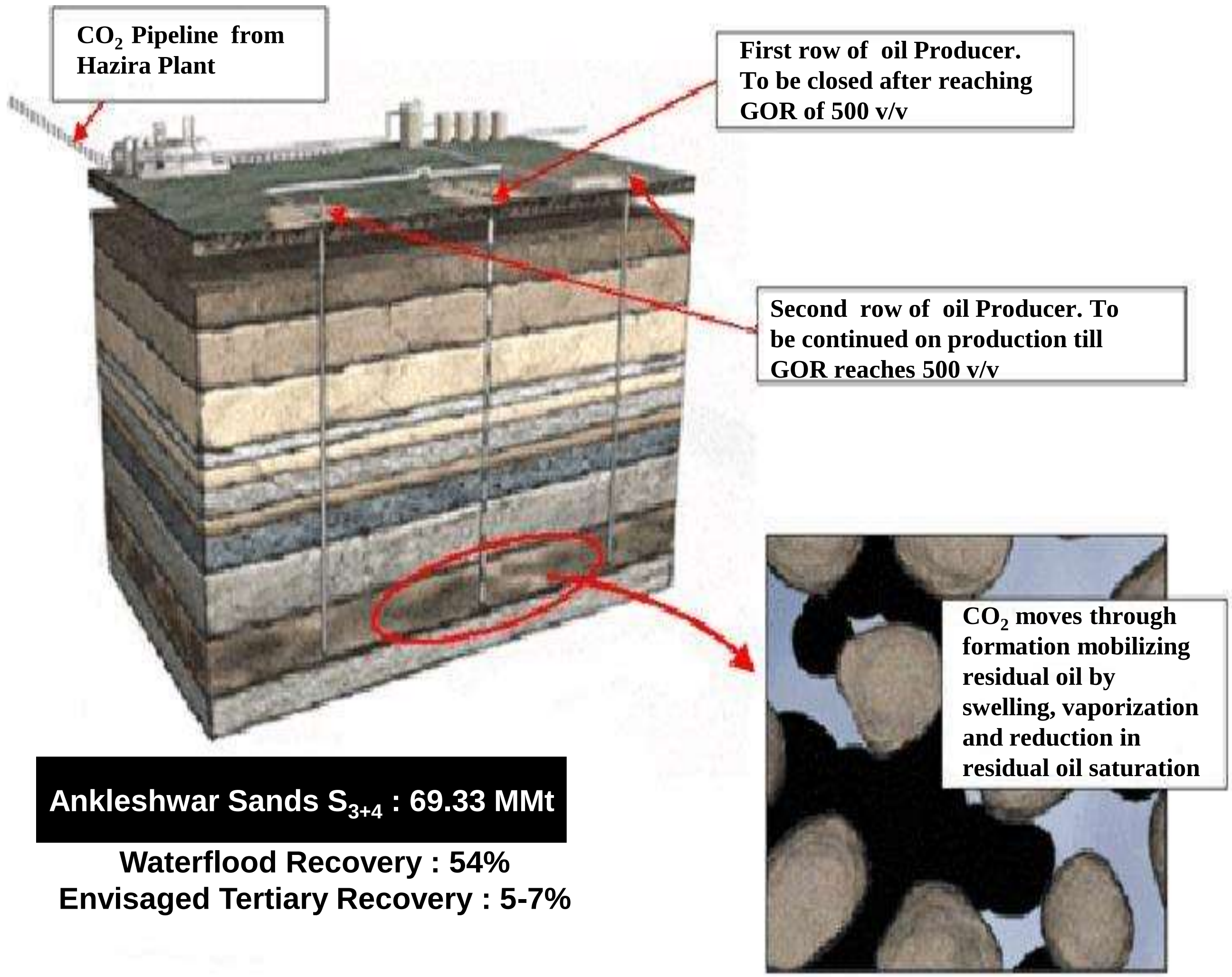
CO_2 enhanced oil recovery



• In India, the Oil & Natural Gas Corp. (ONGC) has proposed **CO_2-EOR for Ankleshwar Oil Field** in Western India.

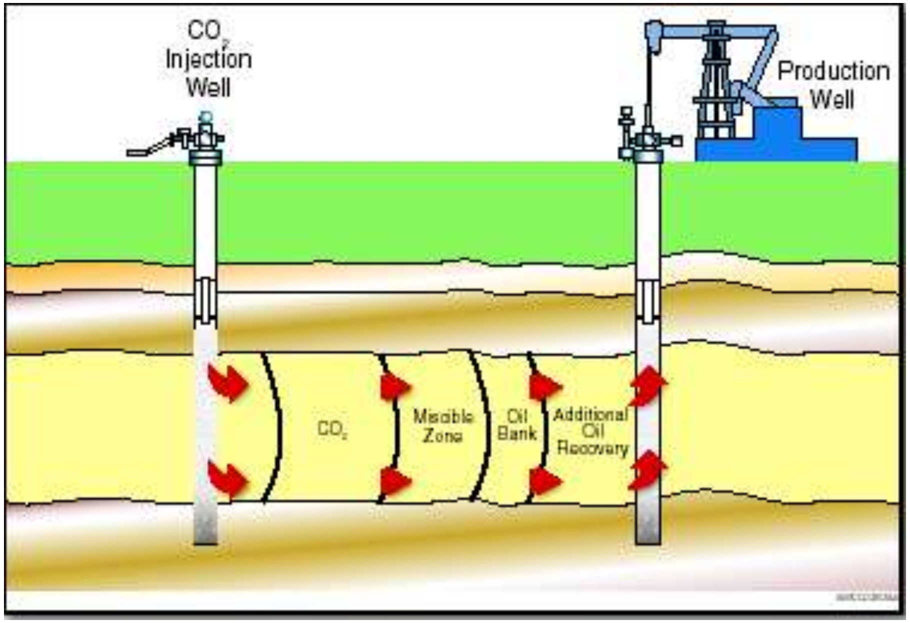
•The CO_2 is planned to be injected @ 600,000m^3/d and is sourced from ONGC gas processing complex at Hazira.

•The experimental and modeling studies have indicated an incremental oil recovery of ~ 4 % over the project life of 35 years besides the potential to sequester 5 to 10 million tons of CO_2



After, Suresh Kumar, Abstract, IWCCS-07

Weyburn–Midale CO_2 monitoring and storage project, Canada

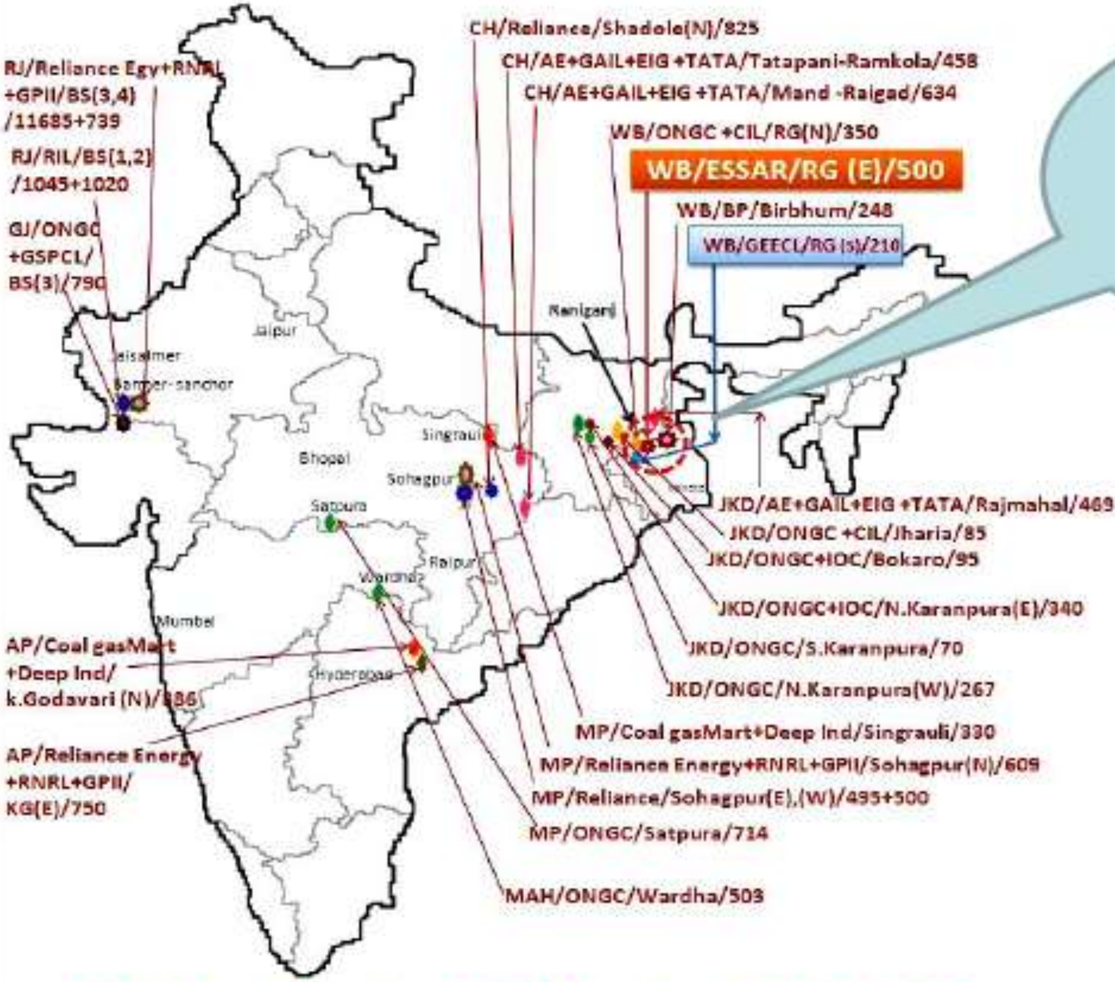


Injection of CO_2 in the Oil Producing Formations of the Weyburn Field

- Amongst the largest ongoing projects for CCS in the world.
- The Encana Cooperation has been injecting 5,000 tonnes of CO_2 per day into in the Weyburn oil field for the dual purpose of enhancing oil recovery and the CO_2 storage while increasing the field's production by an additional 10,000 barrels per day.
- About 30 million tones of CO_2 will be injected and permanently stored over the life of project producing at least 130 million barrels of incremental recovered oil.

After, EERC, North Dakota.

