Recent Advances in Geologic Carbon Storage – Need of Implementation in India

Presented by

Dr. Vinod Atmaram Mendhe

Chief Scientist & HORG/Prof AcSIR

Non-Conventional Gases Group

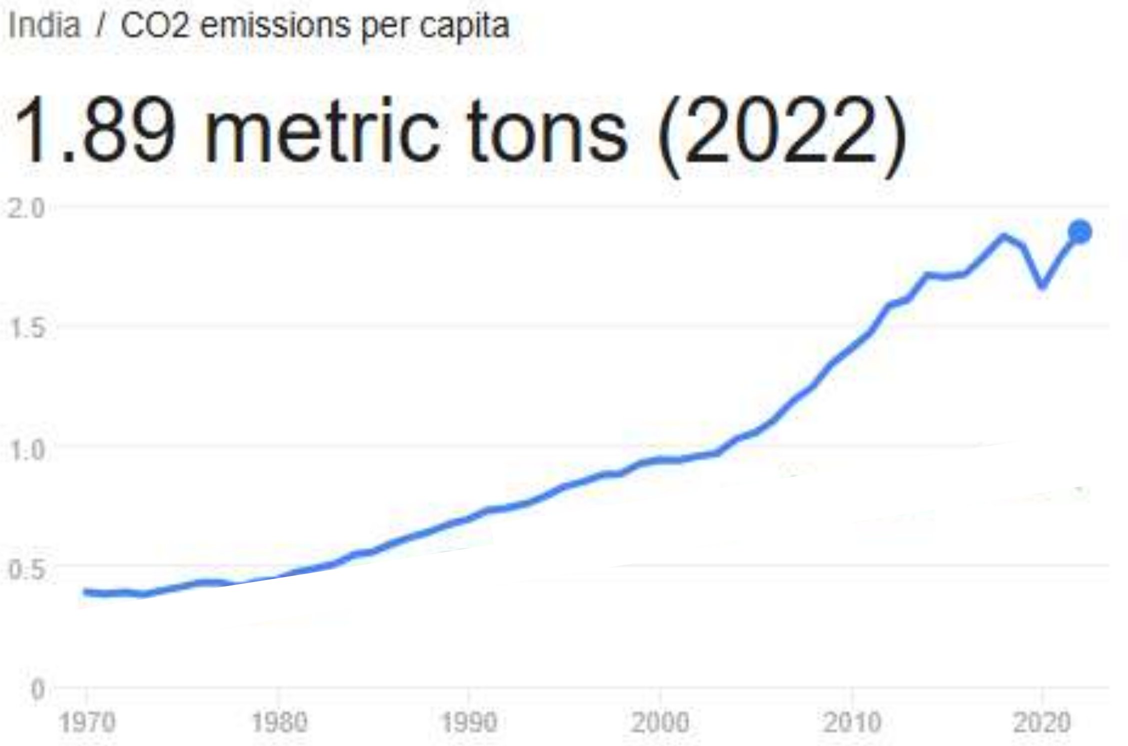
CSIR-CIMFR, Dhanbad, Jharkhand

Email: vamendhe@cimfr.res.in / vamendhe@gmail.com

Research Students: Dr. Sameeksha Mishra, Ms. Sangam Kumari, Ms. Manisha Kumari, Mr. Sayed W. Abrar, Mr. Arnab Bordoloi

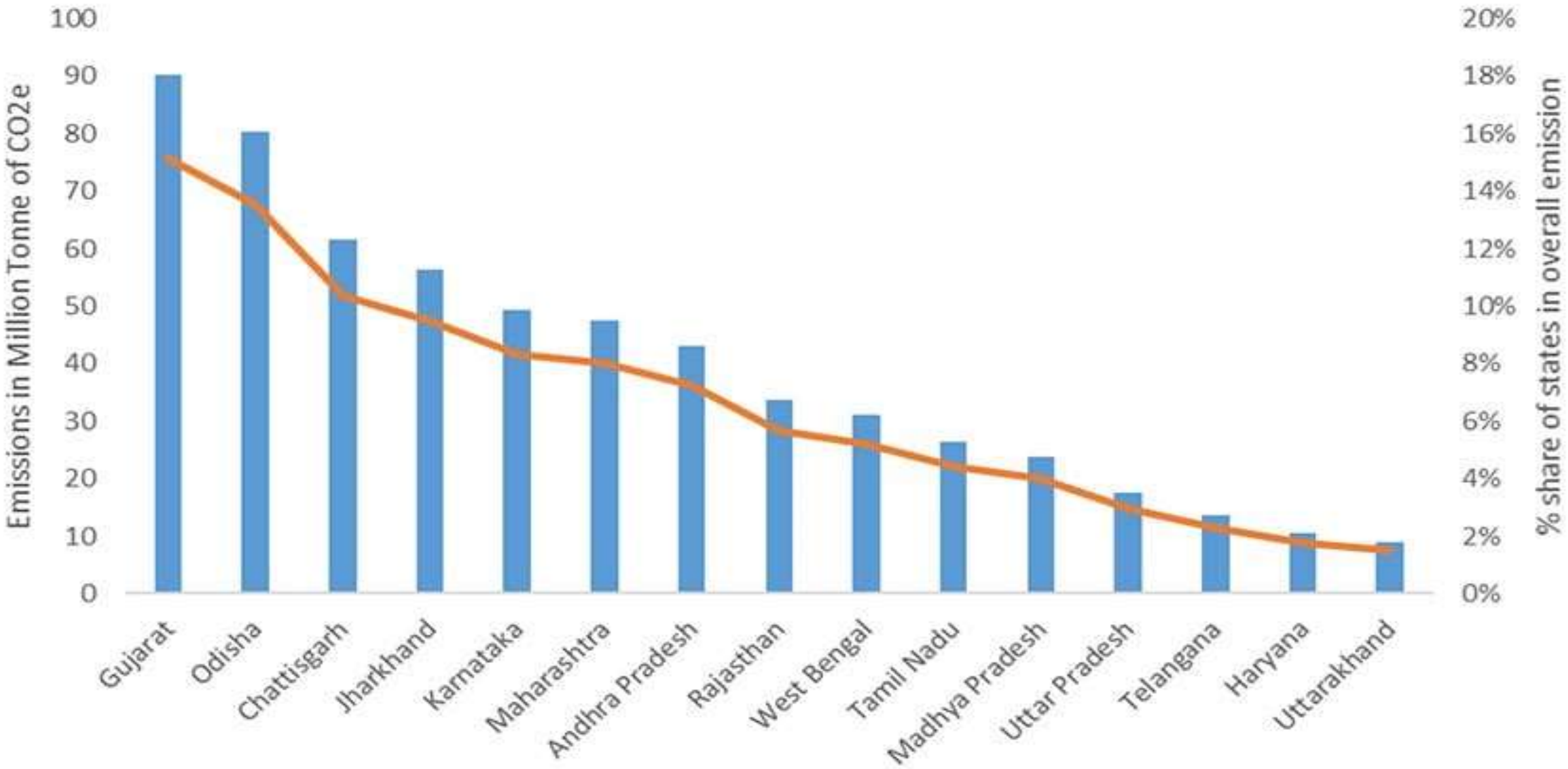
Awareness and Capacity Building Workshop on Carbon Capture, Utilization and Storage (CCUS) Technology, Policy and Regulations: Towards a Net Zero Strategy

CO_2 Emissions in India



Sector	Approximate CO_2 Emissions Share	CO_2 Emissions in Million metric tones
Energy (Power Generation)	42%	1800
Industry	24%	1028.5
Agriculture, Forestry, and Land Use	8%	342.8
Transport	14%	600
Residential & Commercial	4%	171.4
Waste	4%	171.4

Emissions from top 15 states



CO_2 Capturing Status in India

India's existing CO_2 capture capacity is minimal, primarily confined to specific industrial applications:

- **Urea Production**: Approximately 24 million metric tons per annum (mtpa) of CO_2 is captured during ammonia-to-urea conversion processes.
- **Gasification Plants**: Reliance Industries in Jamnagar (10 mtpa) and JSPL in Angul (2 mtpa) capture CO_2 during petcoke and coal gasification, respectively. However, much of this CO_2 is currently released into the atmosphere rather than being utilized or stored.
- **Steel Plant**: Tata Steel in Jamshedpur capturing 5 metric tons per day of CO_2 from blast furnace gases.
- **Power Plant:** NTPC's Vindhyachal Super Thermal Power Station in Madhya Pradesh, has initiated a pilot carbon capture project. This project aims to capture 20 tonnes per day (TPD) of CO_2 and conversion to methanol.

Principles of CO_2 Geo-Storage

i. **CO_2 geo-storage involves capturing CO_2 from emission sources or the atmosphere and isolating it underground to prevent its release.**

ii. **Underground geo-storage is a viable sequestration approach, converting captured CO_2 into liquid form (supercritical) and injecting it deep into geological formations.**

iii. **However, injecting large volumes of high-pressure liquid CO_2 underground carries risks, as it can disrupt the reservoir's mechanical balance.**

iv. **Therefore, careful selection of the precise approach is crucial for effective and safe CO_2 geo-storage.**

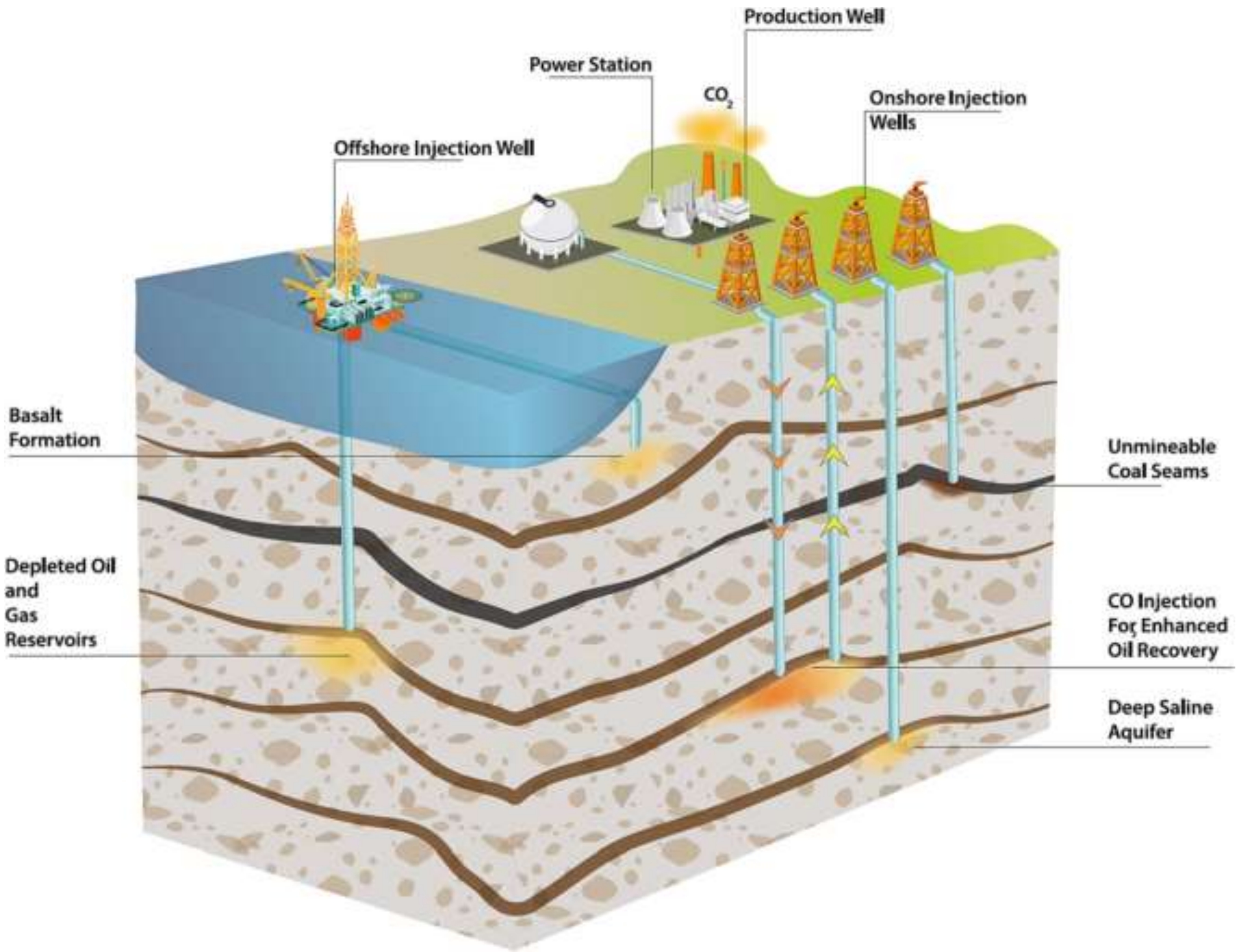
Capture CO_2
From emission sources or atmosphere.

Convert to Liquid
For efficient injection.

Inject Underground
Into suitable geological formations

Secure Isolation
Preventing atmospheric release.

Underground CO_2 Geo-Storage Options



- **Saline Aquifers:**
Porous rocks with saltwater, high storage potential.

- **Depleted Oil/Gas Reservoirs:**
Known geology, existing infrastructure.

- **Unmineable Coal Seams:**
Adsorption trapping, enhanced methane recovery.

- **Basalt Formations:**
Mineral carbonation for stable storage.

- **Hydrate Storage:**
Solid crystalline structures in deep oceans/permafrost.

Technological Advancements in CO_2 Geologic Storage

- High resolution subsurface imaging like use of 3D and 4D seismic surveys for detailed reservoir mapping and monitoring.
- Geochemical kinetic modeling to better understanding of CO_2-rock-brine interactions helps in selecting suitable formations and predicting long-term stability.
- Fiber-optic sensors can be deployed in wells for real-time temperature and pressure monitoring.
- Advancement in in-situ mineralization where CO_2 reacts with formation minerals to form stable carbonates. Pilot projects like CarbFix (Iceland) show successful and rapid mineral trapping of CO_2 in basalt.
- Multi-physics simulators for better prediction of CO_2 behaviour in the subsurface (fluid flow, geochemical reactions, mechanical deformation).
- Sleipner (Norway) and Snøhvit: Long-term offshore saline aquifer storage, Illinois Industrial CCS Project (USA): Injection into deep saline formations. Gorgon Project (Australia): One of the world’s largest CCS operations with lessons on technical and regulatory challenges.

CCUS Advancements in India

i. Government Initiatives and Policy Framework - India is working on a national (CCUS) mission to provide financial incentives. NITI Aayog has proposed a CCUS policy involving industry clusters.

ii. Industrial Collaborations - OIL plans to capture CO_2 emissions from its natural gas field in Rajasthan and store it in nearby dry wells. NTPC has established a facility that captures and converts 20 tonnes of CO_2 to methanol daily.

iii. India's total unconstrained CO_2 storage potential is estimated at 629 gigatonnes (Gt), with 326 Gt in deep saline formations and 316 Gt in basalts.

iv. Oil and Natural Gas Corporation (ONGC) has signed a Memorandum of Understanding (MoU) with Shell to evaluate CCUS opportunities in India. The partnership focuses on joint CO_2 storage studies and enhanced oil recovery assessments in key basins, including depleted oil and gas fields and saline aquifers.

