Demonstration of capture, injection and geological Sequestration (storage) in Flood Basalt Formation of India.

National Thermal Power Corporation Ltd.

India

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• Evaluation of Basalt Formation in India (Deccan Trap) for environmentally safe and irreversible long time storage of CO₂

• The Indian study will establish globally basalt formation as potential storage for CO₂ by leveraging study carried out in Columbia River basalt group under US-DOE.
Why Basalts are attractive proposition?

Internal flows of Basalts provide large volume due to its very chemical nature.

Basalts provide solid caprock and high level of integrity.

Mineralization process super fast.

Interflow zone vesicular, brecciated, basal pillow complex & basal breccia zones.

Interflow provides major permeability & porosity.
1. Indian Deccan Volcanic Province (DVP) is one of the largest terrestrial flood basalt formations covering nearly 500,000 sq. KM

2. DVP is comprised of 13-20 flows consisting of massive vesicular, amygdaloidal basalt tuffs providing a volume in excess of 550,000 KM3 – three times CRBG, US

3. It can provide almost 300 GT of storage potential (Resource wise)
Basalt Area of India

• Total Basalt Formation area: 500000 sq km
• Composed of typically 14 different flows
• More than 2000 m depth in western side & few meter in eastern side
• Generally seismically stable
• Approx. 300 Gt CO₂ can be stored
• Equivalent to 250 years of CO₂ at present level of power generation in India

The Deccan Volcanic Province (DVP) located north-west of India
**CO₂ storage in formations**

CO₂ is injected in sedimentary rocks above its super critical temperature and pressure.

Minimum depth 800 m

- Hydrodynamic Trapping
- Solubility Trapping
- Mineralization

Phase Diagram for CO₂

- CO₂(s)
- CO₂(l)
- CO₂(g)

Pressure
- 73 atm
- 5.11 atm
- 1 atm

Temperature (°C)
- -78.5
- -56.4
- 31.1
CO2 sequestrated in Internal Flow Zone between two basalt layers

Structure of flows depend on Physico-chemical phenomenon

Basalt Formations

- Lava/magma cooling
- Degassing/bubble formation
- Thermal contraction

Interaction with Water and ppt. formation

- Formation of void space
- Physical Trapping
- Mineralisation
- Chemical Trapping
Basalt Formations

Mineralization reactions in basalt formations

\[
\begin{align*}
\text{CO}_2(g) & \rightarrow \text{CO}_2(aq) \\
\text{CO}_2(aq) + \text{H}_2\text{O} & \rightarrow \text{HCO}_3^- + \text{H}^+ \\
(Ca,Mg,Fe)_x\text{Si}_y\text{O}_x\text{H}_2y & \rightarrow x(Ca,Mg,Fe)^{2+} + y\text{H}_4\text{SiO}_4(aq) \\
(Ca,Mg,Fe)^{2+} + \text{HCO}_3^- & \rightarrow (Ca,Mg,Fe)\text{CO}_3^- + \text{H}^+
\end{align*}
\]

Induction Time for Calcite Precipitation

<table>
<thead>
<tr>
<th>Depth, m</th>
<th>T, °C</th>
<th>pH_0</th>
<th>pH_f</th>
<th>(r_p), g m(^{-2}) d(^{-1})</th>
<th>(C_{\text{p}}), M</th>
<th>(t_p), d</th>
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</thead>
<tbody>
<tr>
<td>800</td>
<td>35</td>
<td>3.72</td>
<td>4.97</td>
<td>0.047</td>
<td>0.035</td>
<td>122</td>
</tr>
<tr>
<td>900</td>
<td>38</td>
<td>3.70</td>
<td>4.95</td>
<td>0.052</td>
<td>0.034</td>
<td>104</td>
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<tr>
<td>1000</td>
<td>42</td>
<td>3.68</td>
<td>4.92</td>
<td>0.060</td>
<td>0.032</td>
<td>85</td>
</tr>
<tr>
<td>1100</td>
<td>48</td>
<td>3.65</td>
<td>4.90</td>
<td>0.073</td>
<td>0.031</td>
<td>67</td>
</tr>
<tr>
<td>1200</td>
<td>56</td>
<td>3.63</td>
<td>4.87</td>
<td>0.093</td>
<td>0.029</td>
<td>50</td>
</tr>
<tr>
<td>1300</td>
<td>67</td>
<td>3.61</td>
<td>4.85</td>
<td>0.128</td>
<td>0.028</td>
<td>35</td>
</tr>
</tbody>
</table>

( Source : PPNL)

Lab. scale study & geo-chemical modeling establish

• 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 \(\text{CO}_2\) and not by kinetics of the reactions

Calcite deposition on basalt (Source: PPNL)
The basic reaction:

$$M_x \text{SiO}_4 + \text{CO}_2 \rightarrow M_x\text{CO}_3 + \text{SiO}_2$$

The mineralisation process

**Direct carbonation**

- In aq. solution of sodium bicarbonate & chloride
- Reactants: Magnesium silicates (Olivine, Serpentine)
- Temp.: 155°C & P$_{\text{CO}_2}$ = 185 atm.
- 78% conversion in 30 minutes of contact

**Reaction in basalt**

- In saline aquifers (NaCl, KCl)
- Reactants: Basalt rich in Mg, Fe, Ca silicates
- Temp.: 35-45°C & P$_{\text{CO}_2}$ > 75 atm.
- Expected mineralisation in few hundred years

Weathering of silicate rocks is one of the natural process of atmospheric CO$_2$ mitigation

Ca, Mg, Fe silicates → Ca, Mg, Fe Carbonate

Organic acid from biomass

Basalt rich in Mg, Fe & Ca silicates potential candidate for CO$_2$ sequestration
## Basalt Composition