CBM Blocks in India - An Overview

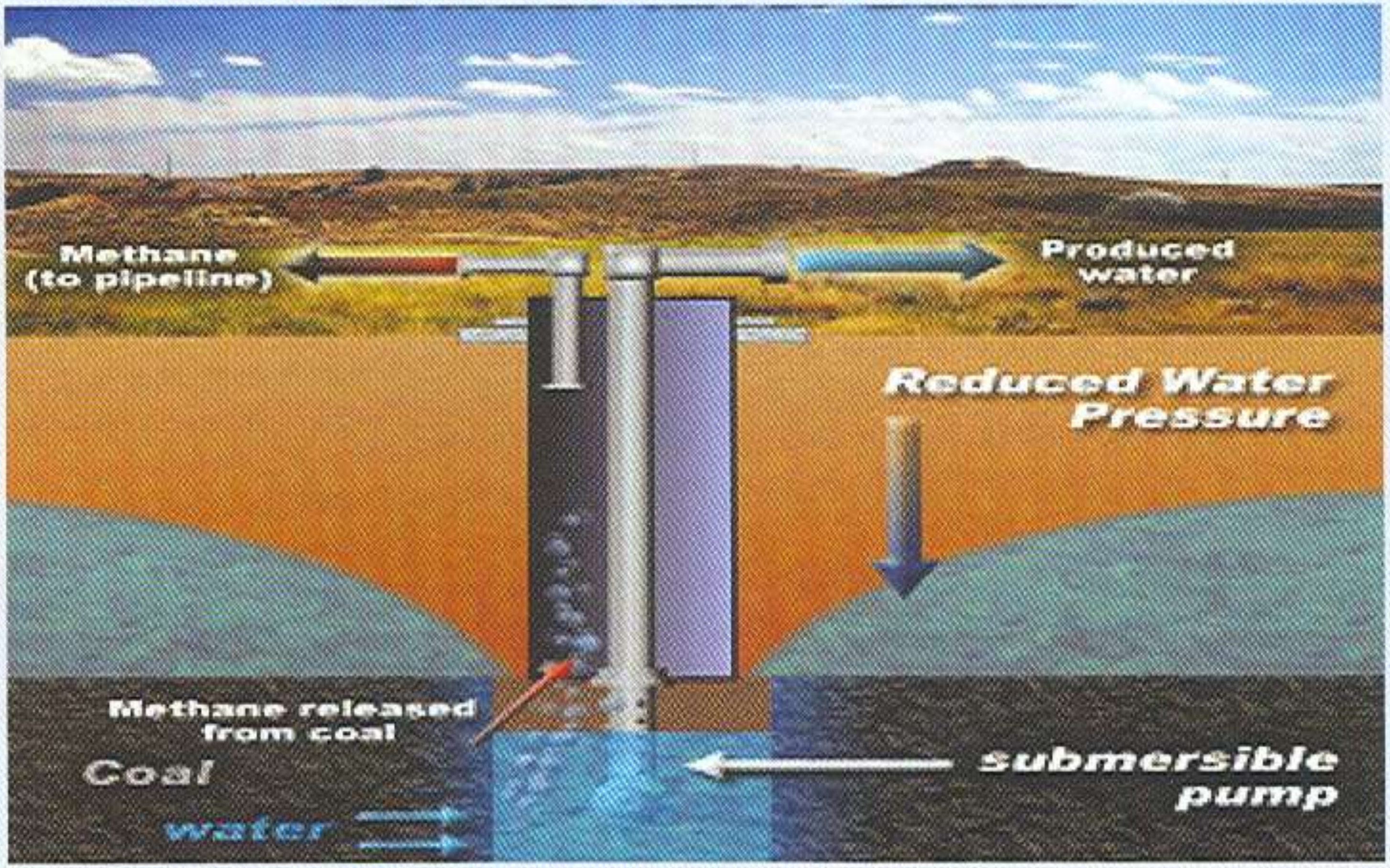


Eastern region presently deprived of natural gas

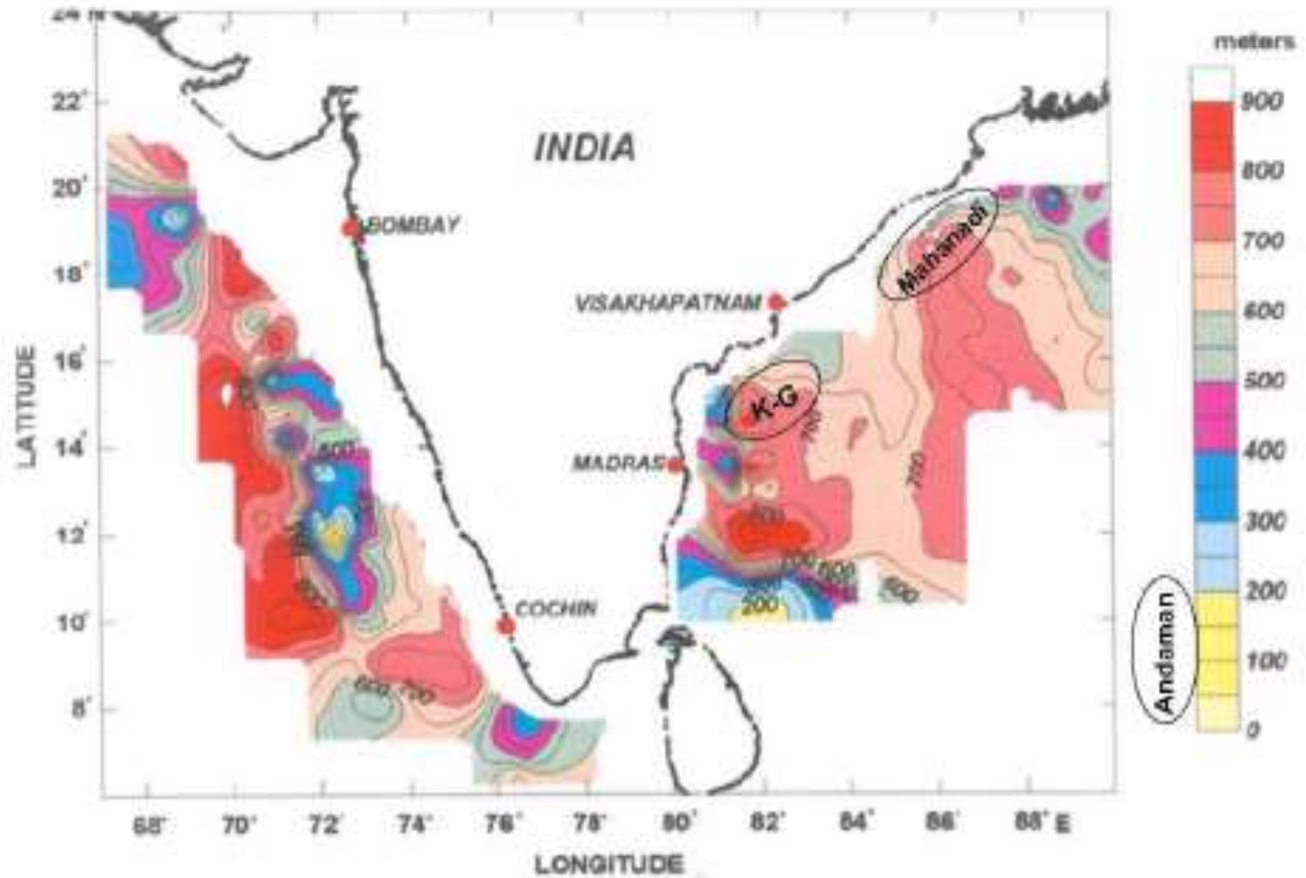
CBM Blocks of India		
State	**No. of Blocks**	**Area (Sq. Km)**
West Bengal	4	1308
Jharkhand	6	1326
Madhya Pradesh	5	2648
Rajasthan	4	3972
Chattisgarh	3	1917
Andhra Pradesh	2	1136
Maharashtra	1	503
Gujarat	1	790
Total	**26**	**13600**

Total estimated CBM potential 70 TCF

SOURCE :DGH,

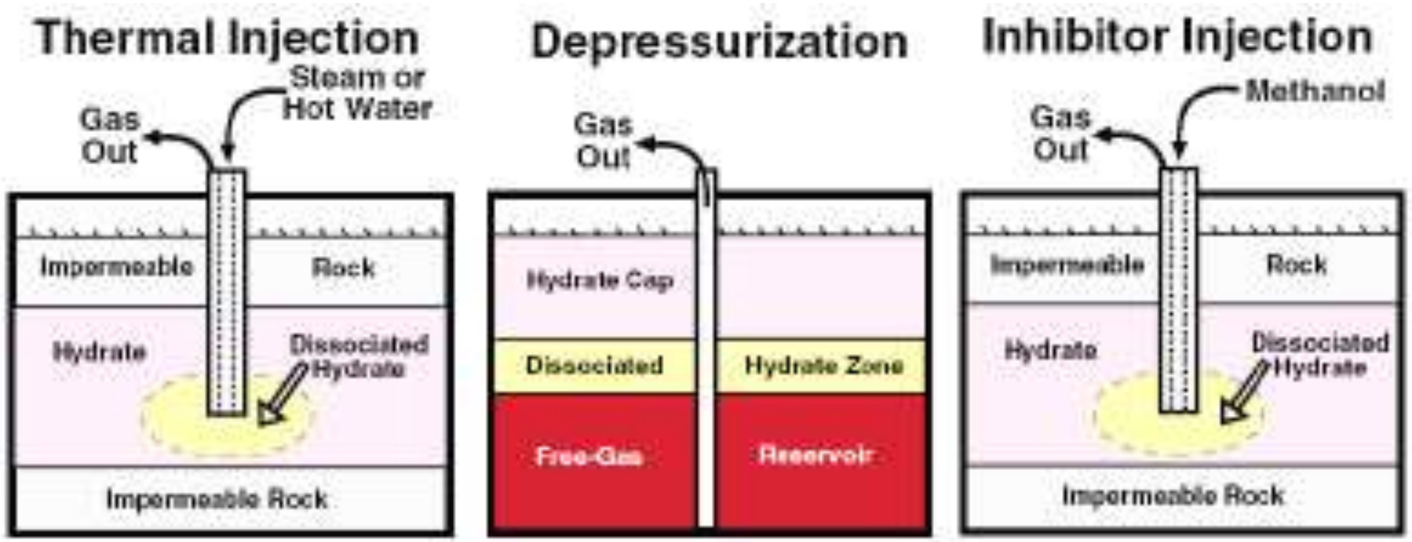


PRODUCTION PROCESS OF A CBM WELL



Location in the Eastern Offshore, superimposed on Gas Hydrate stability thickness map along the Indian margin, from where the gas hydrate samples have been recovered (after Sain & Gupta, 2008).