Why CCUS implementation in India

- **Climate Commitments and Net-Zero Target - India has committed to achieving net-zero emissions by 2070 under the Paris Agreement.**
- **CCUS is crucial for decarbonizing hard-to-abate sectors like steel, cement, oil & gas and thermal power plants, where direct emission reductions are difficult.**
- **Coal-Dependent Energy Sector - relies heavily on coal for 70% of its electricity generation.**
- **While renewable energy is growing, coal will continue to play a major role in India's energy mix for the next few decades.**
- **Industrial Decarbonization - Cement, steel, oil refining, and fertilizers are CO_2-intensive and difficult to decarbonize without CCUS.**

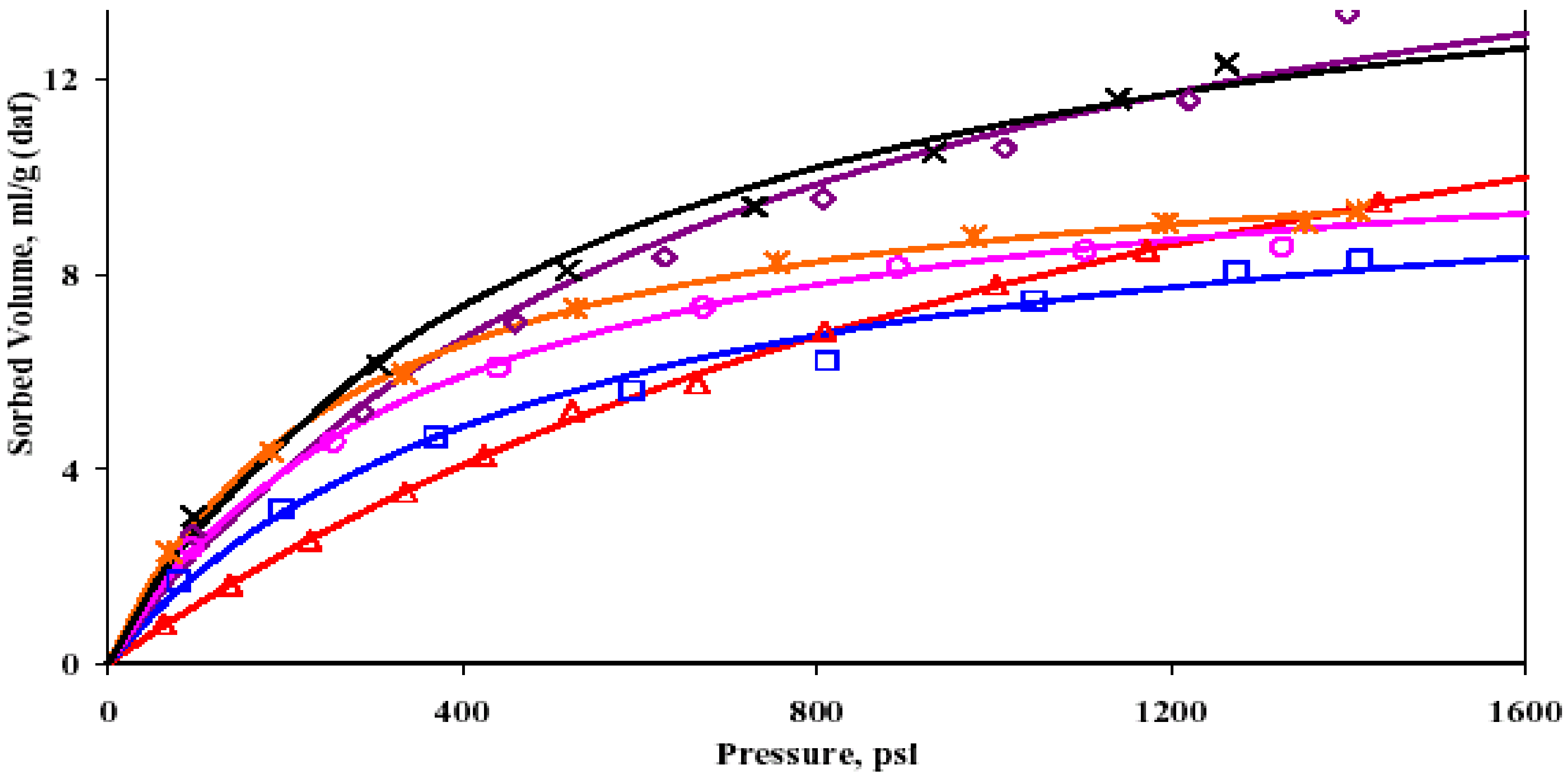
Comparative Adsorption of CO_2 and CH_4

- Studies conducted so far supports stronger affinity of CO_2 to the coal molecule.
- 2 to 3 molecules of CO_2 may displace one molecule of methane
- It means carbon dioxide is preferentially adsorbed onto the coal structure over methane (2:1 ratio).
- Methane sorption capacity for Indian coals has been investigated by CIMFR.
- Understanding controls on CO_2 and CH_4 adsorption in coals is important for the modeling of both CO_2 sequestration and CBM production.

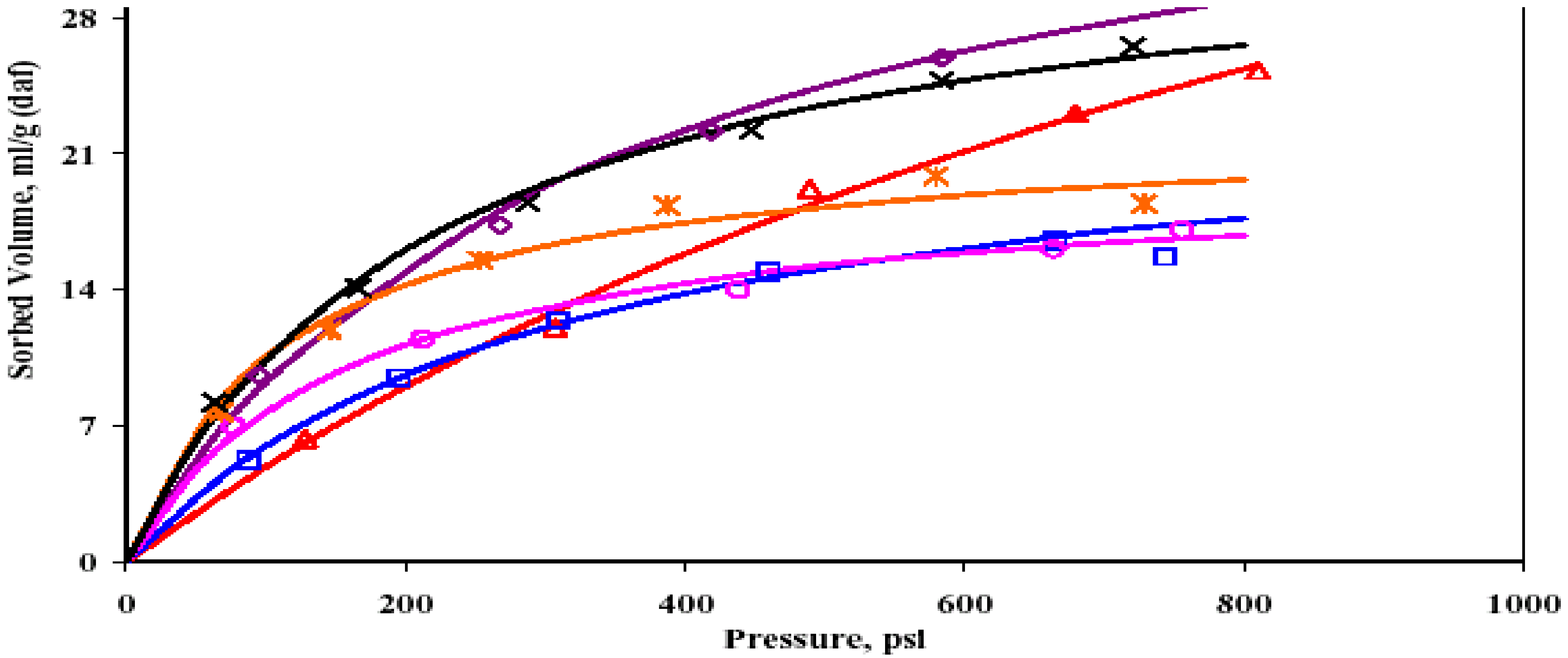
POSSIBLE AREAS FOR DEEPER (>800M) LEVEL COAL RESOURCE

- *Eastern part of Raniganj Coalfield*
- *Western part of Ib-River & Talcher Coalfield*
- *West-central and southern part of Mand-Raigarh Coalfield*
- *Central part of main basin, Singrauli Coalfield*
- *Eastern part of Birbhum-Rajmahal Coalfield*
- *Eastern part of Pench-Kanhan Coalfield*
- *Central part of north Godavari Coalfield*