<table>
<thead>
<tr>
<th></th>
<th>Indian Basalt</th>
<th>Sentinel Bluff Basal - USA</th>
<th>(Source: PPNL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>59.07</td>
<td>54.35</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.22</td>
<td>14.27</td>
<td></td>
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<tr>
<td>FeO</td>
<td>6.45</td>
<td>12.39</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>6.10</td>
<td>7.43</td>
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</tr>
<tr>
<td>MgO</td>
<td>3.45</td>
<td>3.13</td>
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<tr>
<td>Na₂O</td>
<td>3.71</td>
<td>2.82</td>
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<tr>
<td>K₂O</td>
<td>3.11</td>
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<tr>
<td>P₂O₅</td>
<td>0.30</td>
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<tr>
<td>TiO₂</td>
<td>1.03</td>
<td>2.09</td>
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</tr>
<tr>
<td>MnO</td>
<td>0.11</td>
<td>0.21</td>
<td></td>
</tr>
</tbody>
</table>

- Expected a great potential for CO₂ storage in Indian Deccan trap
- Shows promising potential in Laboratory
Schematic of CO2 in Basalt (DVP)
The Project at a Glance

Study on CO₂ Sequestration (storage) in Flood Basalt Formation (Deccan trap)

- Site Identification & Pre-injection Characterization: 18 months
- Detailed Planning: 6 months
- Post-injection characterization & Monitoring (short/long term): 48 months

Project Cost: $1.30 million
Site Identification / Pre-injection Characterization

Important milestones
- Overall feasibility
- Storage capacity
- Storage impact assessment
- Basic data for permission from regulatory authority

Detailed planning

Evaluation of important geo-chemical parameters
- Thickness and depth
- Porosity and permeability
- Lateral and vertical connectivity
- Cap rock fracture pressure
- Chemical composition
- CO2-basalt reaction kinetics
- Pore water chemistry, etc.

Major activities
- 3D Seismic study of host and cap rock
- Sample coring
- Down hole vertical seismic study [VSP]
- Wire line logging
- Physical and chemical characterization
- Modeling and CO2 movement prediction
- CO2 storage impact assessment
- Identification of most suitable site and permission, etc.
Post-injection Characterization & Monitoring

Injection of CO₂
- Infrastructure mobilization including drilling rig
- Transport of CO₂
- Drilling of injection well, deep and shallow observation well
- Wire line logging (sensors etc.)
- Injection of tracer (suitable tracer SF₆, CH₂F₂ etc.)

Monitoring & Measurement
(on line, frequent, periodical)

- CO₂ dispersion
- CO₂ transport, etc.
- Migration of CO₂ in formation
- Residence & reaction time
- Horizontal anisotropy & vertical continuity, etc.
- CO₂ leakage from reservoir
- Mineralisation and reservoir fluid characterization
- Tracer break through & recovery pattern
- Geophysical probes
- Distance monitoring well
- Tracer
- Subsurface sites & shallow well
- Sample bore hole within reservoir periphery
Progress in the Project

- Formulation of the project has been completed
- National and International research partner have been identified
- Resource mobilization is in progress
Define Demonstration Requirement
Determine Data Gaps
Hydrogeologic Characterization
Site Selection
Site-Specific Characterization
Injection System Design
Identify CO₂ Source
Supply System Design
Injection System Construction
Supply System Permits
Injection Permit Application
Injection System Construction
Supply System Construction
Demonstration Startup
Operation and Monitoring
Lessons Learned
Monitoring and Verification Plan
Baseline Monitoring
Public and Stakeholder Participation; Risk Assessment
Baseline Monitoring
Monitoring and Verification...continuing
Public and Stakeholder Participation; Risk Assessment
Review Data
(continued from above)
“When you really want something to happen, the whole universe conspires to help you to achieve your dreams”

........ The Alchemist

by Paulo Coelho

Thank You
<table>
<thead>
<tr>
<th>Capture</th>
<th>NT</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC-CBM Can, US, UK</td>
<td></td>
<td>√ Can, US &amp; UK</td>
</tr>
<tr>
<td>CANMET-Canada</td>
<td></td>
<td>√ (Oxyfuel) Can &amp; US</td>
</tr>
<tr>
<td>CASTOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 capture (ph II)</td>
<td></td>
<td>√ (UK, US, Nor, Italy)</td>
</tr>
<tr>
<td>CO2 from pressurised gas stream</td>
<td></td>
<td>Japan, US</td>
</tr>
<tr>
<td>CO2 sink</td>
<td></td>
<td>EC &amp; Germany</td>
</tr>
<tr>
<td>CO2 Store</td>
<td></td>
<td>Norway &amp; EC</td>
</tr>
<tr>
<td>Frio</td>
<td></td>
<td>US &amp; Aus</td>
</tr>
<tr>
<td>ITC CO2 cap with chemical solvents</td>
<td></td>
<td>Canada &amp; US</td>
</tr>
<tr>
<td>Weyburn II</td>
<td></td>
<td>US, Canada &amp; Japan</td>
</tr>
</tbody>
</table>
Dioxide Sequestration Project
Brent Lakeman, Program Leader, Carbon Management, Sustainable Energy Futures, Alberta Research Council, Canada

Anoxic Microbial Sequestration of Carbon Dioxide Present in Flue Gases to Methane/ Methanol/ Other Biomass
R.R. Sonde, Executive Director, Energy Technology, National Thermal Power Corporation, India

Regional Opportunities for CO2 Capture and Storage in China
James Dooley, Co-Director, Carbon Management Solutions, Joint Global Research Institute, Pacific Northwest National Laboratories, United States