Gas hydrate are solid ice like crystal form of water that contain Methane Molecules in its Molecular Cavities, Prognostic Resources of Gas Hydrate : ~ 2000 tcf.



Possible production methods for Gas Hydrates

CO_2 Sequestration in Methane Hydrates

- Methane Hydrates are class of solids in which methane molecules occupy cages made up of hydrogen- bonded water molecules.
- CO_2 can also be stored as hydrates with simultaneous conversion of in situ methane hydrates into natural gas.
- At temperatures below 10°C, there is a pressure range in which methane hydrate is unstable while CO_2 hydrate is stable.
- The heat released from the formation of CO_2 gas hydrate is greater than that needed for CH4 hydrate dissociation:
  $CH_4(H_2O)n \Rightarrow CH_4 + nH_2O$; Hf = 54.49 KJ/mole
  $CO_2(H_2O)n \Rightarrow CO_2 + nH_2O$; Hf = 57.98 KJ/mole
  where *n* is the hydration number for CH_4 hydrate and CO_2 hydrate
- *n* is dependent on pressure, temperature and the composition of the gas in the gas phase which implies that under certain pressure and temperature conditions, the replacement of CH_4 in the hydrate with CO_2 is thermodynamically possible.

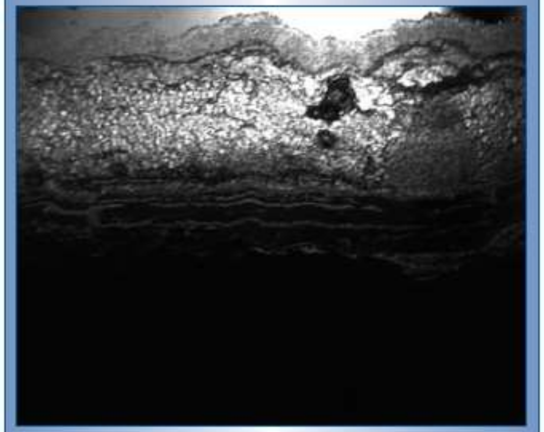


Figure 4. This laser image shows methane hydrate embedded in the sediment at the start of CO_2 injection.

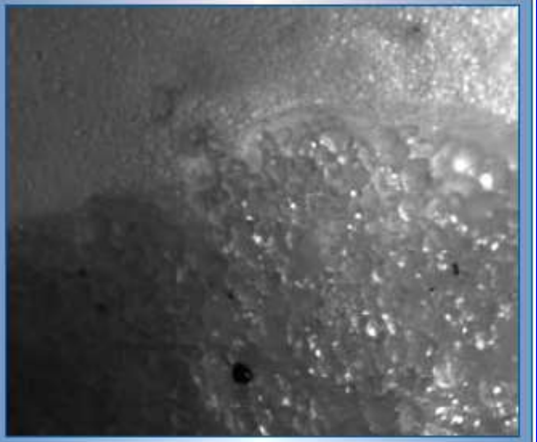
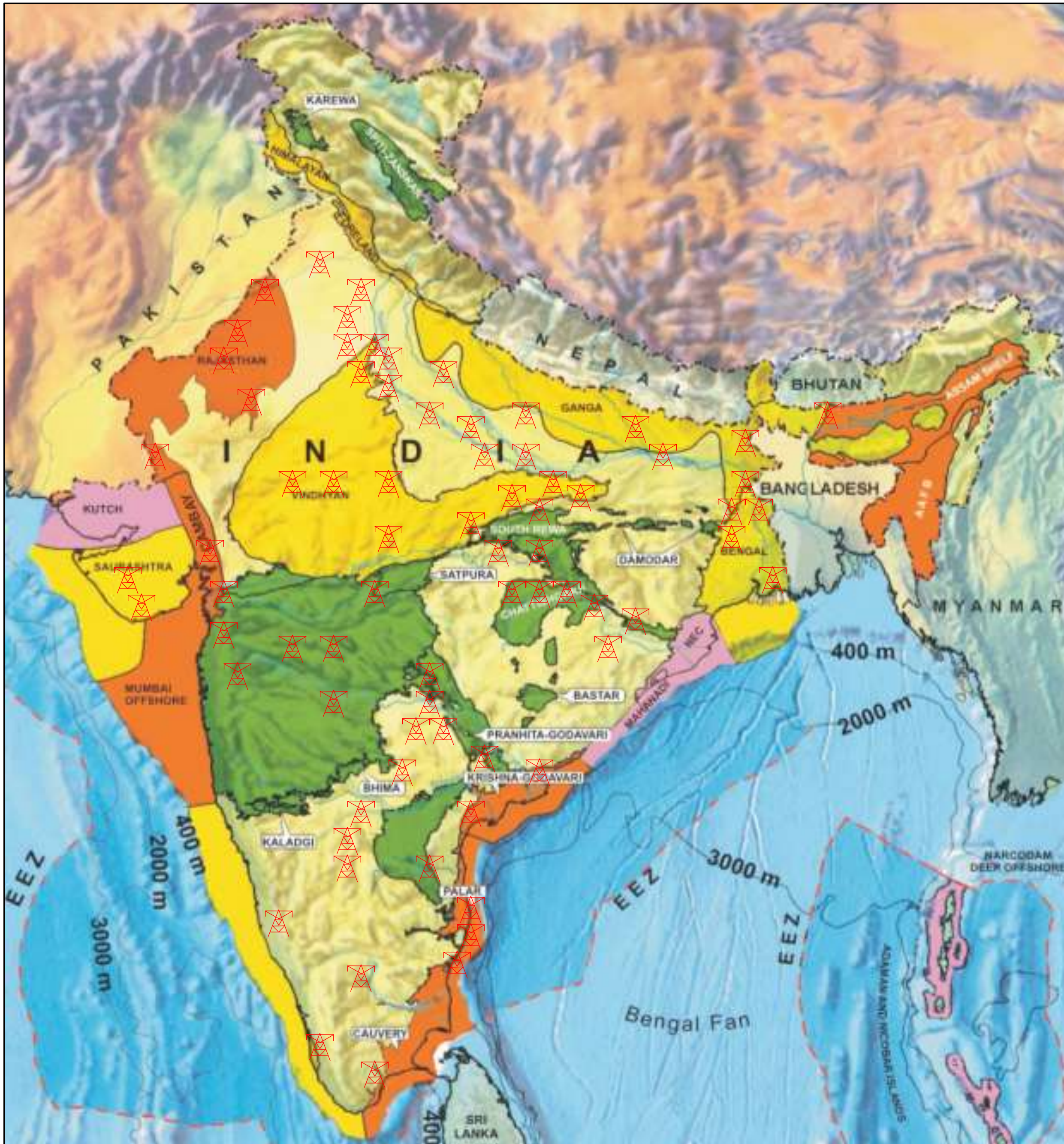


Figure 5. This laser image shows hydrates embedded in the sediment after 92 hours.