Methane adsorption

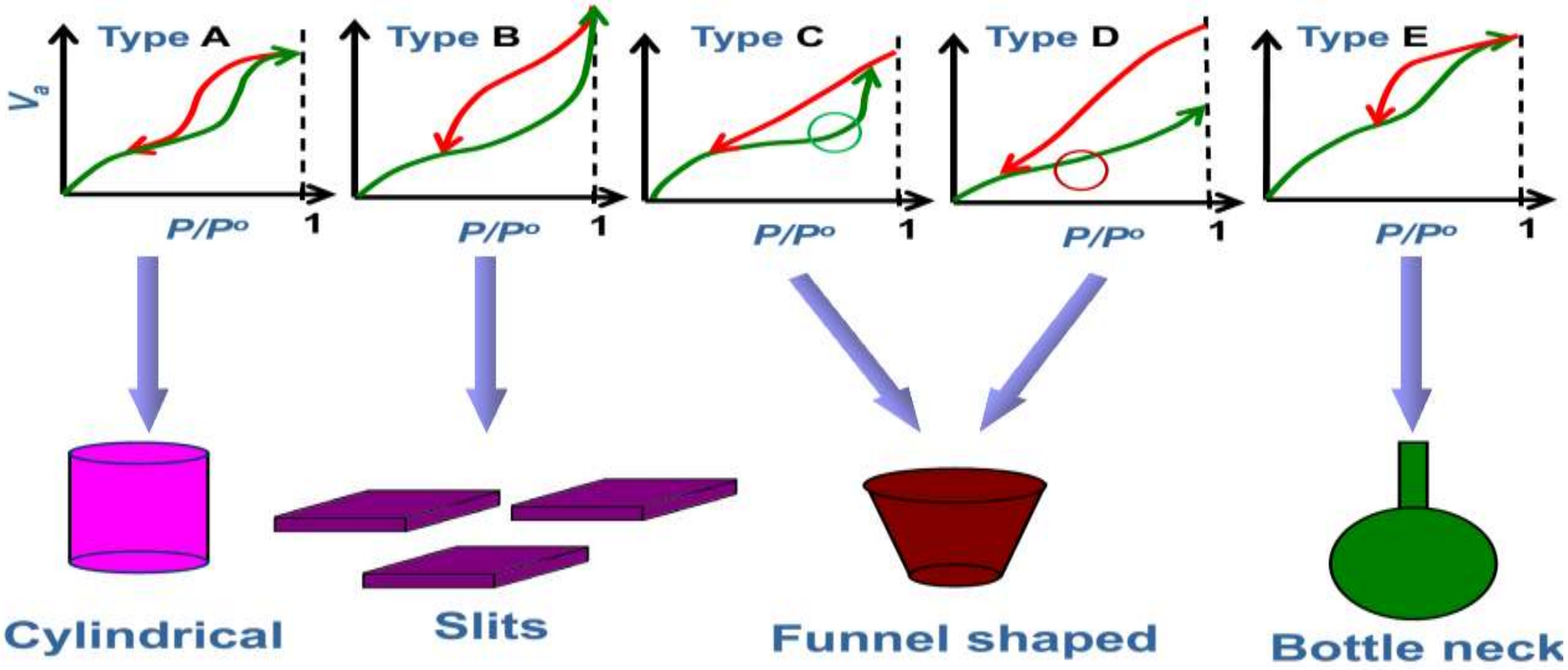


Carbon dioxide adsorption

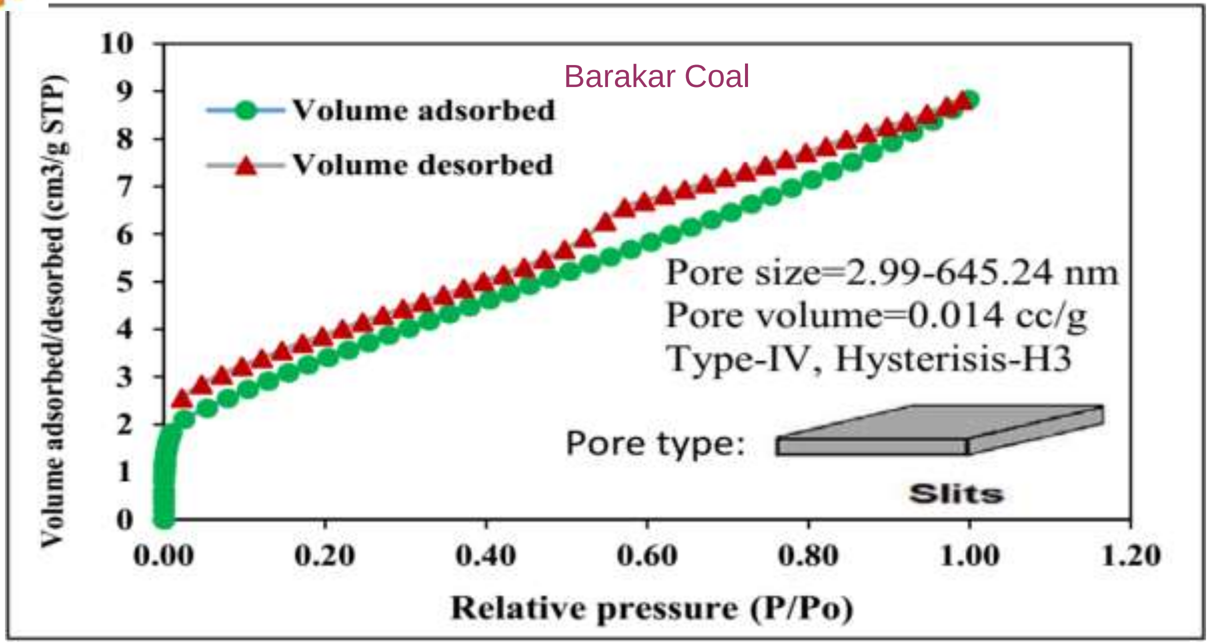


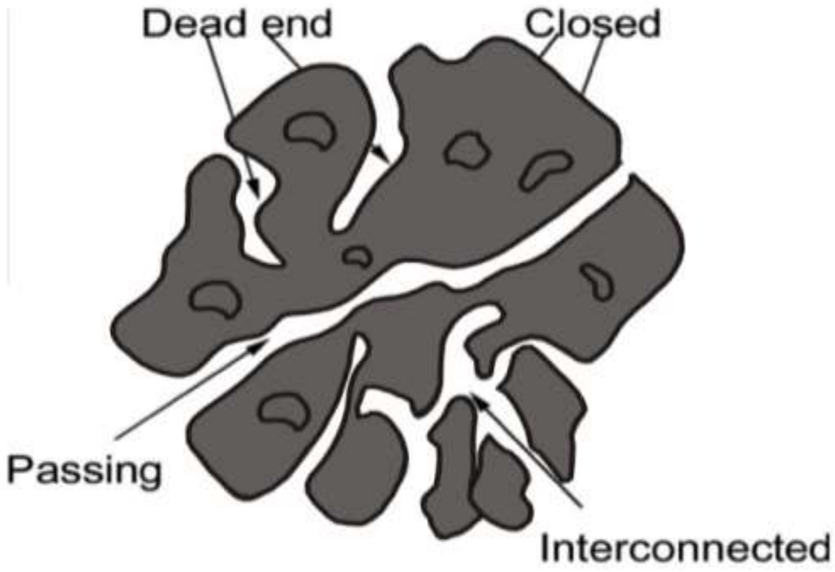
Low Pressure N_2 Sorption Isotherms

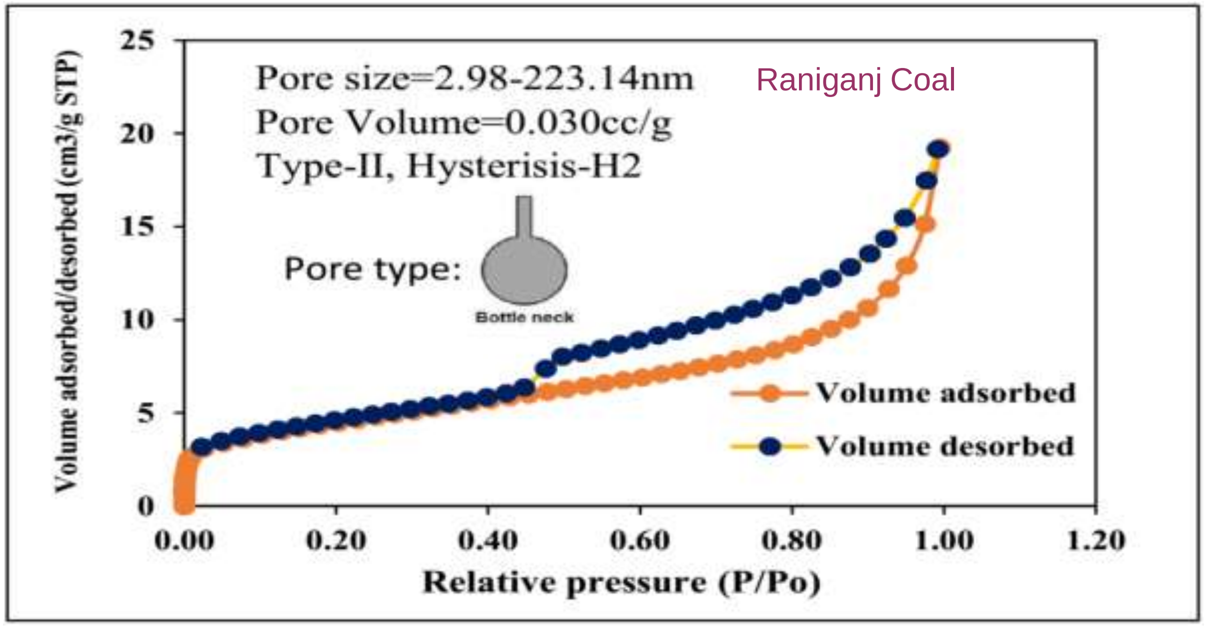
- ❖**Surface Area** – used to estimate the amount of adsorbed gas
- ❖**Pore Size** – micro, meso and macro
- ❖**Pore Volume** – porosity and estimating original gas in place
- ❖Pore Structure – pore geometries