After Gas Technology Institute, USA

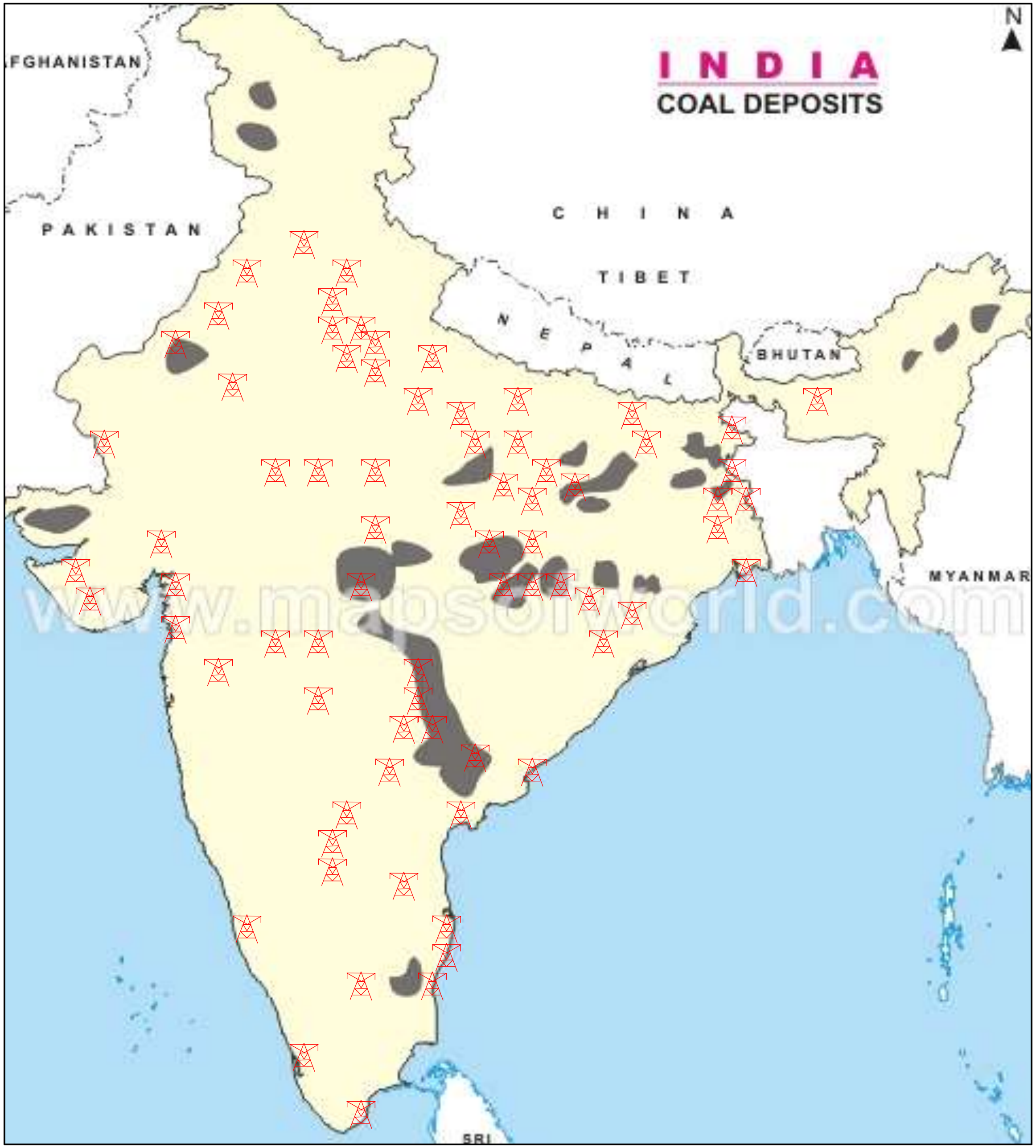


THERMAL POWER PLANTS OVERLAIN ON SEDIMENTARY BASIN MAP OF INDIA

LEGEND

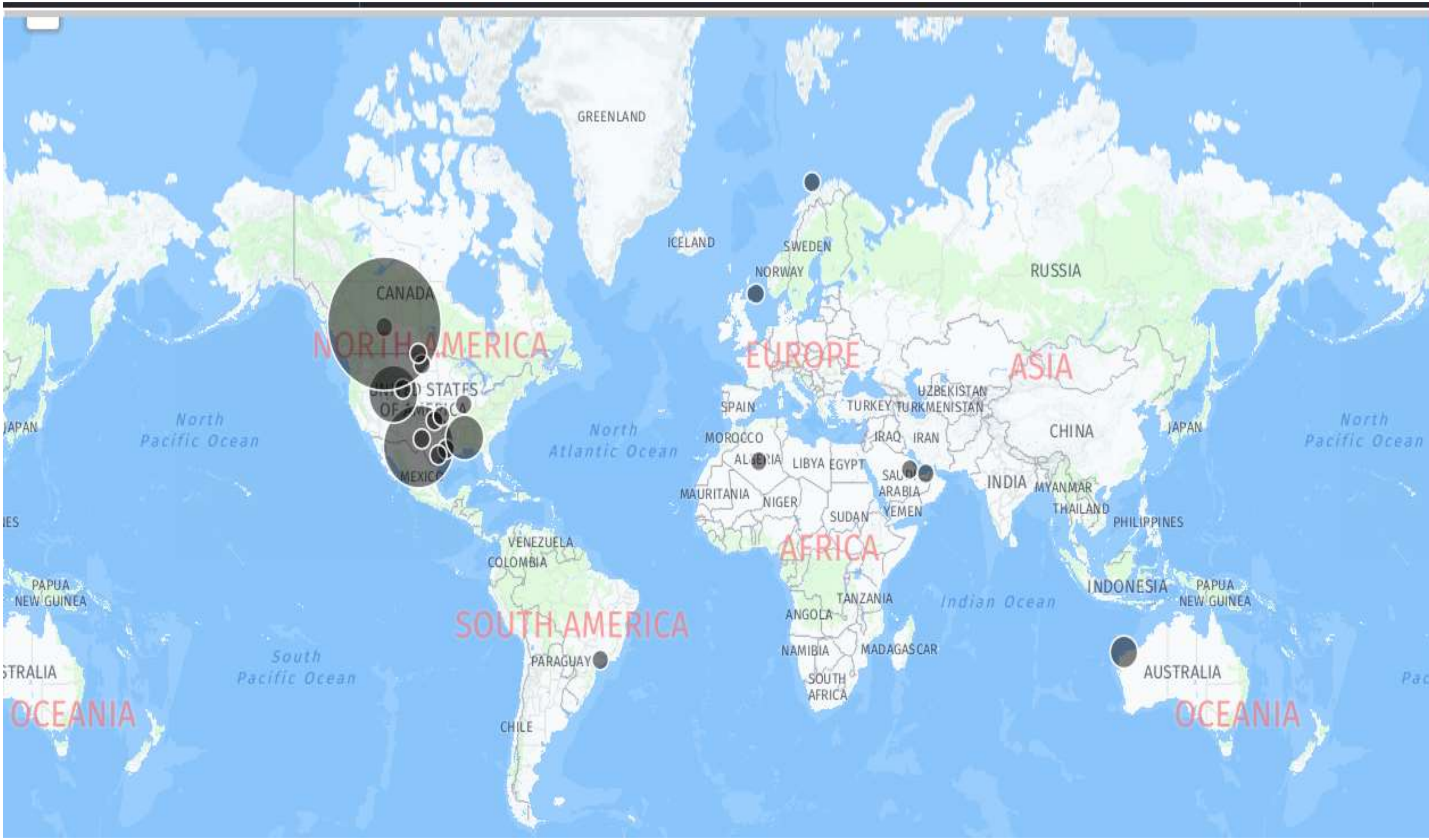
- CATEGORY-I BASIN (Proven commercial productivity)
- CATEGORY-II BASIN (Identified prospectivity)
- CATEGORY-III BASIN (Prospective Basins)
- CATEGORY-IV BASIN (Potentially Prospective)
- PRE-CAMBRIAN BASEMENT/ TECTONISED SEDIMENTS
- DEEP WATER AREAS WITHIN EEZ

THERMAL POWER PLANTS OVERLAIN ON COAL DEPOSITS MAP OF INDIA



Large scale Carbon Capture & Storage projects around the World

(400,000- 800,000 tons of CO_2 per year) Source: Carbon Brief



USA-11, Canada-3, Norway-3, Australia-1, Brazil-1, UAE-1, Algeria-1, Saudi Arabia-1

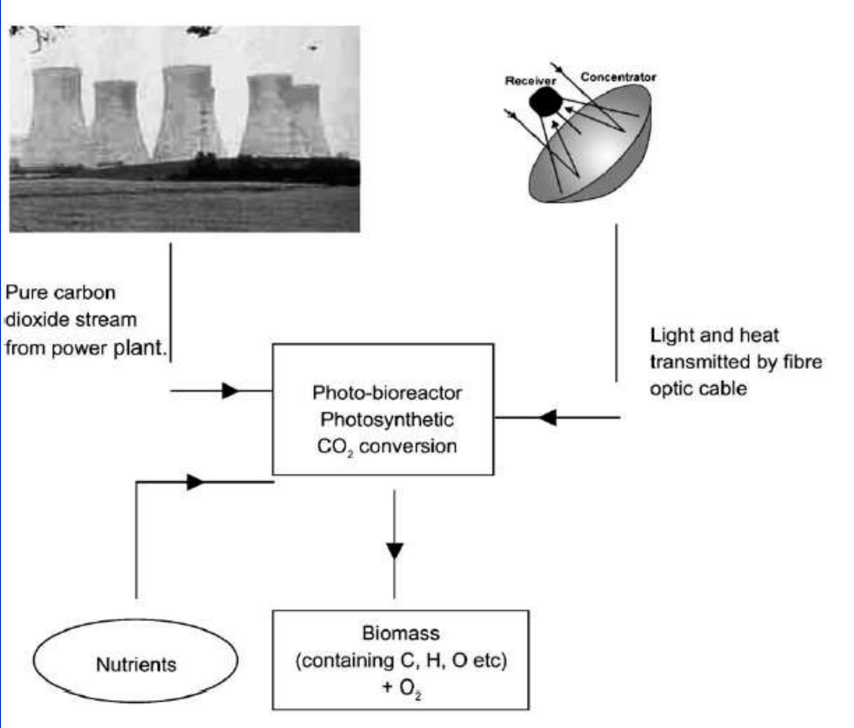
BIO - CCUS

Bio-CCUS is the capture,utilization and storage of the atmospheric and power plant exhaust carbon dioxide by biological processes.

This may be by increased photosynthesis (through practices such as reforestation/ preventing deforestation and genetic engineering); by enhanced soil carbon trapping in agriculture; or *by the use of miro-algae processes to absorb the carbon dioxide emissions from Industrial plant exhaust.*

Bio- CCUS :

The concept of photosynthetic conversion to fix carbon dioxide using bacteria or micro-algae under a controlled environment.



Conceptual diagram of Photosynthetic conversion of carbon dioxide to biomass.

- The solar energy is collected using Fresnel lens devices/parabolic concentrator and a fibre optic light delivery system is used to stimulate biological organisms like cyanobacteria or micro-algae in a bio-generator to produce useful by-products from carbon dioxide.
- For uniform growth of the organisms, the distribution of photosynthetic photon flux light in the wavelength range of 400–700 nm needs to be delivered to the bioreactor.
- The photo-bioreactor system makes use of the natural process 'photosynthesis' to convert light, heat and carbon dioxide to useful products, such as carbohydrates, hydrogen and oxygen.

$$6CO_2\ (aq) + 6H_2O(l) + \text{light} + \text{heat} \Rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$$

- Assuming that the carbon uptake rate of 1.5 g/day for the particular micro-organism, *Synechocystis aquatilis,* up to 2.2 ktonne C/year could be sequestered from the environment.

(After Energy Conv. and Manag.46 (2005) 403–420)

INTERNATIONAL SCENARIO ON BIO-CCUS:

USA

- One of the most recent algae-inspired projects is being undertaken by Washington-based Columbia Energy Partners (CEP), which plans to convert carbon dioxide from a coal-fired electricity plant into algal oil.
- NASA OMEGA. Project aims to investigate the technical feasibility of a unique floating algae cultivation system for waste water treatment
- Arizona public service Co. , USA have taken a loan/grant of $ 70.0 Million to grow Algae from CO2 released from their coal fired plants.

Australia

- Australian firms, Linc Energy and BioCleanCoal, have partnered together in a joint venture to sequester carbon dioxide emissions from Australian coal-fired power stations to use as fuel or fertiliser, even re-burning it to produce additional energy.
- MBD Energy, Melbourne is planning to introuse teccnology that will allow algae to capture CO2 from a power station at no virtual cost to utility.