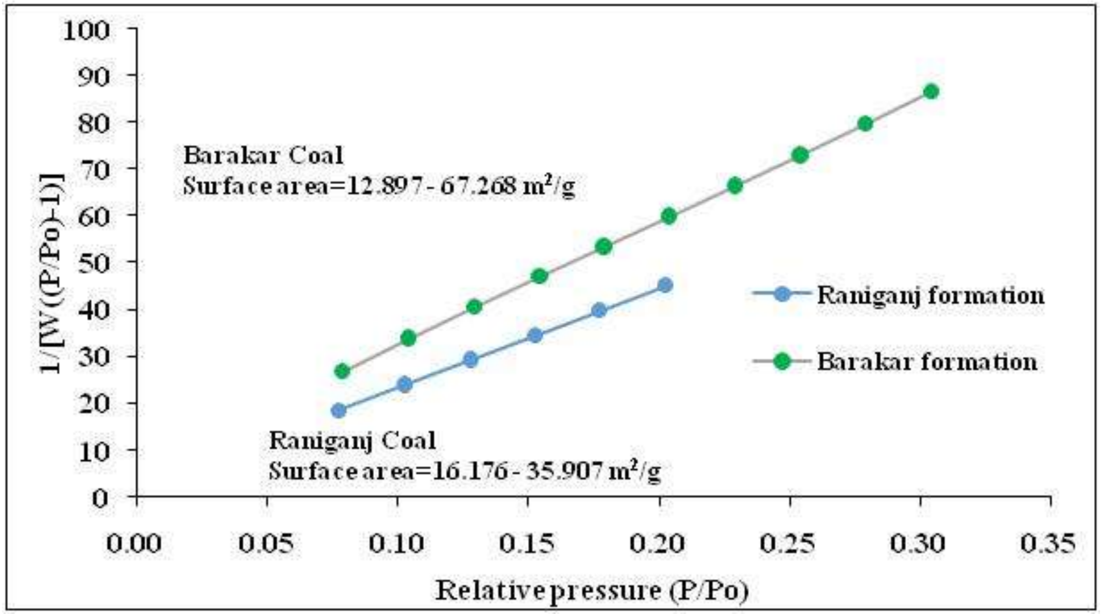


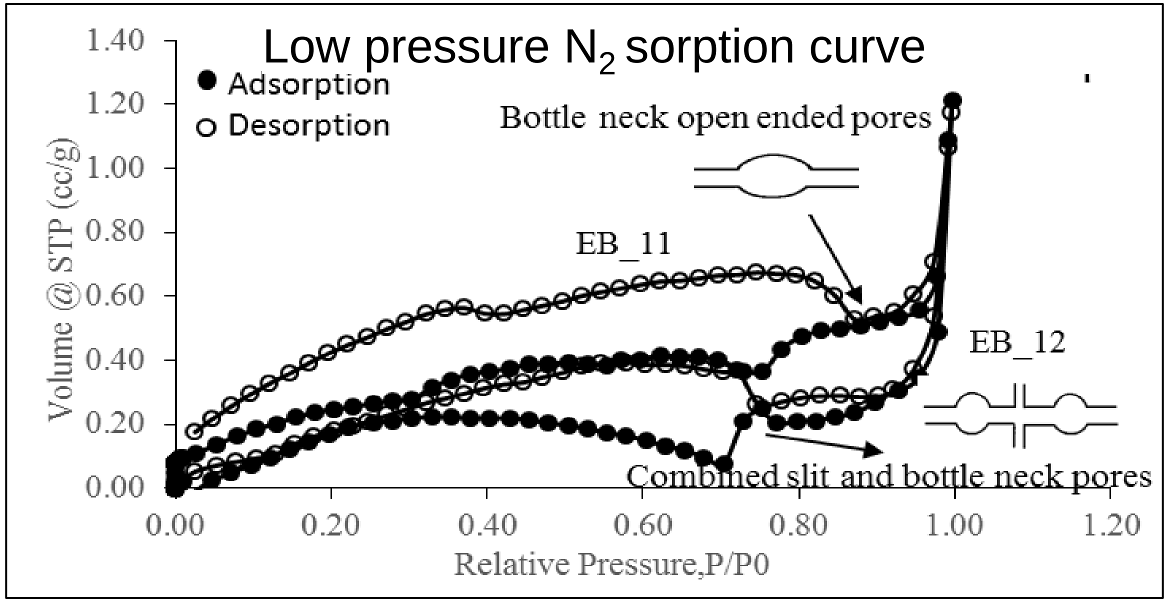
Surface Area and Pore Structure

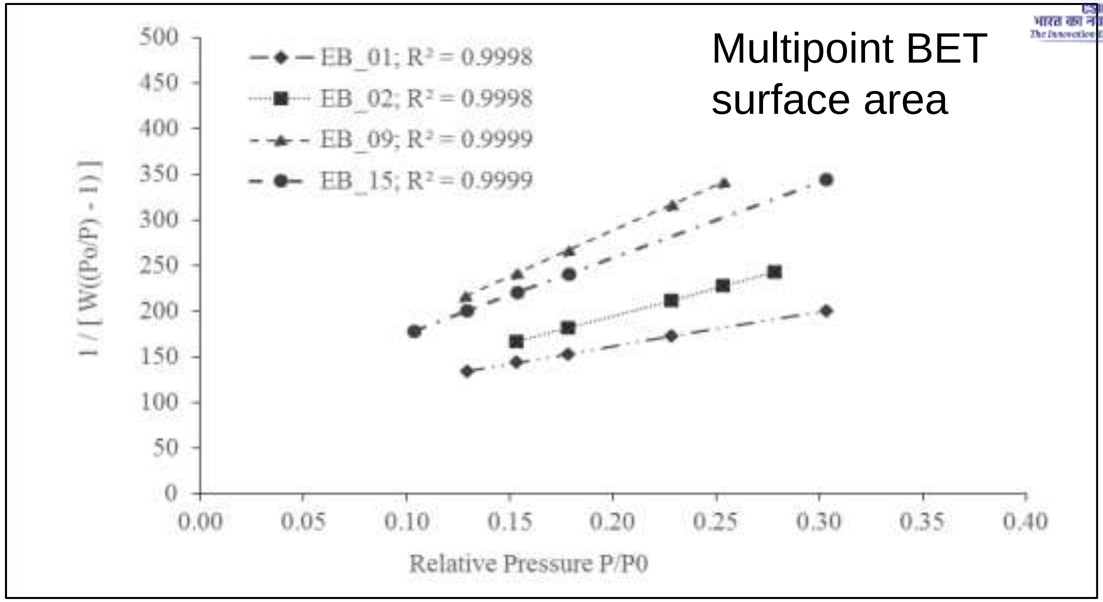


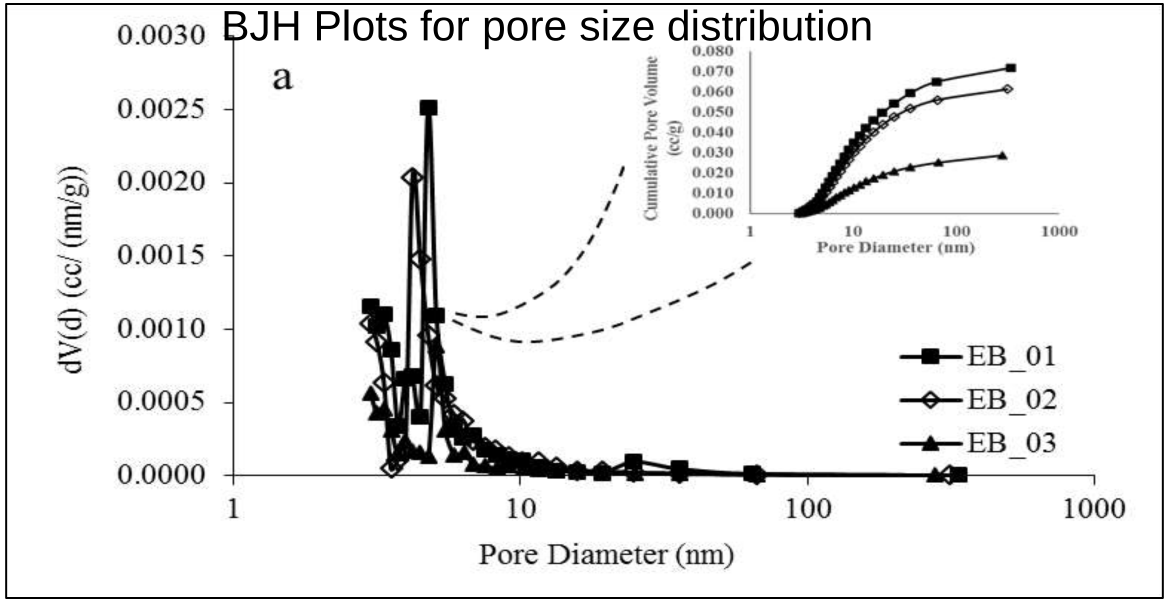


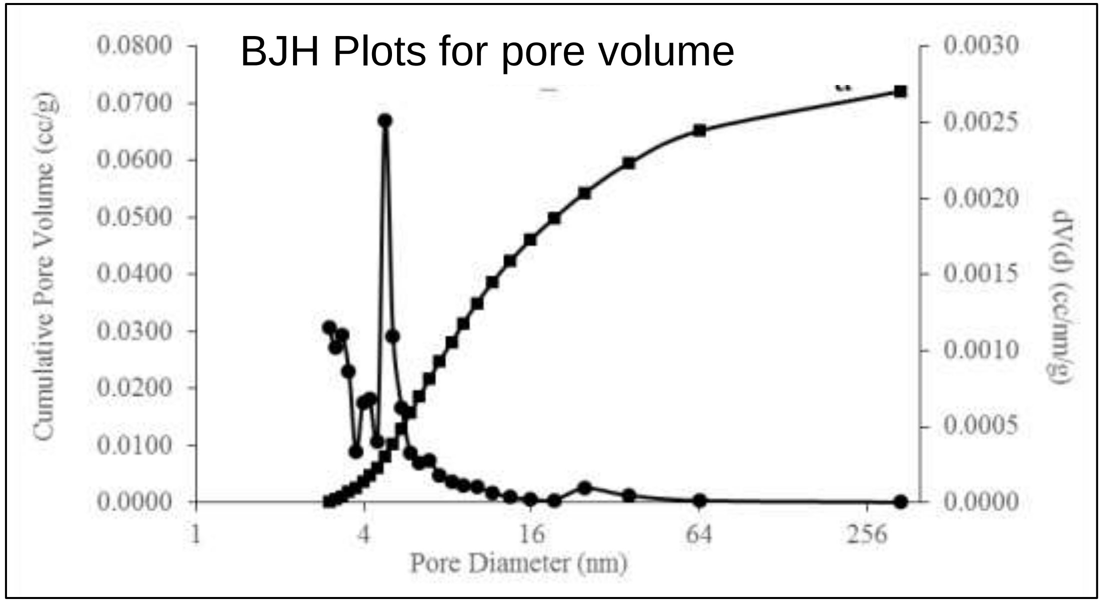




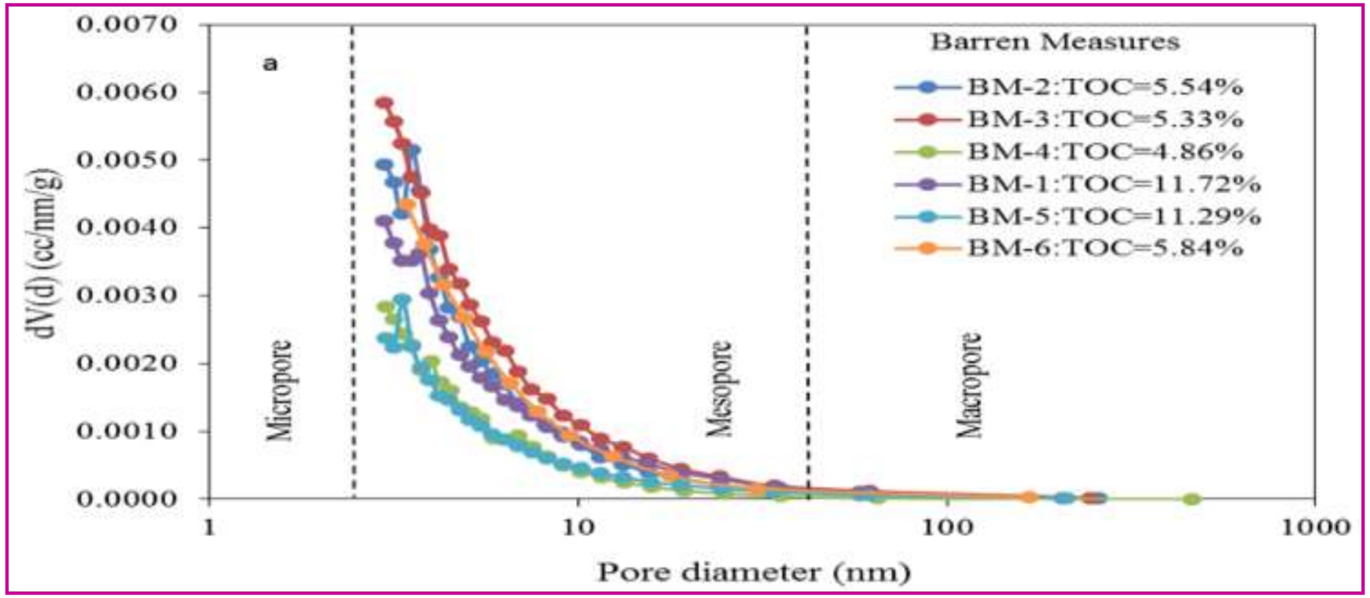

Low pressure N2 sorption curve
Adsorption
Desorption
Bottle neck open ended pores
EB_11
EB_12
Combined slit and bottle neck pores
Volume @ STP (cc/g)
Relative Pressure,P/P0
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20

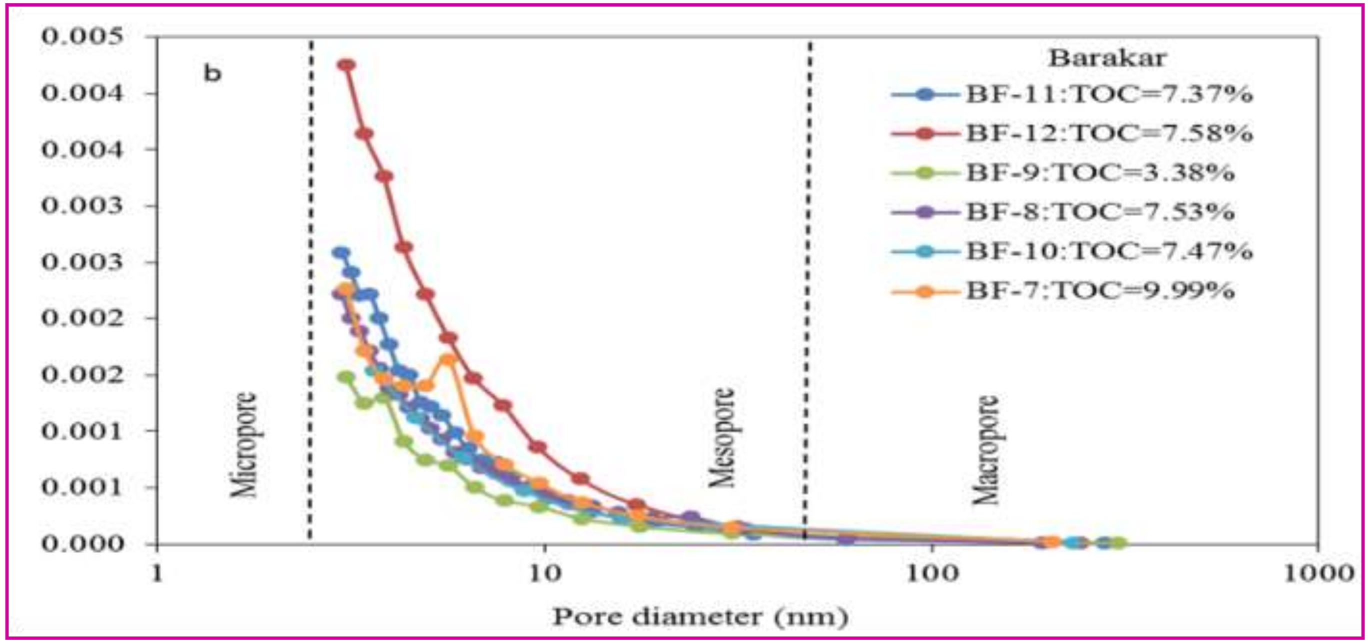

Multipoint BET surface area
EB_01; R² = 0.9998
EB_02; R² = 0.9998
EB_09; R² = 0.9999
EB_15; R² = 0.9999
1 / [W((Po/P) - 1)]
Relative Pressure P/P0
500
450
400
350
300
250
200
150
100
50
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40


BJH Plots for pore size distribution
a
dV(d) (cc/ (nm/g))
Pore Diameter (nm)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
1
10
100
1000
EB_01
EB_02
EB_03
Cumulative Pore Volume (cc/g)
Pore Diameter (nm)
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000

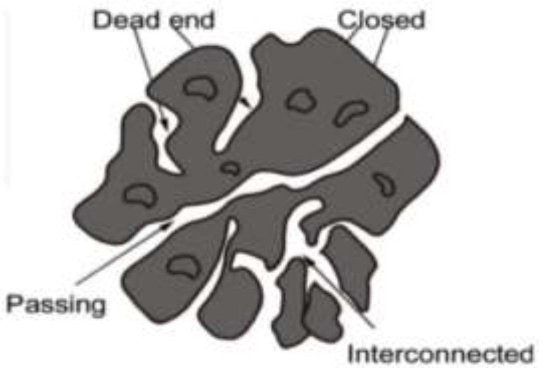

BJH Plots for pore volume
Cumulative Pore Volume (cc/g)
dV(d) (cc/nm/g)
Pore Diameter (nm)
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
1
4
16
64
256

Pore Size Distributions - BJH Method

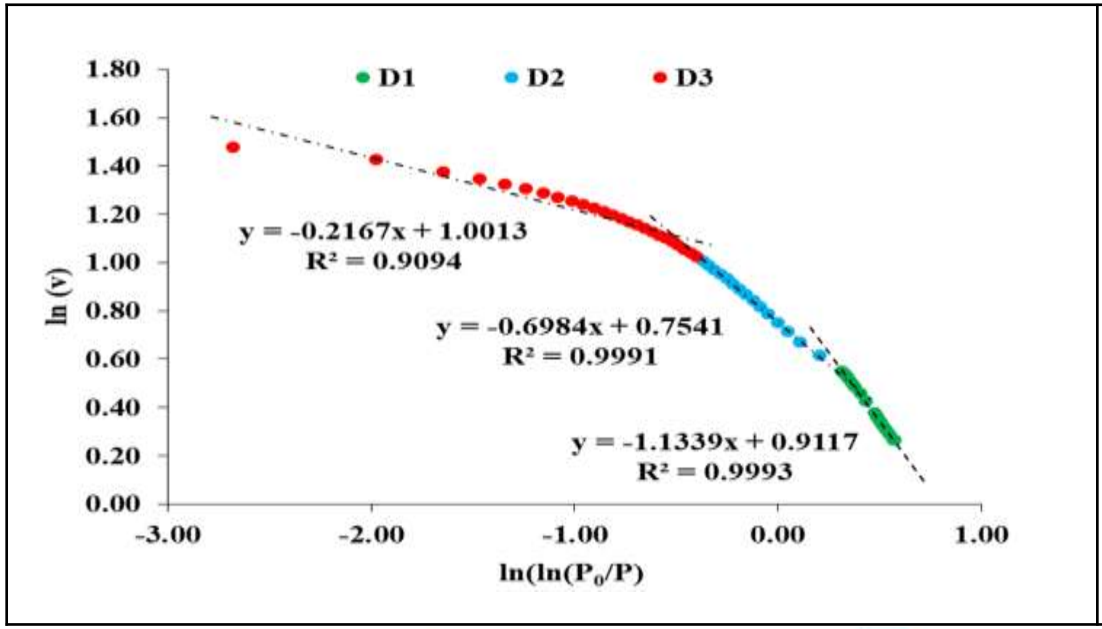


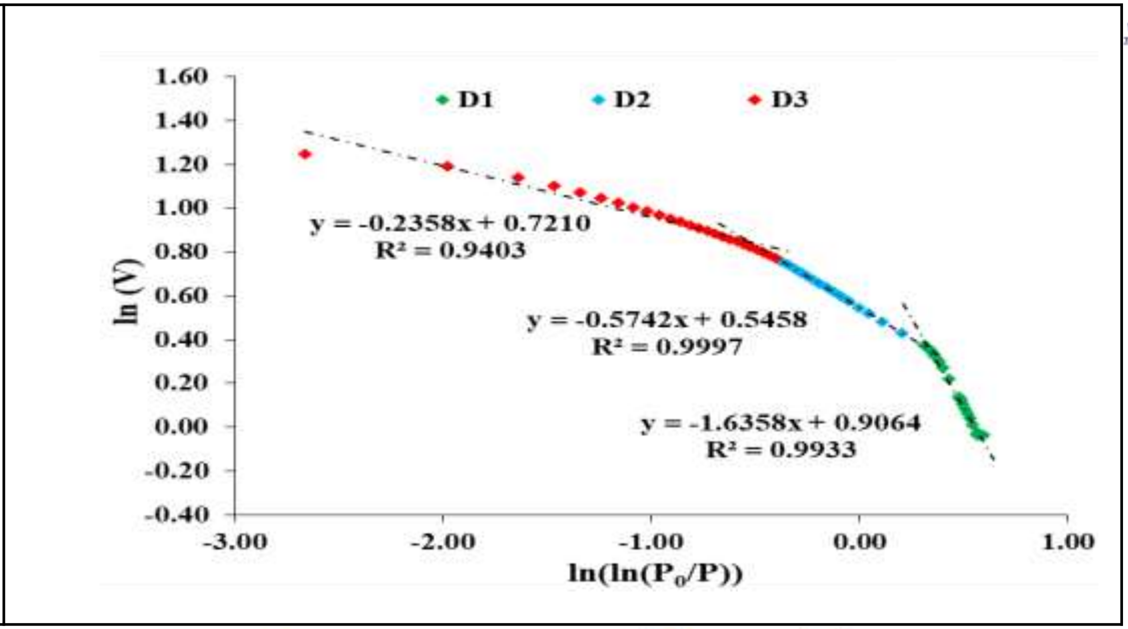


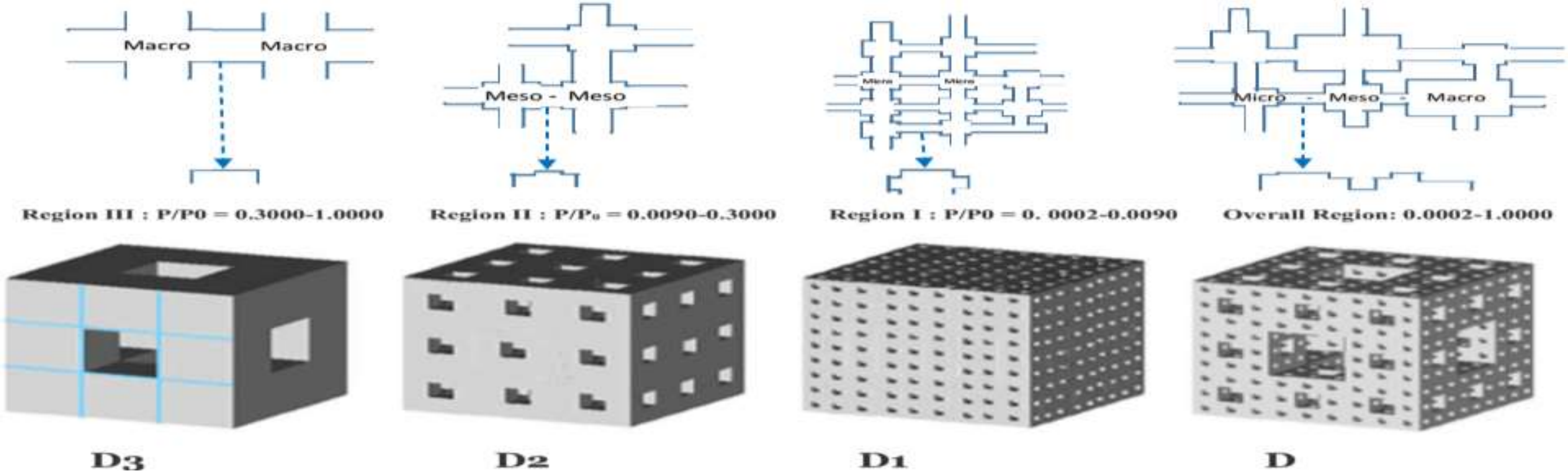
Barren Measures and Barakar shales exhibit porosity range less than 10 nm and the concentrations of pores decrease with the increasing of pore size.



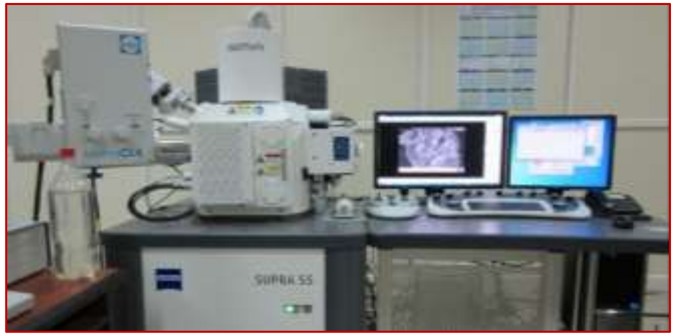
Fractal Characterization of Raniganj Shales







Scanning Electron Microscopy (SEM): Pore Classification – In Indian Shale



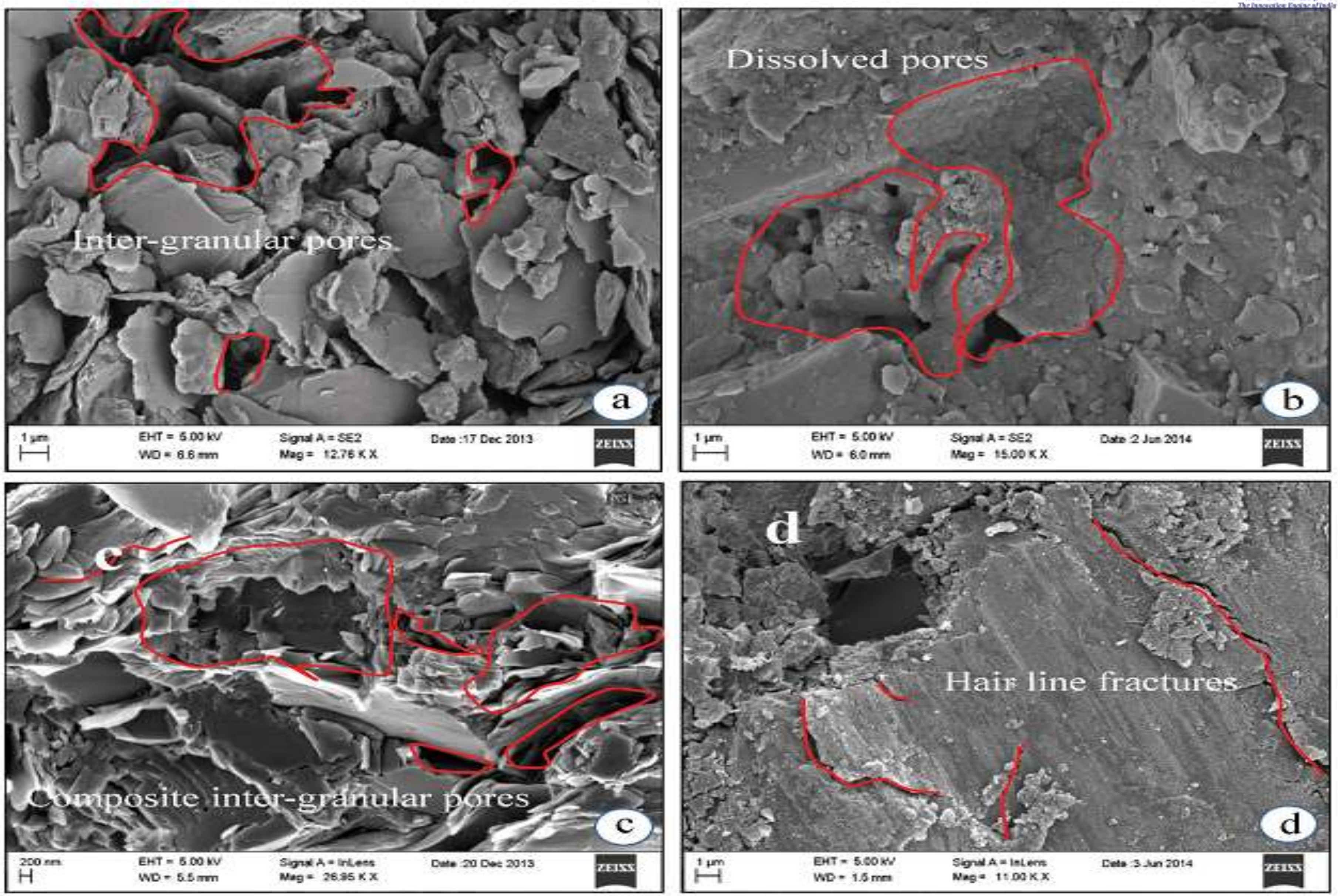
Pore classification:

a. Inter–granular pores

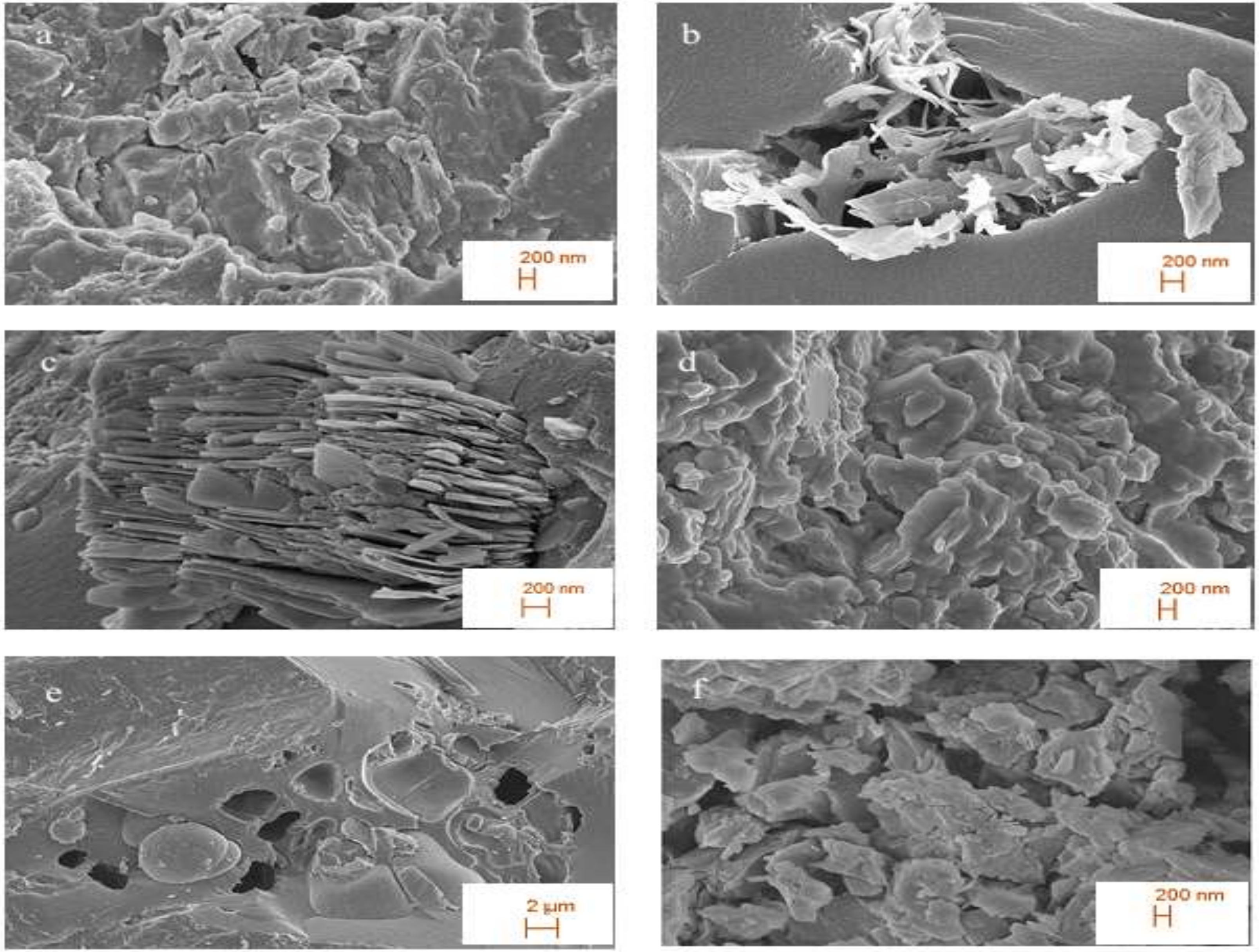
b. Dissolved pores

c. Composite inter–granular pores

d. Hair line fractures



SEM Images of Coals from East Bokaro Coalfield



a) Homogenised dissolved pores

b) Macropores with secondary minerals infillings

c) Thin pellets of kaolinite clay filled in organic matter containing macropores showing fissile bedding planes with interconnected pores through spacing

d) Gelified organic matter destroyed pore network due to blocking effect of volatiles

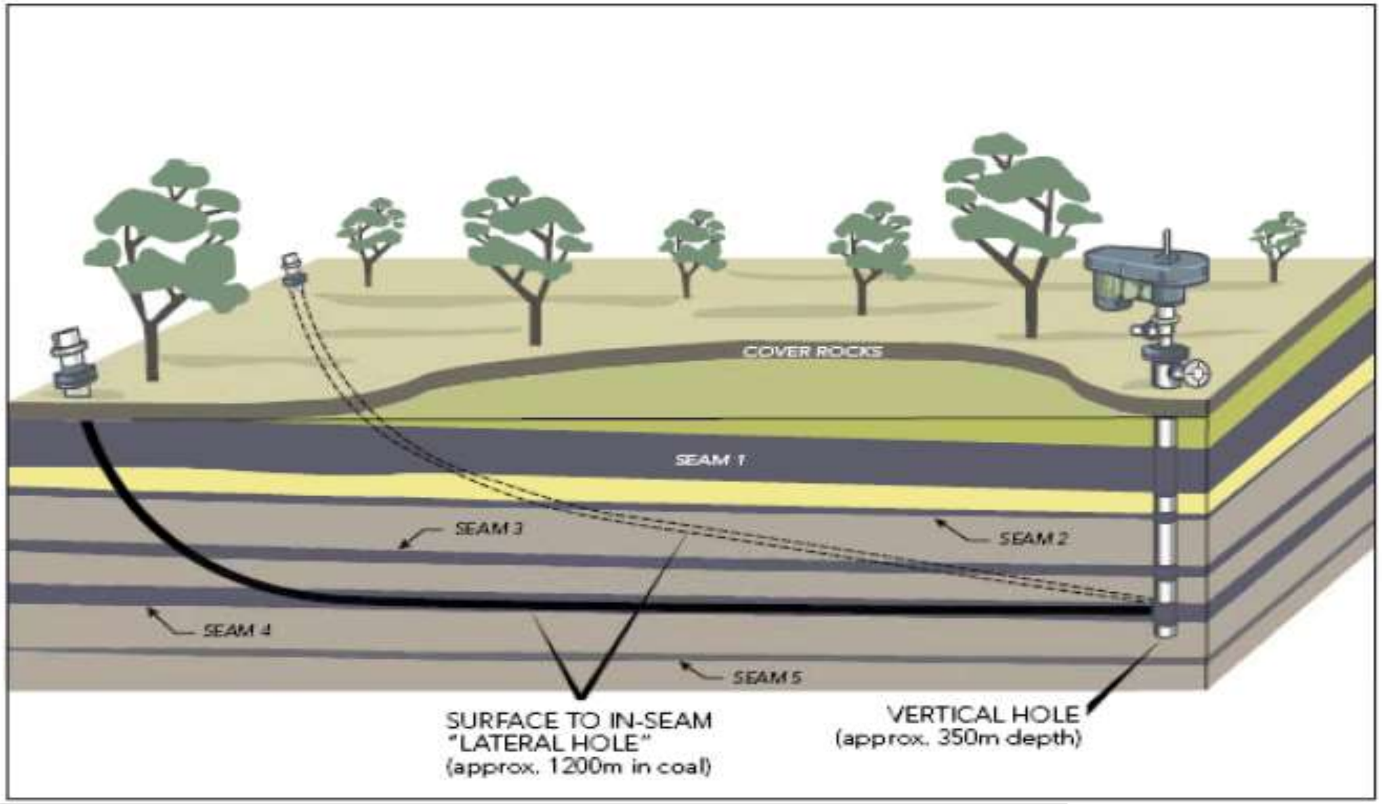
e) Rounded hollow deep macropores

f) Intergranular pore structures contained by meso and macropores

Advanced Drilling Technology Providers

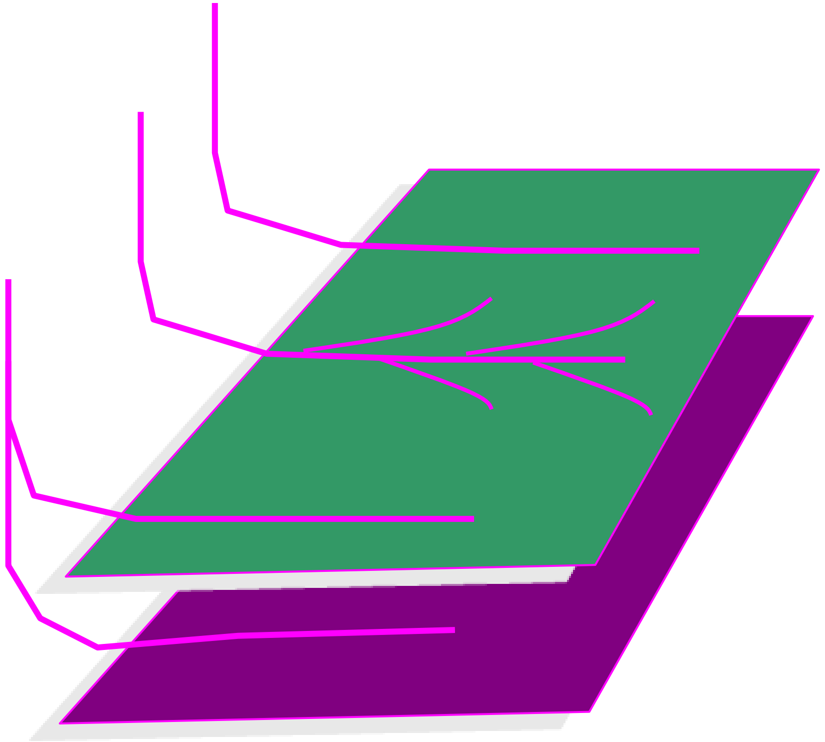
Sl No	Name of Technology	Name of the Company
1	Horizontal Lateral/Multilateral Drilling	Weatherford,USA
2	Z- Pinnate	CDX-Gas,USA
3	Radial – Horizontal – Multilateral drilling	Gardes Energy,USA
4.	Dimaxian – Horizontal drilling	AJ Lucas & Mitchel drilling, Australia