Israel

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

Source: www. ***Oilgae.com***

Canada

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

Italy

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

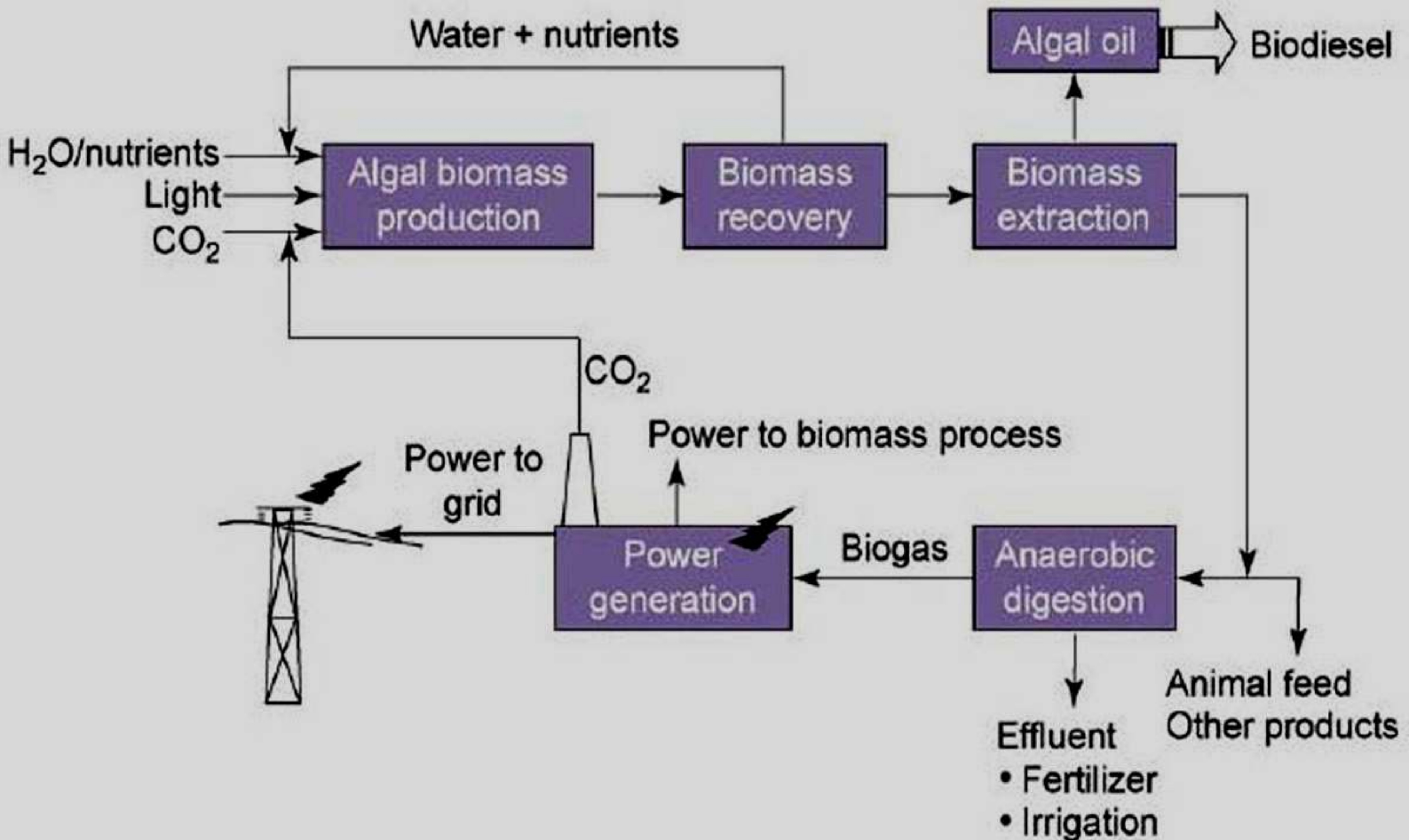
Germany

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

China

Source: www. ***Oilgae.com***

BIO- CCUS Indian Scenario



Integrated process of algal biodiesel production with CO2 capture from thermal power plant(A joint project of Adani Power and Training & Central Salt and Marine Chemical Reseaech Institute, Gujarat).

(Source: Gao et al. Chemistry Central Journal 2012)

Pilot project on Bio- CCUS in West Bengal:

Kolkata based organization is conducting a pilot project at the Kolaghat thermal power plant. The 1,260-MW Kolaghat plant emits ~15,000 T of CO_2 every day. It is proposed that this gas be trapped and channelized into a pond where algae will be farmed.

The company is attempting to use the CO_2 from the power plant as follows: Fifty percent of the CO_2 emitted is planned to be used for algal farming, 25% for farming of Spirulina, and the rest to be compressed in its uncontaminated form to produce dry ice. The oilcakes (left over after the oil is extracted) are could be burnt to generate power to run this entire process.

The company plans to design this into a self-sustaining technology. The power plant will be assisted by Sun Plant Agro, and plans to start commercial production of algae bio-fuel by.

Both West Bengal Power Development Corporation (WBPDCL) (which owns the power plant) and Sun Plant Agro will earn carbon credit for the algae project. The power plant plans to use the wastelands near the plant for algal farming.

ALGAL BIO- CCUS CONCEPT OF NALCO PROJECT

500 MW power plant generating about 8000 tons of CO_2 per day is a huge resource, if can be utilized.

The amount of CO_2 sequestered in Algae Biomass sequestration Calculated as a unit of Tons/ Acre/Year #Carbon Content Assumed in Biomass is ~ 50 %

Carbon to CO_2 : 1 kg of carbon is equivalent to 3.6 kg of CO_2

1 mole of carbon give 1 mol of CO_2, Molecular wt of C = 12 & CO_2 is 44, So Molar ratio = 44/12 = 3.6

One ton of Microlgal Biomass would be generated by capturing 1.8 ton of CO_2

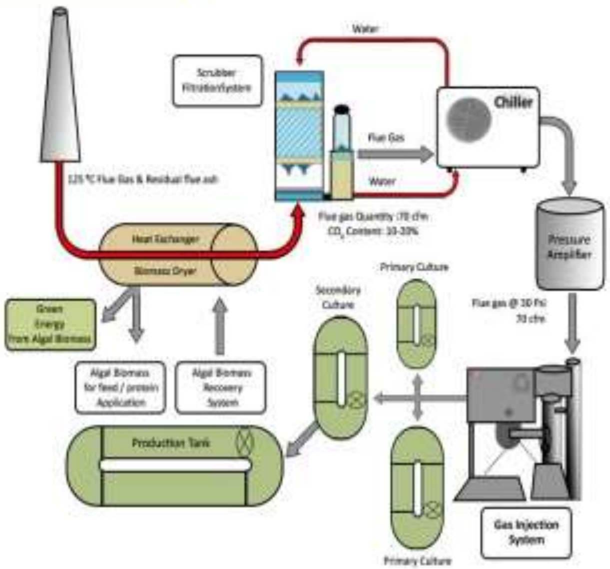
(National Forest Assessments, Food and Agriculture Organization of United Nations) http://www.fao.org/forestry/17111/en/

Concept Implementation

PILOT-CUM-DEMONSTRATION PROJECT FOR CARBON DIOXIDE SEQUESTRATION BY ALGAE

FLOW DIAGRAM FOR MICROALGAE PRODUCTION FROM FLUE GAS

THERMAL POWER PLANT



OBJECTIVE:

CO_2 Sequestration	:	32 TON/ACRE/YR
Algal Biomass Production	:	20 TON/ACRE/YR

SALIENT FEATURES OF THE PROJECT:

A. CO_2 is selectively separated from the flue gas by Biotechnological process

B. CO_2 will expedite growth of algae in pond water and inturn sequester in biomass

C. Algal biomass so produced can be utilized as biofuel, biofertilizer or high protein feed applications etc.

D. This is a unique step for sustainable GHG emission reduction and revenue earning in terms of Carbon credit under CDM.

REQUIREMENT:

1. LAND	:	0.18 ACRE
2. WATER	:	200 KL
3. POWER	:	40 kw
4. FUND	:	₹ 94 LAKHS

Volume of carbon sequestered through this process is 100 times the volume that is sequestered by a pine plantation of the same area

Zero Date: **3rd November 2010** Target Date of Completion: **30th April 2012**

CAPATIVE POWER PLANT

नालको NALCO

Technology & Consultancy by: **M/s INDOCAN TECHNOLOGY SOLUTIONS**

INDOCAN Technology Solutions

UNDER THE GUIDANCE OF STATE POLLUTION CONTROL BOARD (SPCB), ODISHA

Foundation stone laid by Sri Siddhanta Das, IFS Member Secretary, SPCB, ODISHA, in the presence of Sri AK Sharma, Director (Prod), NALCO On 21st March' 2011

Global data base of CO2 utilization projects

(Source: Global CCS Institute, Australia)

Contd.-

Name	Location	Industry	Status	Type of Utilisation	Summary	Full Details
AES Shady Point & Warrior Run CO2 Recovery Plants	United States	Power Generation	Operating	Food & beverage	Summary	Members
Alcoa Kwinana Carbonation Plant	Australia	Fertiliser Production	Operating	Residue carbonation	Summary	Members
Chongqing Hechuan Shuanghuai Power Plant CO2 Capture Industrial Demonstration Project	China	Power Generation	Operating	Various	Summary	Members
CO2 Recovery Plants in China	China	Industrial Applications	Operating	Various	Summary	Members
CO2 Utilisation Plants using the Fluor Econamine FG Process	Multiple	Industrial Applications	Operating	Various	Summary	Members
CO2 Utilisation Plants using the KM CDR Process®	Multiple	Industrial Applications	Operating	Various	Summary	Members
CO2 Utilisation Plants – Europe	Europe	Industrial Applications	Operating	Various	Summary	Members
CO2 Utilisation Plants – North America	Multiple	Industrial Applications	Operating	Various	Summary	Members
CO2 Utilisation Plants – Oceania Region	Multiple	Industrial Applications and Power Generation	Operating	Various	Summary	Members
Huaneng Gaobeidian Power Plant Carbon Capture Pilot Project	China	Power Generation	Operating	Food & beverage	Summary	Members

Tuticorn CCUS Plant, India

- **A breakthrough in the race to make useful products out of our planet-heating CO2 emissions has been made in southern India.**

- **A plant at the industrial port of Tuticorin is capturing CO2 from its own coal-powered boiler and using it to make baking soda.**

- **Crucially, the technology is running without subsidy, which is a major advance for carbon capture technology as for decades it has languished under high costs and lukewarm government support.**

- **The firm behind the Tuticorin process says its chemicals will lock up 60,000 tonnes of CO2 a year and the technology is attracting interest from around the world**

Concepts of Germi, Gujarat and Colorado School of Mines, Golden, USA planned Bio-CCUS project

- Project will target the application of micro-algae to sequester CO_2 released from coal based thermal power plants.The mechanism is based on the ability of micro-algae to capture CO_2 through photosynthesis during sunlight and artificial light.