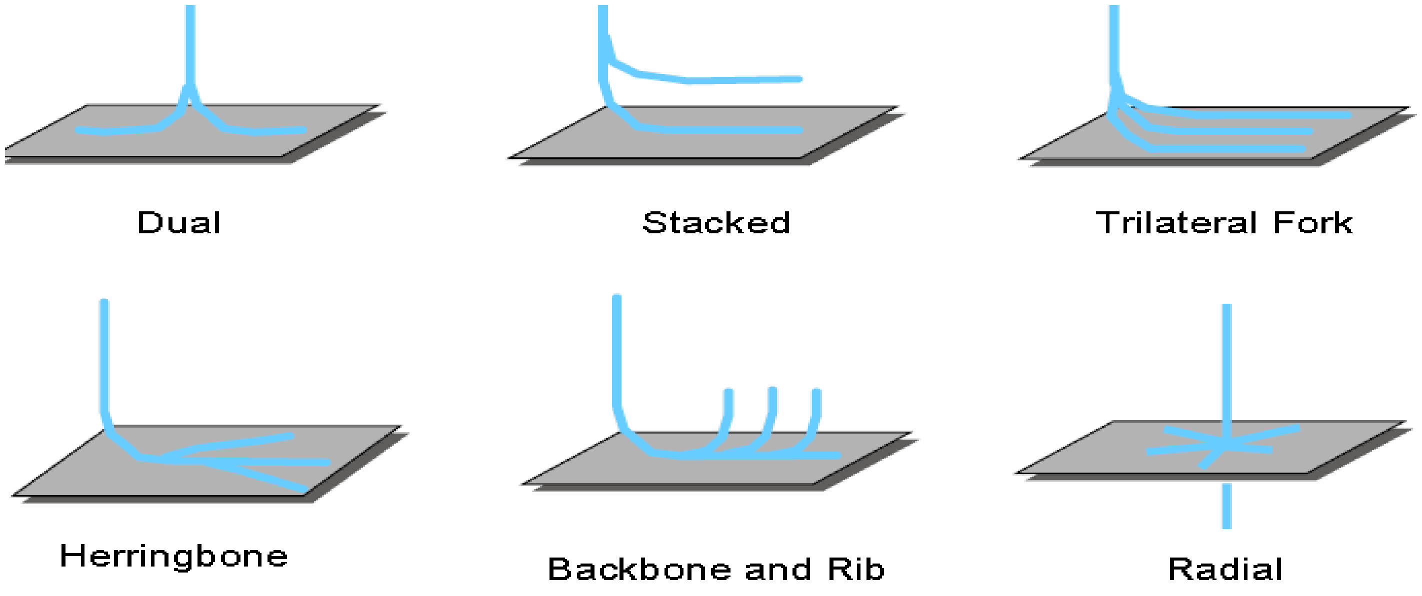
Horizontal Drilling

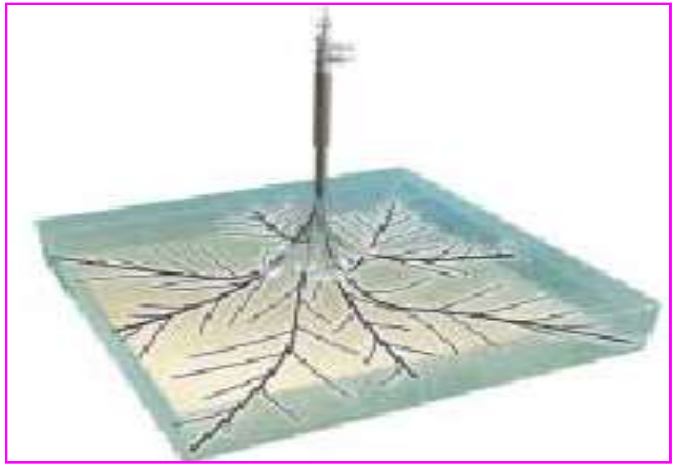


- In-seam well lengths up to 4000ft
- Entry angle (50^0 to 90^0 from horizontal)
- Bend angle of 7^0 per 100ft
- Intersection with vertical well is accomplished using magnetic guidance tool

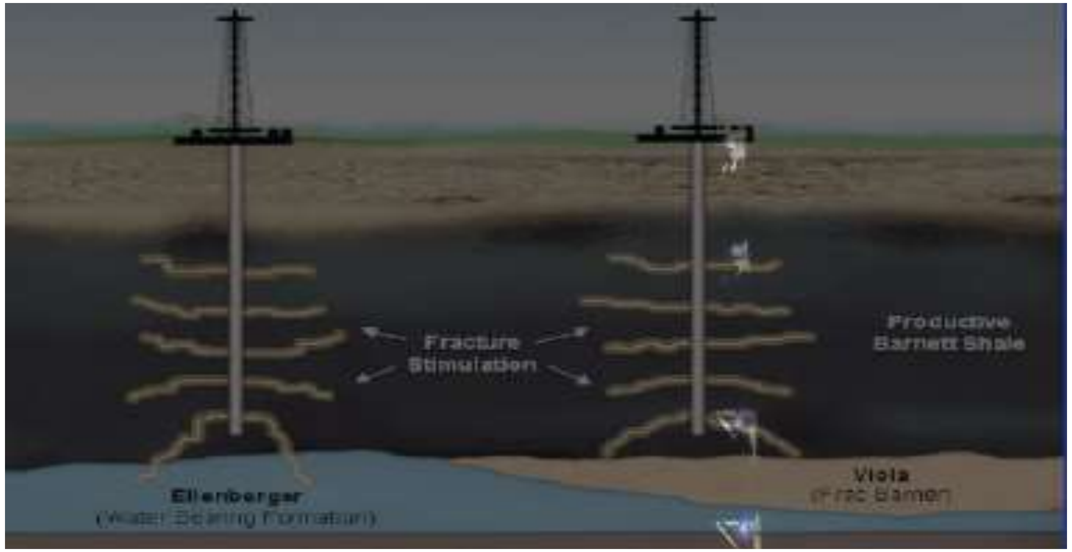
Multilateral Drilling





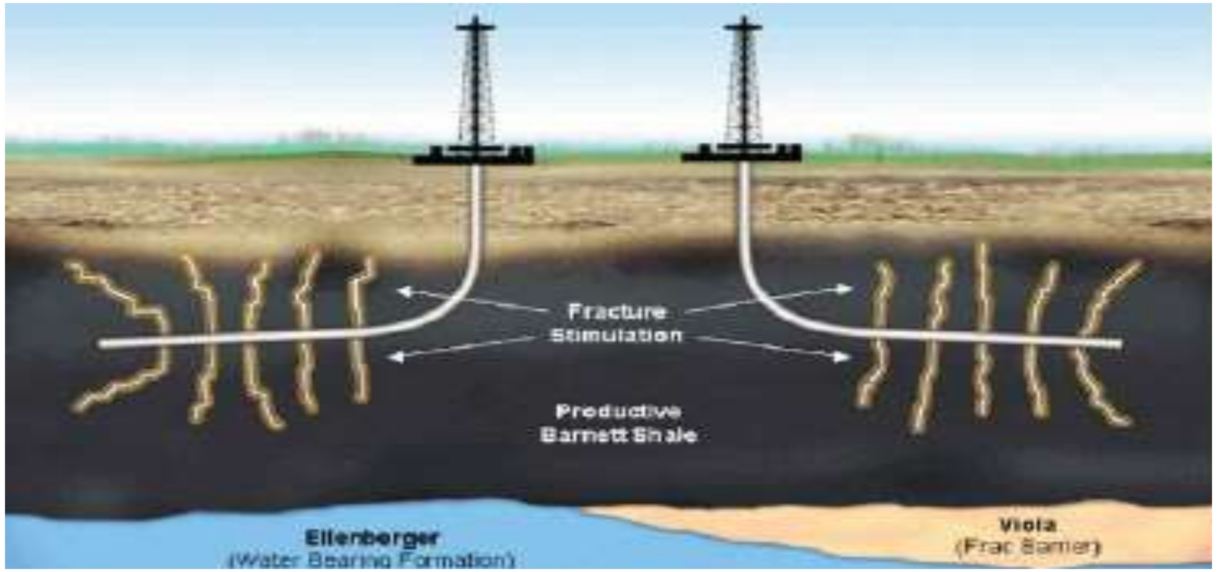


Horizontal Vs Vertical Stimulation/Hydrofrac

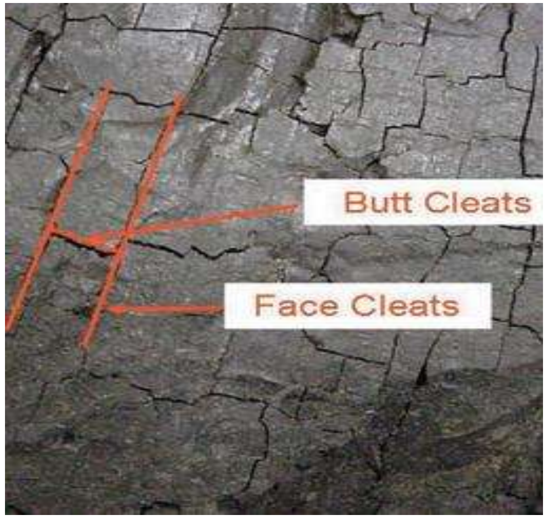


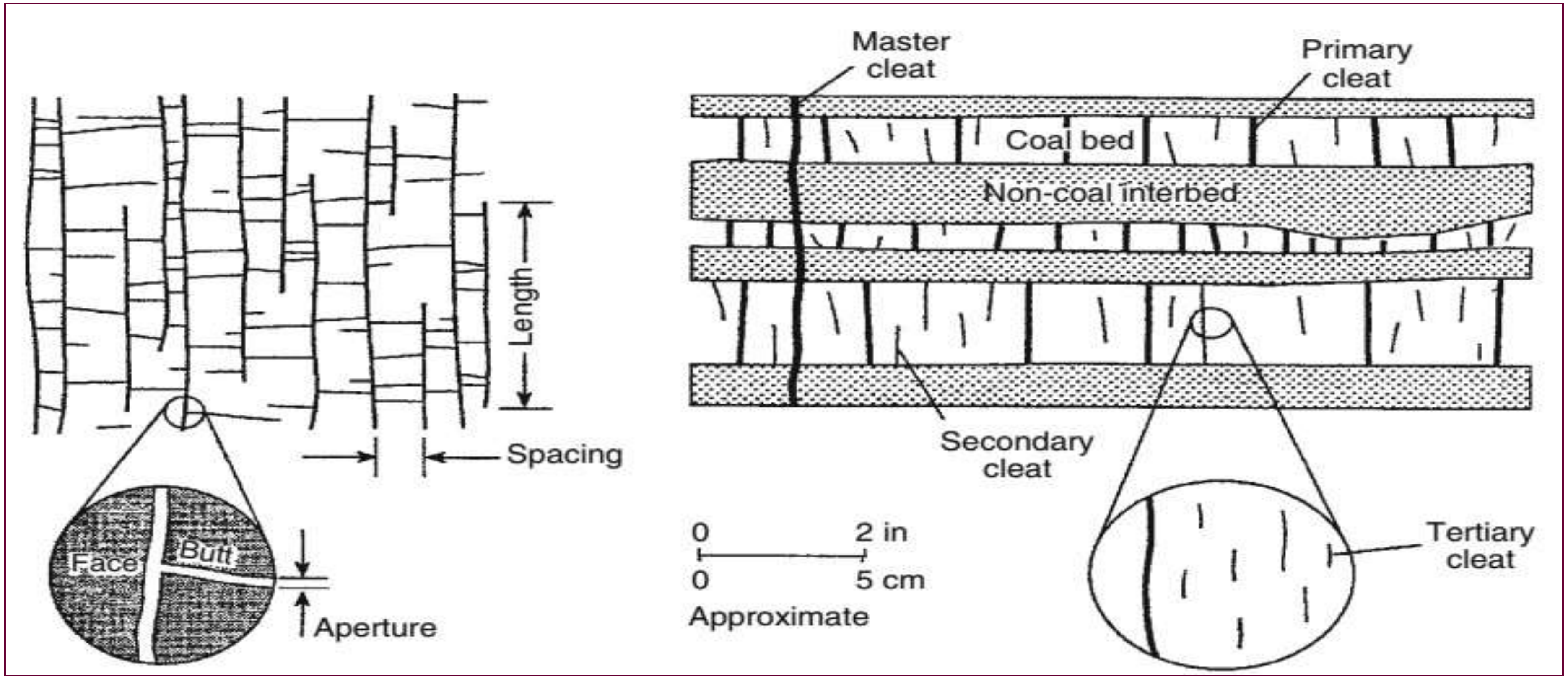
Vertical Fracture Stimulation

Horizontal Fracture Stimulation

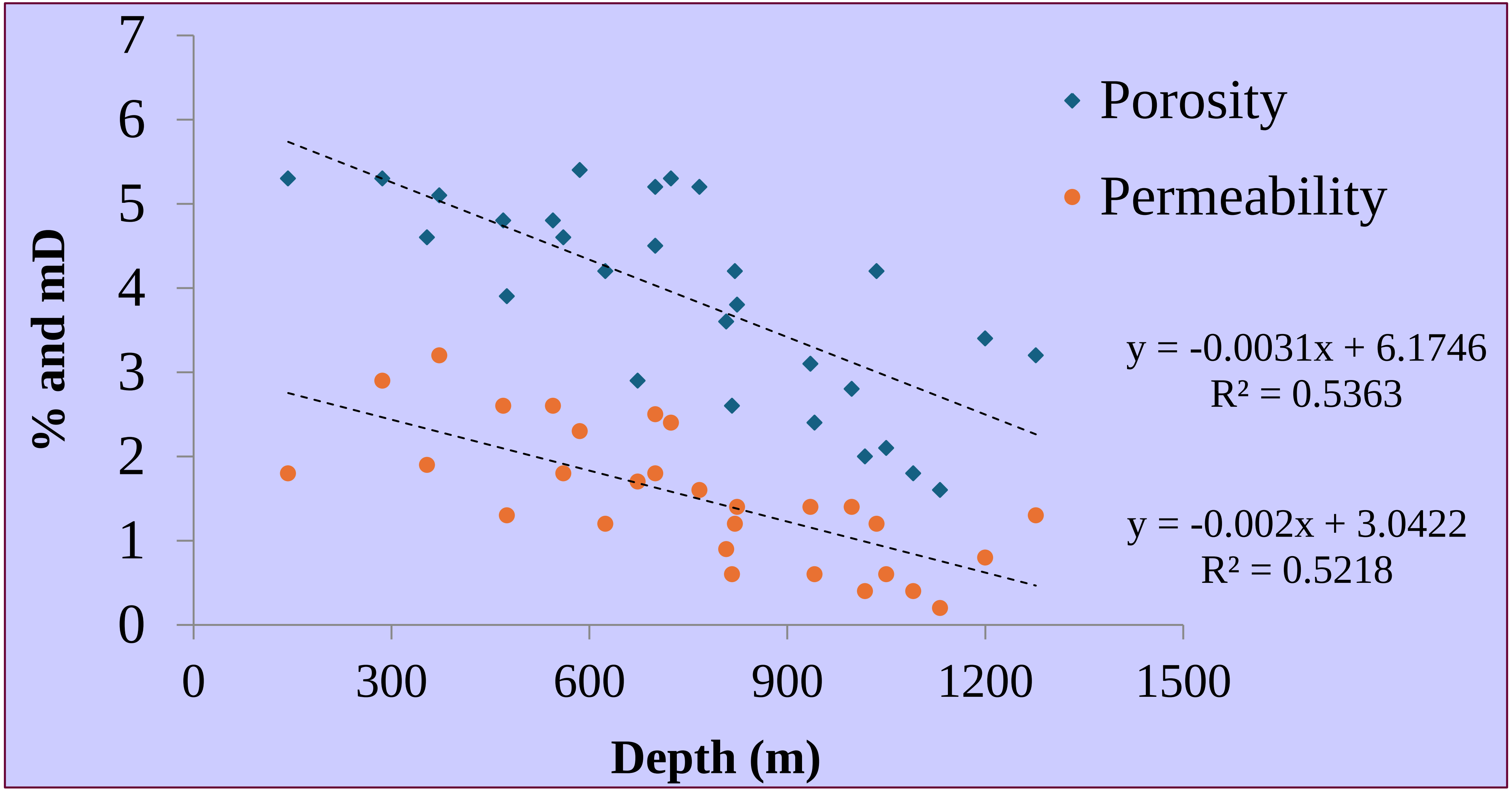


Permeability in Coalbeds

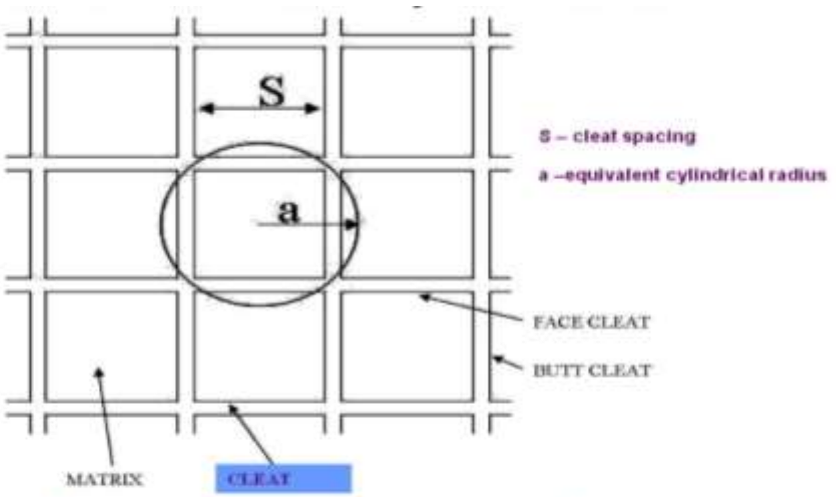




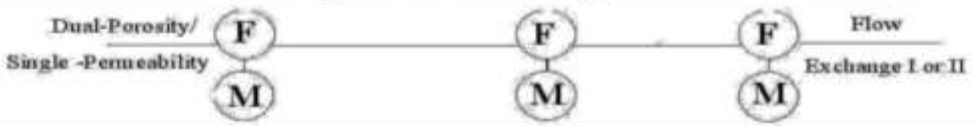
Porosity/Permeability with Depth

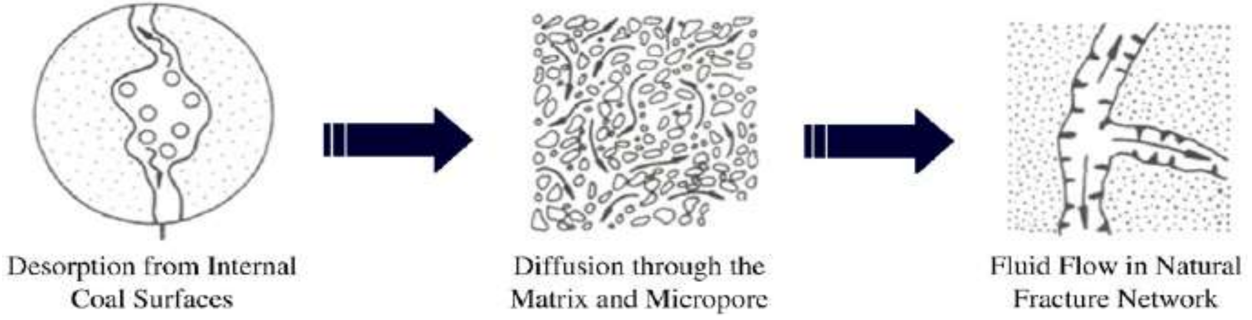


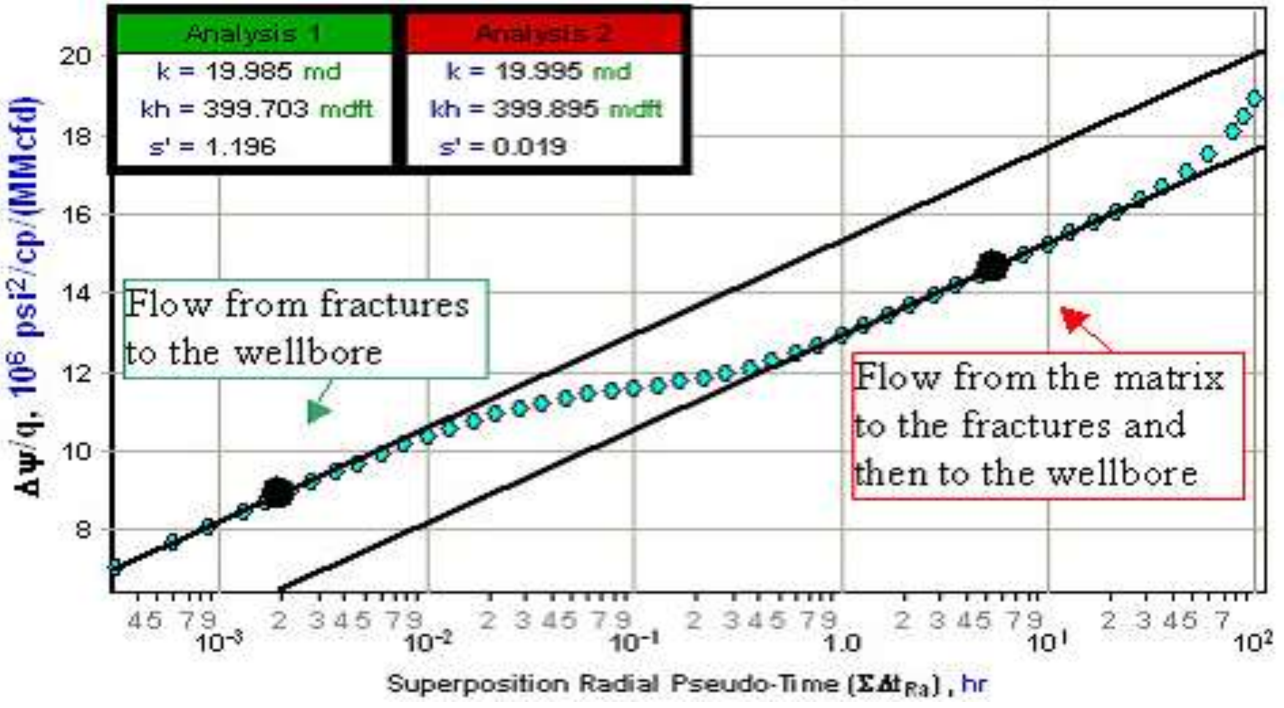
Dual Porosity and Flow Mechanism



- One dimensional flow diagram for illustrating reservoir flow models







ECBM - Field Experience

USA

1. Allison CO_2 - ECBM Pilot Project
2. Location - San Juan basin
3. Producer well - 16
4. Injector well - 4
5. Average depth - 3100 feet
6. Permeability 100 md
7. Initial pressure - 1650 psi
8. Temp. - 160^{o}F

Observations

1. CO_2 injection improved methane recovery from 77 to 95% of GIP
2. Ratio of injected CO_2 to produced CH_4 - 3:1

Canada

1. Alberta Research Council
2. Location - Fenn BIG Valley, Alberta Province
3. Producer well - 1
4. Injector well – 1

Observations

1. Injectivity improves with continued CO_2 injection and methane production

Japan

1. Operated by JCOAL
2. Location - Yubari site, Ishikari Coalfield
3. Producer well - 1
4. Injector well - 1

Observations

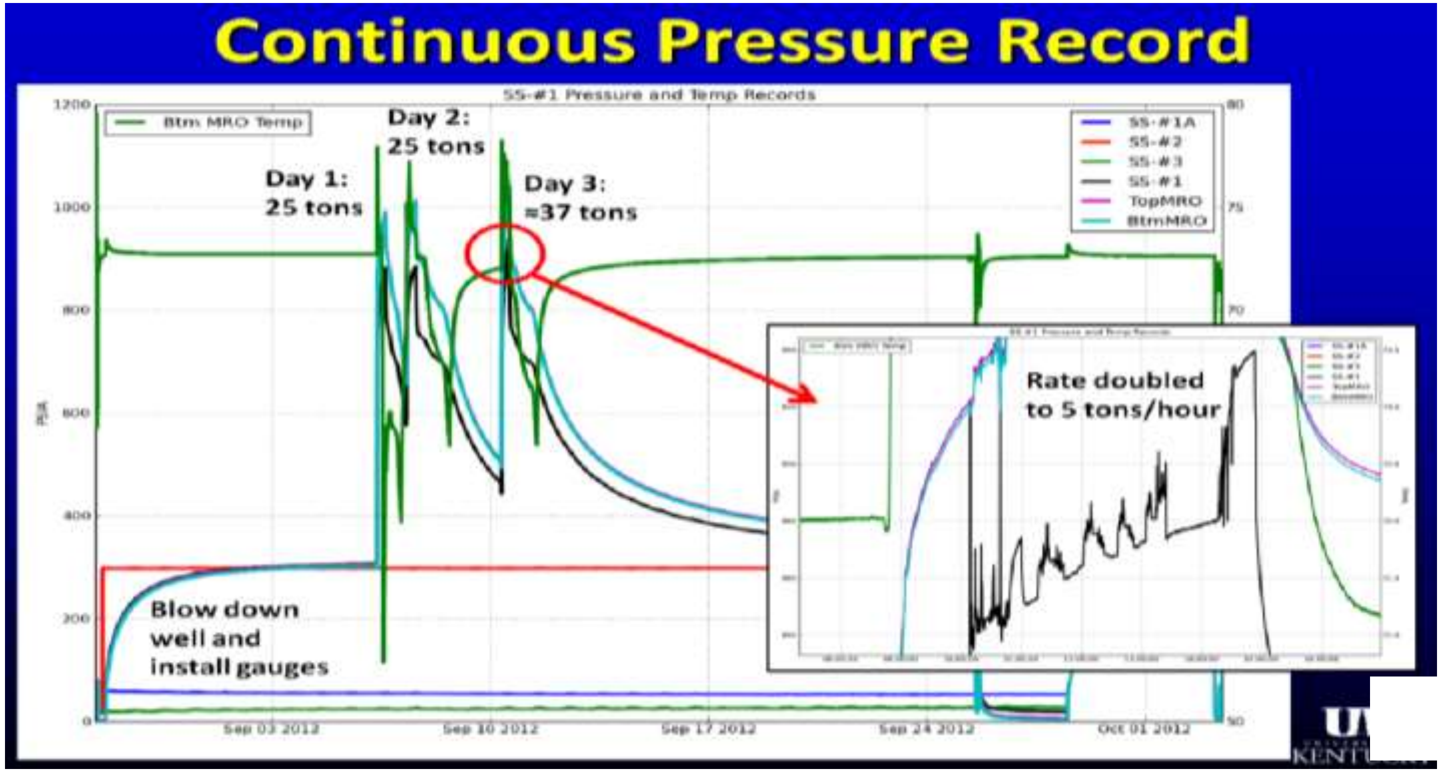
1. Gradual increase of injection rate
2. 90% of injected CO_2 stored in coal seams
3. Gas production increase with CO_2 injection, and dropped after injection was stopped- indicating ECBM effect

CO_2 Storage – ESGR

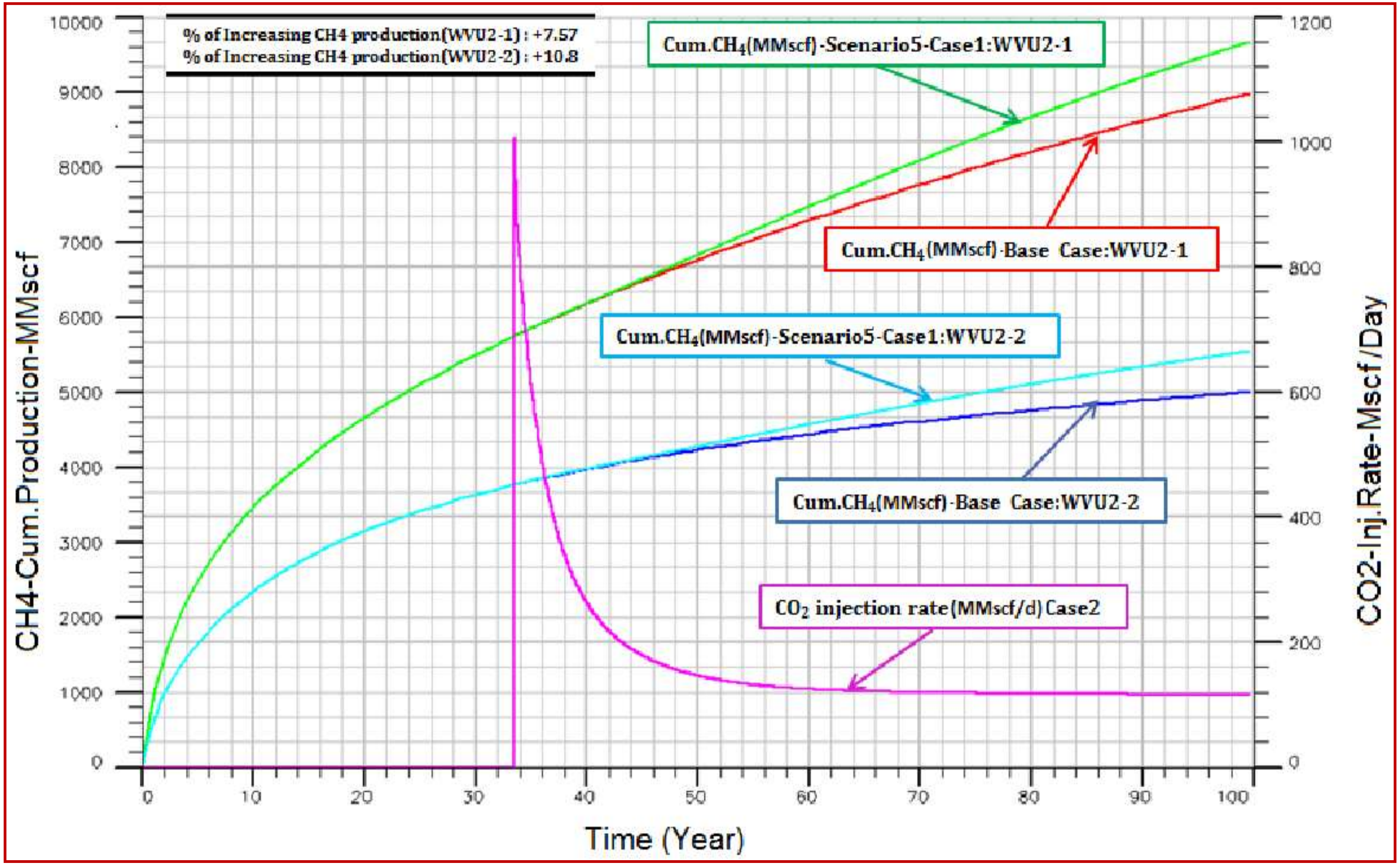
Observations

- Can pump CO_2 with N_2
- Effective permeability increase
- Linear flow indicates open fractures
- No migration of gas to monitor wells was observed