- The flue gas is gathered at the exhaust point and after scrubbing, transported to the algal harvesting tanks / photo -bioreactors for biomass production. The key factors are: Bio-strain selection; optimization of culture conditions and physiological parameters; design and construction of photo-bioreactors and modeling of experimental parameters for a pilot scale project using solar energy.

- Germi have a working prototype to investigate the efficiency of different micro-algal strains such as Chlorella pyrenoidosa (NCIM 2738), Spirulina platensis (NCIM 5143), Scenedesmus sps. (TAP4) and K4 to sequester CO_2.

Project work plan

- **Isolation, screening and evaluation of naturally occurring photosynthetic micro-algae strains that exhibit high growth rate and high resistance with CO_2.**

- **Optimization of parameters for the enhancement of algal growth along with CO_2 sequestration through selected strain.**

- **Design and construction of photo bioreactors for micro algae harvesting**
- **using optimized laboratory and field parameters.**

- **By product utility assessment and commercialization of project.**
-

-

Challenges & Development Direction

¶Achievement of higher photosynthetic efficiencies for a commercial realization of carbon capture using algal growth.

· Meeting of challenges for micro- algal growth in reference to sensitivity of flue gas components and finding types of right scrubber,which can help in removing the H_2S, SO_2 and NO_2 gases for effective CO_2 sequestration and good biomass yield.

· Design and development of a thermal power station for the meeting the energy requirement for microbial growth

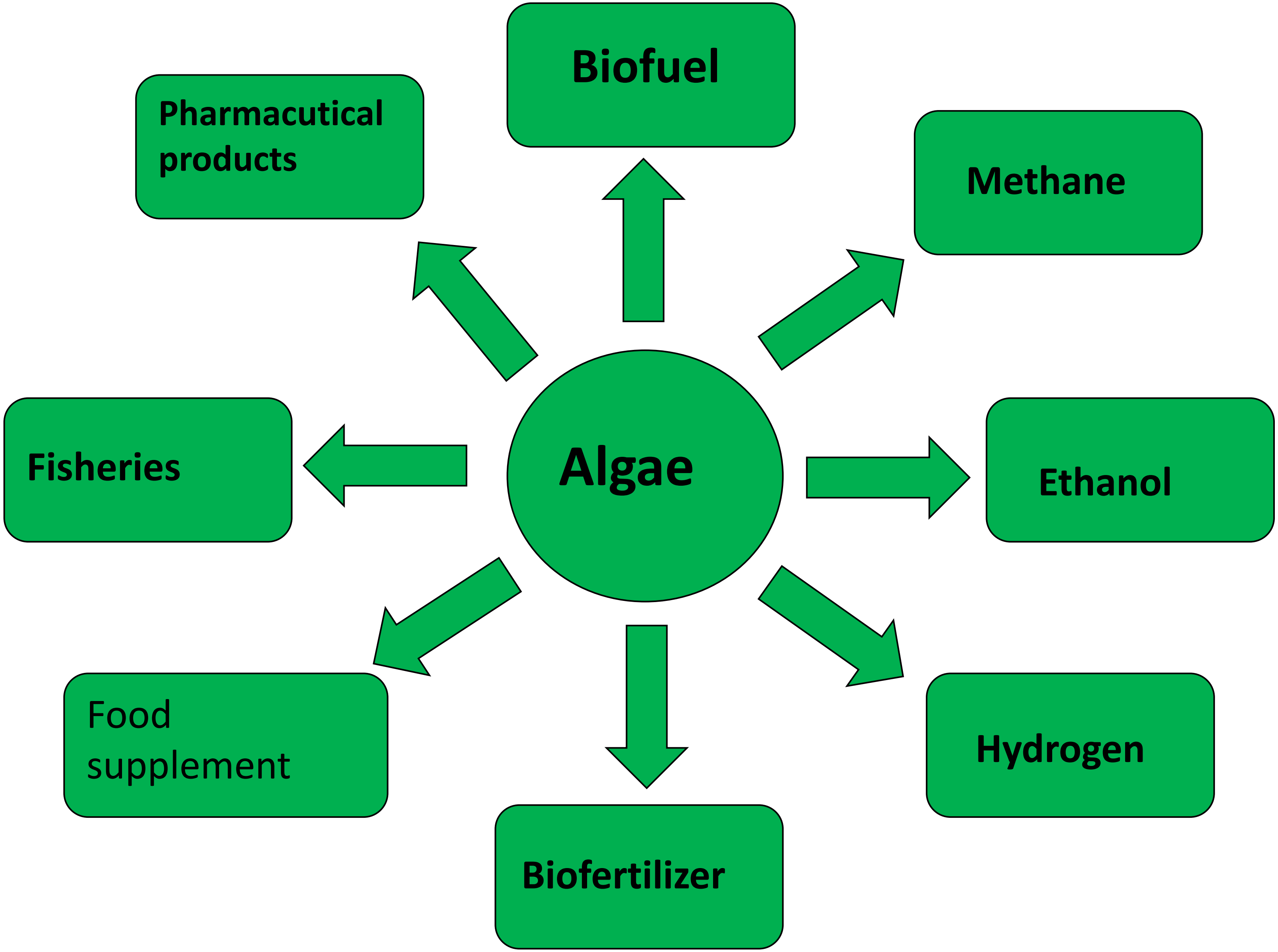
· Volumetric productivity of bio-mass ; need to handle quantities of water for harvesting; energy cost and carbon foot print of dewatering; strain selection; adaptation and process engineering; use of extremophilic algae; breeding or genetic engineering to improve photosynthetic efficiency etc.

100-200 Kg. of CO2 per day for laboratoty scale project and 1-2 tons of CO2 per day for one unit of a commercial scale project, the capacity can be enhanced by putting a series of units depending upon the land availability
8 – 12 hours using microalgae (continous phase)

Algal cultivation in horozontal Glass tubular column

Algal cultivation using CO_2 in vertical Glass Containers

Algal cultivation using Race way ponds



Wide Applications of Algae

Bio- CCUS Versus Geological Storage

Bio- CCUS	Geological Storage
Sustainable	Social problems
Safe	May be unsafe in longer terms
No need to transport CO2	Need to transport CO2 to sequestration site
Generates biomass	No additional revenue expected
Coupled with wastewater treatment	Coupled with oil recovery
carbon credit + nutrient credit + biomass	carbon credit ?

New Ideas for CO_2 Sequestration

- Developing Crops that don't Need Replanting:

Before agriculture, most of the planet was covered with plants that lived year after year. These perennials were gradually replaced by food crops that have to be replanted every year. Now scientist are contemplating reversing this shift by creating perennial version of familiar crops such as corn and wheat (Ed Buckler, Plant geneticist, Cornell University, USA). If they are successful, yield on farmland could soar and plants might also soak up excess carbon on the earth. Converting about 2-5% world annual crops to perennial could remove enough carbon to halt the increase in atmospheric CO_2.

- Soil Productivity ?

Conclusions

- **India have taken initiatives to develop R&D projects for Carbon Capture and Storage (CCS) and mostly CSIR, DST & ONGC have taken the lead. However to meet the challenges of climate change, increasing energy demand, and sustainability an integrated research and development Institute for " CCUS" need to be established by Government/Public/Private partnership and International collaboration.**
- **Geological storage at present is not the viable option for integrating fossil fuel / coal based power generation with CCS, as we have very little R& D data base on the storage potential of geological formations of India. Further, there are no pipe lines for transporting CO2 from power plants to storage sites.**
- **Bio- CCUS/ seems to be the best and safe alternative for India.**

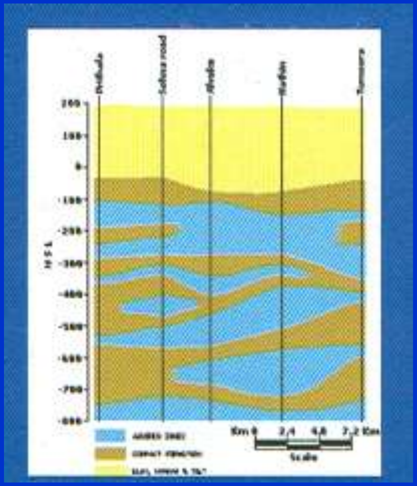
Thank You

CO_2 Storage in Deep Saline Aquifers

- Saline aquifers at depths of ≥ 800 m provide a suitable alternative for the storage of CO_2.
- The high porosity and permeability of the aquifer sands along with low porosity cap rocks such as shales provide favorable conditions for CO_2 storage.
- The CO_2 can be stored in the miscible and/or mineral phase.
- With time, CO_2 gets dissolved in the brines and reacts with the pore fluids/minerals to form geologically stable carbonates.