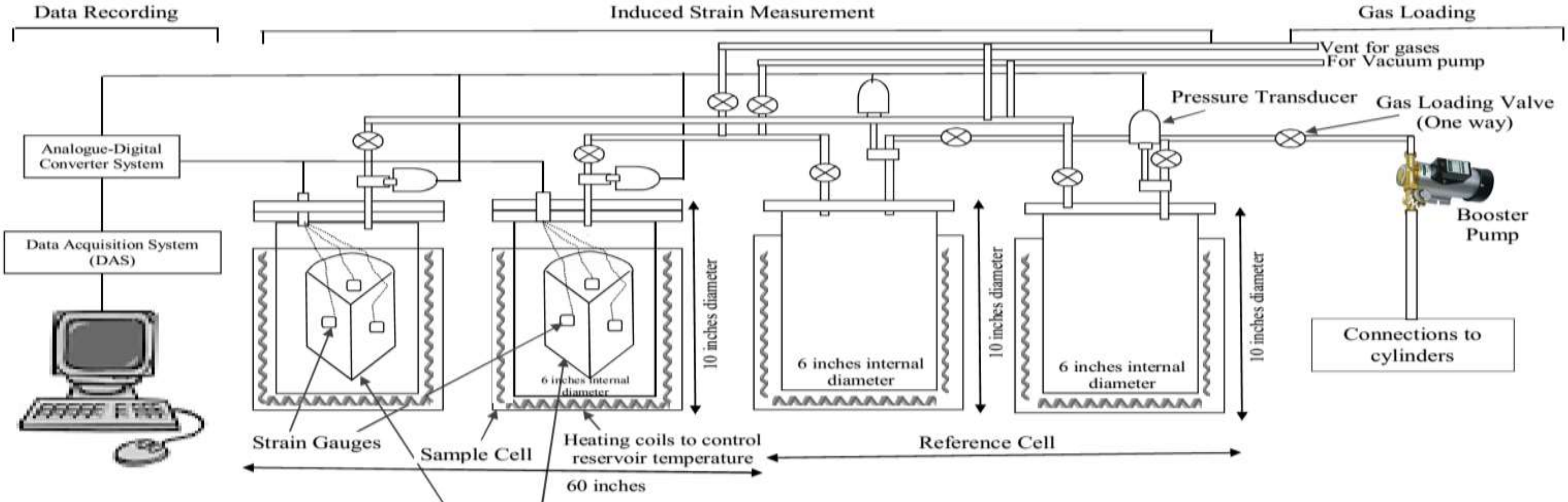
- Active injection testing occurred over 10 hour stretches for 3 days with allowances for pressure falloff.
- The injection rate was held at 2.5 tons of CO_2 per hour with the surface pressure response rising throughout an injection phase to 900+/- psi.
- The records for the monitor wells apparently do not show pressure changes that would indicate migration out of the completed zone (SS-#1A) or displacement of natural gas to surrounding wells (SS-#2 and SS-#3)



Simulation : CO_2 injection rate and Enhancement in CH_4 cumulative production



Development of System for Sorption-Induced Strain Measurement in Coal and Shale as a result of CO_2 injections



General Specs:

- High pressure tubes: size 6mm and should sustain >200kg/cm^2
- Pressure transducer with digital display : 1 to 200kg/cm^2
- High pressure (SS) double stage regulators: inlet >200 and outlet >200.
- Very high precision valve: should sustain >200kg/cm^2
- Reference and sample cell should be of SS 316 and sustain on >200kg/cm^2
- Heating coil surrounded by vessel with temperature controlling unit should heat the cell from room temp. to 100 ^{0}C.
- Booster pump to load the gas up to 200 kg/cm^2
- Vacuum pump: Oil based, single phase, oil based, flow rate >30 l/minute (Full specs. are details are given in the indent)

Screening Model for Change in Permeability as a Result of CO_2 Injection for Indian Coal and Shale Reservoirs

Strain versus time data

$$S = S_1 + \frac{S_L(t - t_1)}{t_L + (t - t_1)}$$

Where S is the calculated strain, S1 is the initial strain at the beginning of the pressure regime, S_L is the Langmuir strain, t is the time in hours, t1 is the time in hours at the beginning of the pressure regime, and t_L is the Langmuir time. Both S_L and t_L can be obtained by fitting the data using least-squares analysis with a Langmuir curve when both S_1 and t_1 are zero.

Strain versus pressure curve

$$S = S_L \frac{p}{p + p_{S_L}}$$

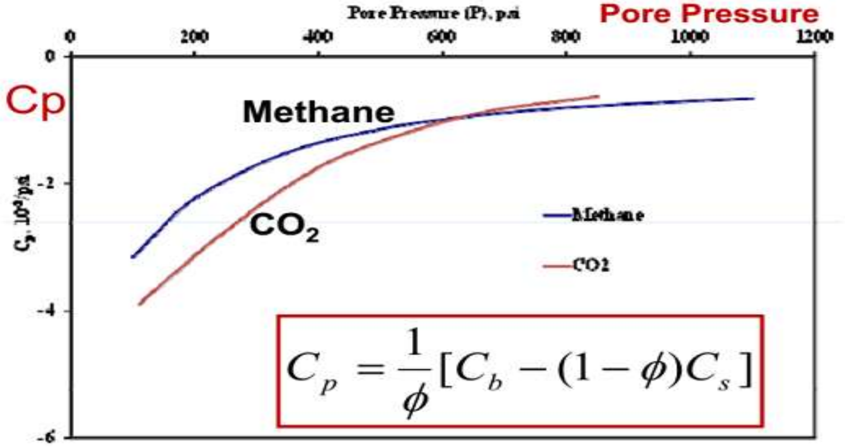
Where S is strain, S_L is the Langmuir strain, p is the gas pressure and p_{SL} is the Langmuir strain pressure

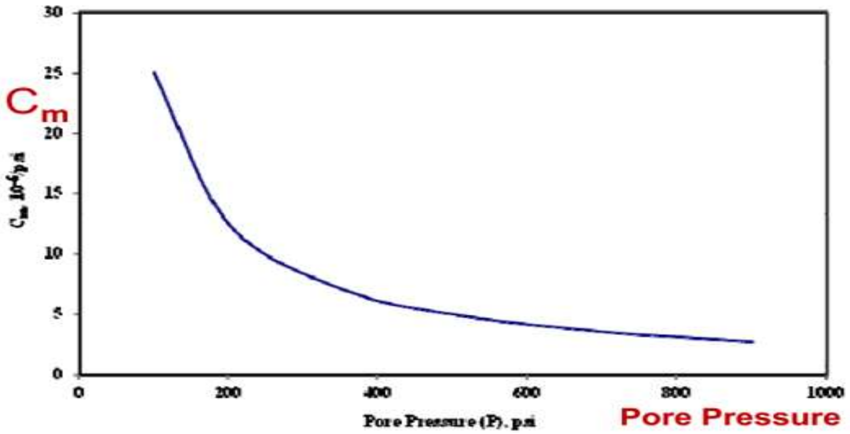
Permeability model for laboratory

$$\frac{k}{k_0} = e^{3\left\{c_0 \frac{1-e^{\alpha(p_p - p_{p0})}}{-\alpha} + \frac{3}{\phi_0}\left[\frac{1-2\nu}{E}(p_p - p_{p0}) - \frac{S_{max} p_L}{(p_L + p_{p0})} \ln\left(\frac{p_L + p_p}{p_L + p_{p0}}\right)\right]\right\}}$$

Where k is measured permeability, k_o is the initial permeability of the coal core, c_0 is the initial fracture compressibility, α is the fracture compressibility change rate, p_p is the pore pressure, p_{p0} is the initial pore pressure, ϕ_0 is the initial porosity, ν is Poisson's ratio, E is Young's modulus, S_L is the Langmuir strain, and p_L is the Langmuir pressure.

Change in coal and shale properties





Stability of CO_2 Geo-Storage

The stability of stored CO_2, both short-term and long-term, is crucial for effective geo-storage. Short-term stability concerns the immediate behavior of CO_2 and the reservoir after injection, including initial movement and leakage risks. Long-term stability focuses on behavior over centuries, involving gradual migration and ongoing interactions between CO_2, fluids, and minerals.

Key factors influencing long-term stability include various trapping mechanisms that immobilize CO_2 within the reservoir. These mechanisms ensure secure containment and prevent CO_2 release into the atmosphere, making geo-storage a vital strategy for mitigating greenhouse gas emissions.

Short-Term Stability

Initial movement, distribution, and immediate leakage risks post-injection.

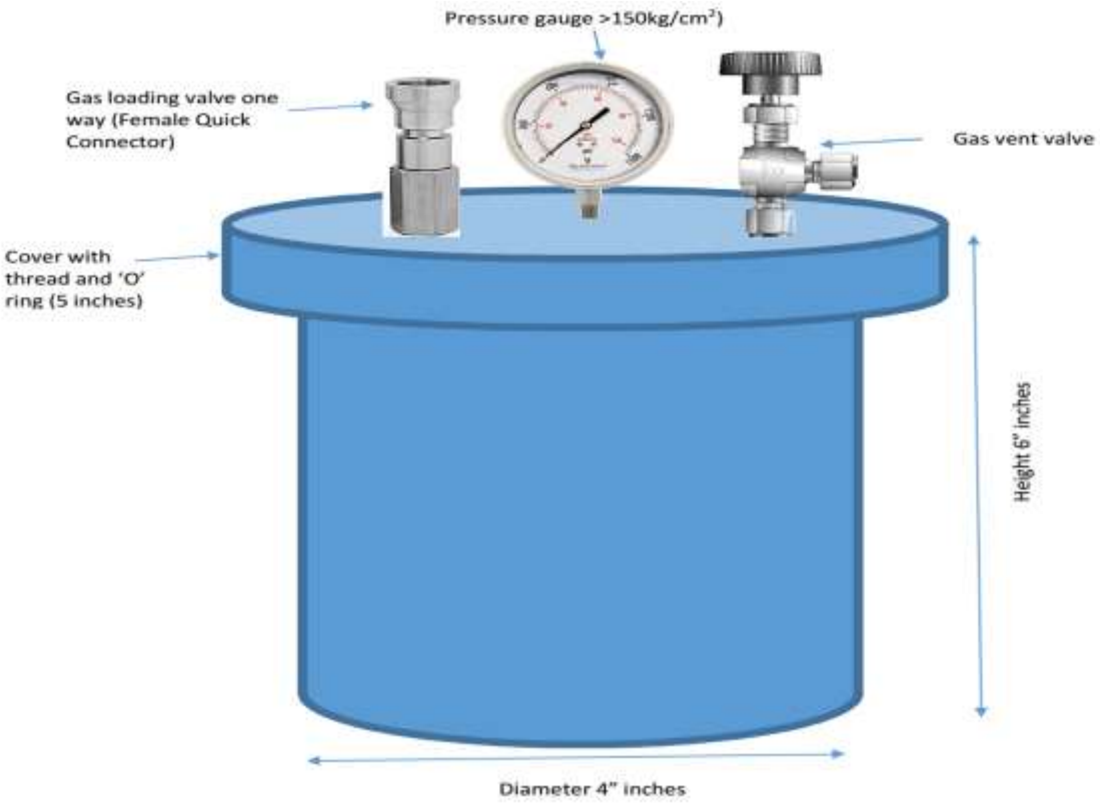
Long-Term Stability

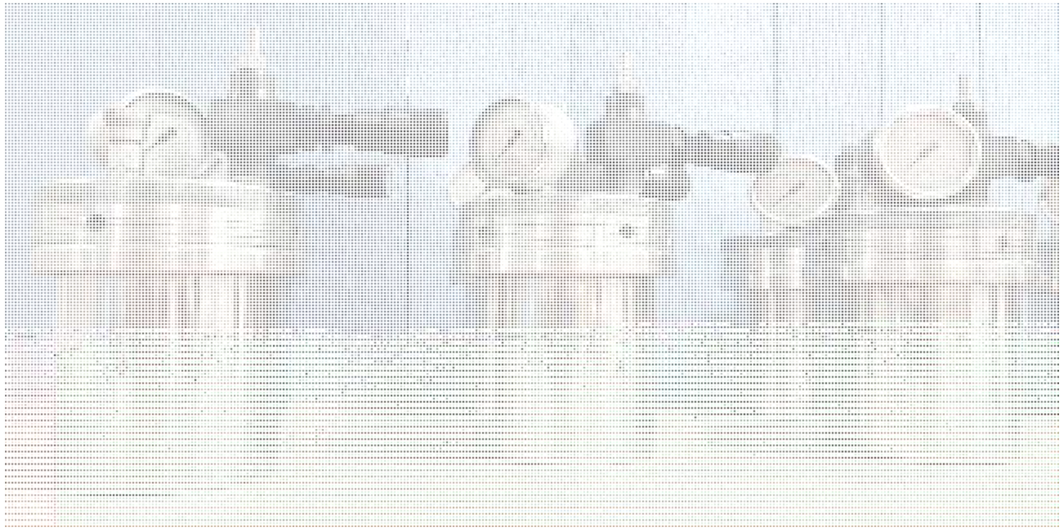
Gradual migration, ongoing interactions, and long-term leakage risks over centuries.

Trapping Mechanisms

Crucial for immobilizing CO2 and ensuring secure, permanent containment.

Stainless Steel High Pressure Autoclave Vessel for CO_2 Mineralization Study and Gas Chromatograph





Specifications for sample cell as below:

- Stain less steel cell body (SS316) should sustain pressure >150 kg/cm² (>2150 PSI) with minimum thickness of the wall not less than 6mm.
- Height of vessel – 6" (inches) and Diameter – 4" (inches-external) and approx. 3.5 inches (internal)
- Cover should have inside thread with 'O' ring for gas tight
- Pressure gauge range 0 to 150 kg/cm² (>2150 PSI)
- Gas loading valve – one way (quick connector) (both male and female)
- Gas vent valve for release of gas
- System should be gas tight at high pressure
- Flexible hose pipe for gas loading with necessary connectors
- Warranty: 2 years for vessel and attachments like valves and pressure gauges

Example: Flexible hose pipe for gas loading

Example: Gas loading valve one way (Male Quick Connector)

Samples for initiation of CO_2 mineralization in coal and shale/rocks

Thanks for Your Kind Attention…