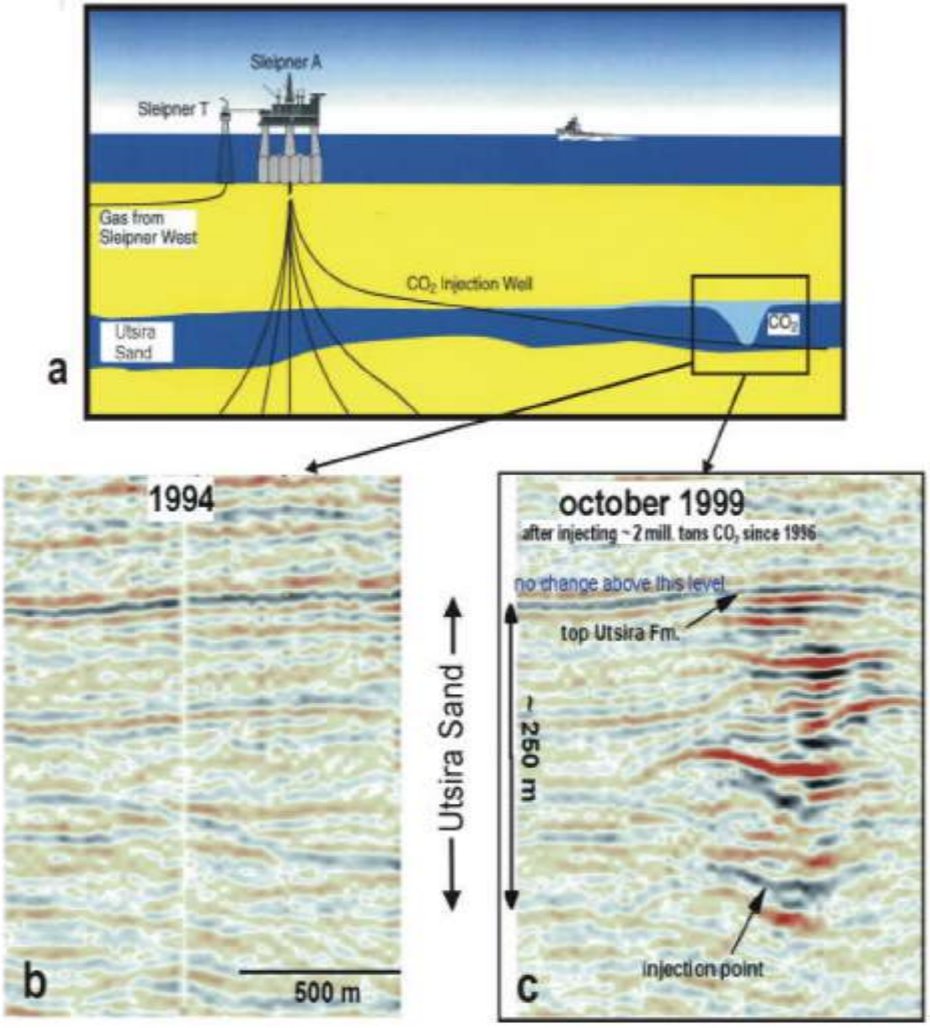
Studies in India

- The Department of Science & Technology , India has initiated studies aiming at identification of deep underground saline aquifers and their suitability for CO_2 sequestration in Sedimentary basins of India namely Ganga, Rajasthan and Vindhyan basins.
- The Central Ground Water Board and Geological Survey of India have established the presence of saline aquifers up to depths of ≥ 300m below ground level in the Ganga basin.
- Deep Resistivity studies carried out at 9 sites around New Delhi have shown the presence of saline aquifers at depths of 800m and beyond, around Palwal and Tumsara.



Storage of CO_2 in Saline Aquifer (Sleipner Project)

- Utsira Aquifer is located 800 m below the bed in the North Sea.
- ~I million tonnes of CO_2 injected per year since 1996
- CO_2 separated from Natural Gas produced from Sleipner West is injected in the Utsira aquifer



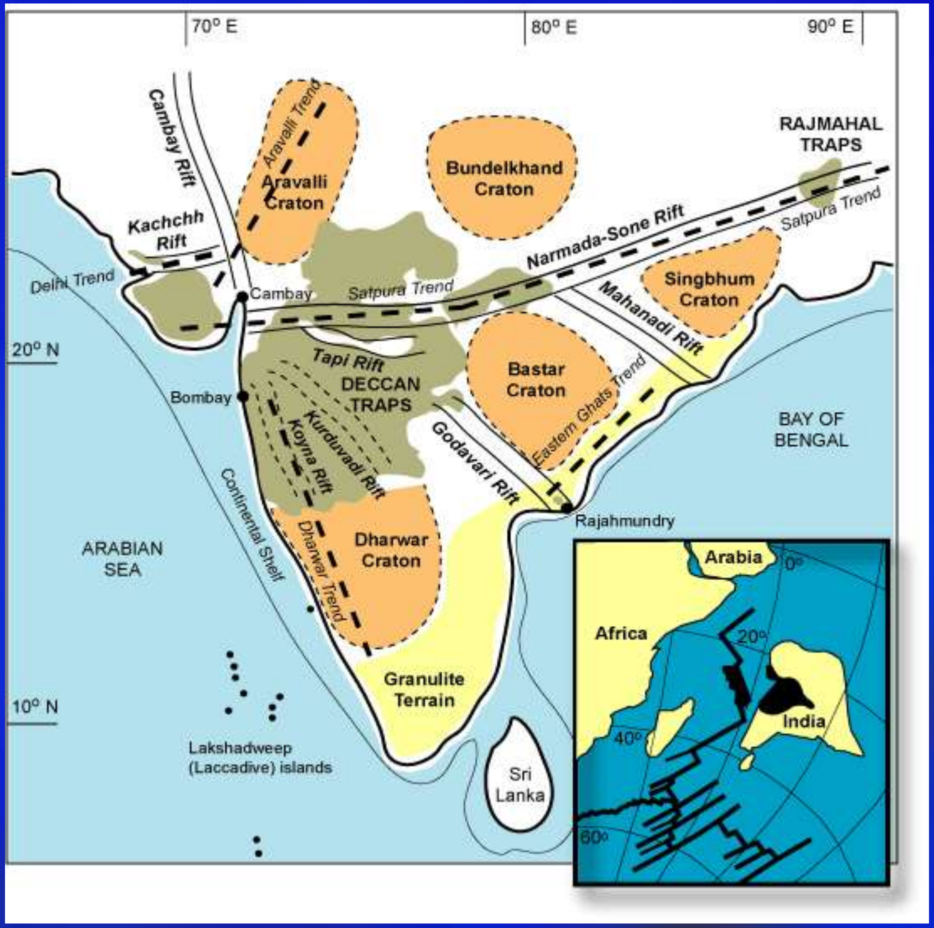
Seismic reflection data prior to sequestration

After 2 million tonnes of CO_2 injection showing amplitudes of high reflection corresponding to CO_2 saturated rocks.

Characteristics of the Utsira Sand

- Mio-Pliocene age.
- High porosity sand (21-37%) capped with low porosity shale.
- Estimated to be capable of storing 600,000 MT of CO_2 .

Why Basalts are attractive proposition for CO_2 storage?

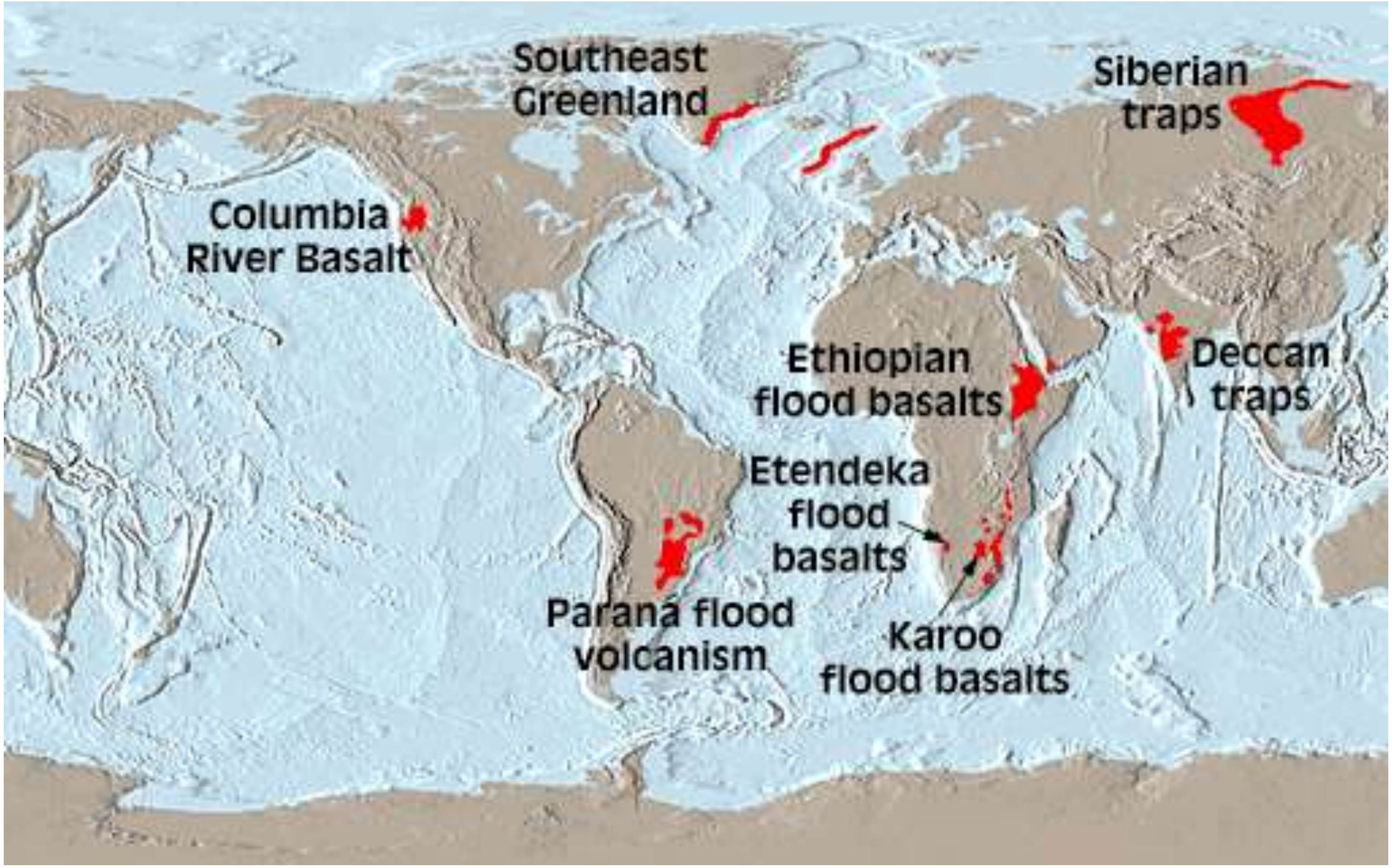


- Deccan Basalts cover an area of 500x10^3 sq. km. and form one of the largest flood eruptions in the world.
- Composed of typically 48 flows.
- The thickness of basalts varies from few hundreds of meters to > 1.5 km.
- Basalts provide solid cap rocks and thus high level of integrity for CO_2 storage.
- Basalts react with CO_2 and convert the CO_2 into the mineral carbonates that means high level of security.
- Intertrappeans between basalt flows provide major porosity and permeability along with vescicular, brecciated zones with in the flows.
- Tectonically the traps are considered to be stable.
- Geophysical studies have revealed presence of thick Mesozoic and Gondwana sediments below the Deccan Traps.

Deccan basalts vs Columbia River basalts

- The most common flow type of the Deccan Trap and Columbia River Basalt is the Pahoeho sheet flows. Due to the lesser viscosity and less strain it forms large horizontal sheets.
- Both Deccan Flood Basalts and Columbia River Basalts are tholeiitic (cinopyroxene and plagioclase) in nature and the eruptions are of fissure type.
- Both are continental basalts. Columbia River Basalt is fully continental and Deccan Traps are partly continental.
- Both the basaltic flows have traveled as much as 300 to 500 km from their sources.
- Chemical composition of both the basalts are similar .

	Deccan Basalt	Sentinel Bluff Basal - USA
SiO_2	59.07	54.35
Al_2O_3	15.22	14.27
FeO	6.45	12.39
CaO	6.10	7.43
MgO	3.45	3.13
Na_2O	3.71	2.82
K_2O	3.11	1.46
P_2O_5	0.30	0.35
TiO_2	1.03	2.09
MnO	0.11	0.21



Major Flood Basalt Provinces			
Name	Volume	Age	Locality
CRB	(1.7×10^5 km^3)	Miocene	NW US
Keeweenawan	(4×10^5 km^3)	Precambrian	Superior area
Deccan	(10^6 km^3)	Cret.-Eocene	India
Parana	(area > 10^6 km^2)	early Cret.	Brazil
Karroo	(2×10^6 km^3?)	early Jurassic	S. Africa

CO_2 Storage in Basalt Formations

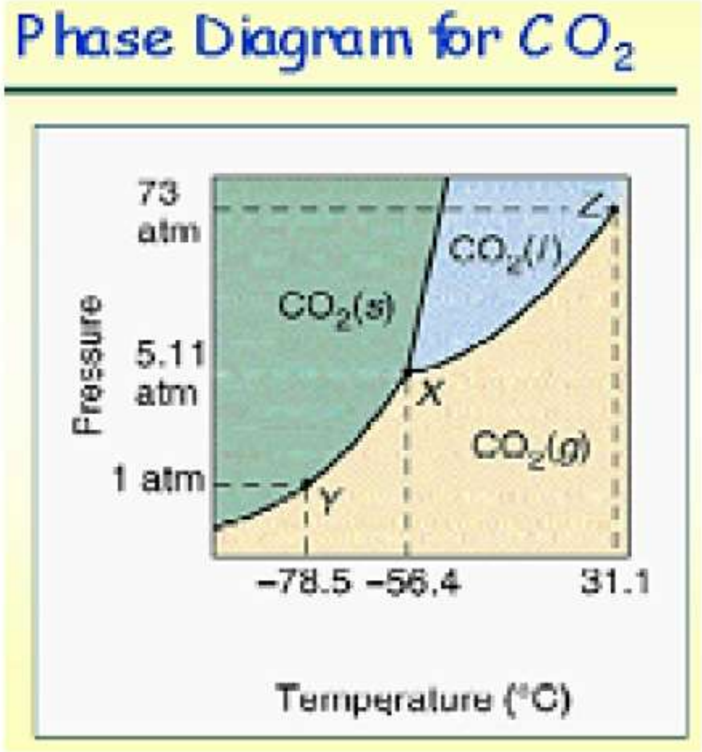
CO_2 is injected in basalt formations above its critical temperature and pressure

↓

Minimum depth 800 m

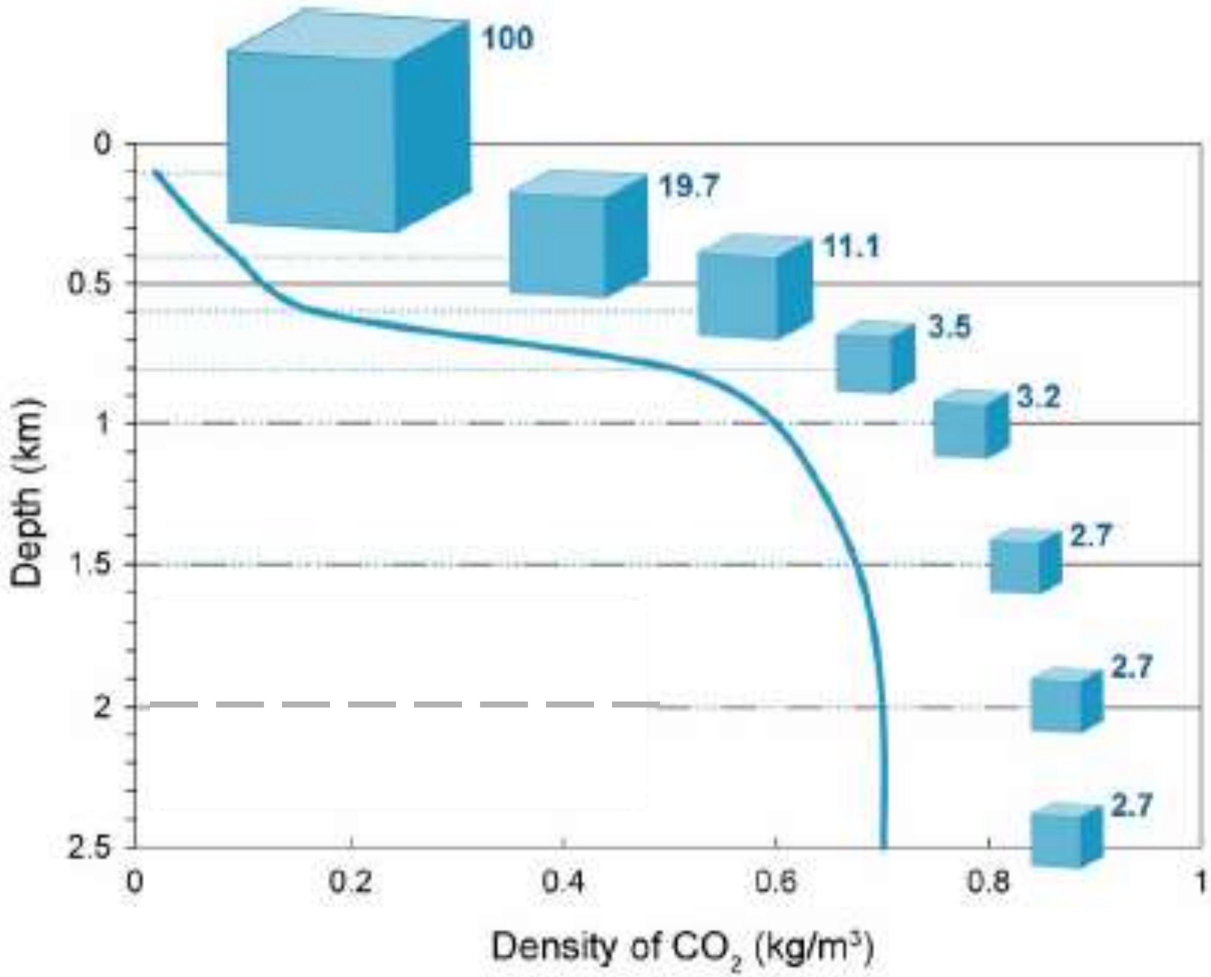
↓

Hydrodynamic Trapping | Solubility Trapping | Mineralisation



Supercritical CO_2

- Physico – chemical properties between those of liquid and gas.
- Dense gas
- Solubility approaching liquid phase
- Diffusivity approaching gas phase



Variation of CO_2 density with depth, (based on the density data of Angus *et al.*, 1973).
Carbon dioxide density increases rapidly at approximately 800 m depth, when the CO_2 reaches a supercritical state. Cubes represent the relative volume occupied by the CO_2, and down to 800 m, this volume can be seen to dramatically decrease with depth. At depths below 1.5 km, the density and specific volume become nearly constant.

Mineralization reactions in basalt formations

$$CO2(g) \longrightarrow CO2(aq)$$

$$CO2(aq) + H_2O \longrightarrow HCO_3^- + H^+$$

$$(Ca,Mg,Fe)_x\, Si_yO_{x+2y} + 2xH^+ + (2y-x)H_2O \longrightarrow x(Ca,Mg,Fe)^{2+} + yH_4SiO_4(aq)$$

$$(Ca,Mg,Fe)^{2+} + HCO3^- \longrightarrow (Ca,Mg,Fe)CO_3 + H^+$$

Induction Time for Calcite Precipitation

Lab. scale & geo-chemical modeling studies by PNNL, USA

Depth, (m)	T, °C	t_p, d
800	35	964
900	38	822
1000	42	678
1100	48	534
1200	56	397
1300	67	275

Calcite deposition on basalt

- Basalt is rich in Ca, Mg & Fe Silicates
- Mineralisation reaction rate is fast on geological time scale
- Mineralisation is appeared to be controlled by mixing behaviour of CO2 and not by kinetics of the reactions

Seismic Zone Map of India: -2002

About 59 percent of the land area of India is liable to seismic hazard damage

Zone	Intensity
Zone V	Very High Risk Zone Area liable to shaking Intensity IX (and above)
Zone IV	High Risk Zone Intensity VIII
Zone III	Moderate Risk Zone Intensity VII
Zone II	Low Risk Zone VI (and lower)

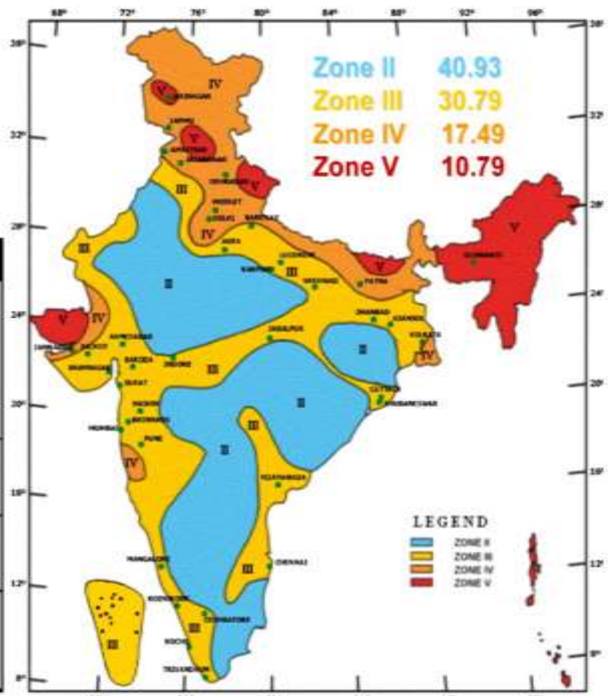


Fig. 1 Seismic zonation and intensity map of India