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India's Energy Future and Carbon Management

B. Kumar & Devleena Mani

National Geophysical Research Institute, Hyderabad-500 007, India Email: baleshk@yahoo.com

Abstract

The energy scenario in India is driven by coal, oil & gas, hydroelectric, nuclear and renewable resources. Coal is the most important & abundant fossil fuel in India and accounts for 51% of India's energy need. 45% of energy requirements are met by petroleum products, 2% by hydroelectric and the remainder by nuclear and other resources. The energy requirements in India are expected to grow at 5-6 percent per annum over the coming years to sustain the GDP growth of around 8%. To meet the challenges of India's energy outlook, R&D initiatives for exploitation of alternate source of fuels (oil shale, gas hydrate and coal-bed methane) and carbon capture & storage have been started.

India is the third largest producer of coal and the present estimates of coal reserves have reached 247.85 billion tons. Coal resource of India mostly occur in sedimentary rocks of Gondwana formations of peninsular India and Tertiary formations of Northeast India with Gondwana coal accounting for 99% of total reserves.

Oil shale is one of the unconventional alternate resources of energy that has emerged as a possible means to supplement declining conventional hydrocarbon production. These are fine grained sedimentary rocks containing relatively large amount of organic matter from which significant quantities of shale oil and combustible gas can be extracted. Studies have shown that similar rocks with most of their oil generating potential still preserved occur in Northeast India interbedded with Tertiary coal. The oil shale formations crop out on the surface mostly in the region called the belt of Schuppen. The estimated in-place oil reserve of this carbonaceous shale is greater than 15 billion tons.

The oil from carbonaceous shale is produced by retorting, an energy intensive process in which the rock is heated to 450-550°C in the absence of oxygen. However, oil shale deposits usually contain carbonate minerals and due to pyrolysis of kerogen and the decomposition of carbonate, shale may evolve significant amount of CO_2 during oil production. This could be a serious defect from the view point of global warming.

Deep coal seams that are not commercially viable for coal production could be used for permanent underground storage of carbon dioxide (CO_2). An added benefit of storing CO_2 in this way is that additional useful methane will be displaced from the coal beds. CO_2 released from oil shale could also be used for Enhanced Oil Recovery in depleted oil fields of Northeast India.

Introduction

Global climate change is one of the greatest environmental challenges the world community is facing and increase of CO_2 in the atmosphere is the major cause for climate change. Excess CO_2 in the atmosphere is mostly released by coal, oil and gas fired thermal power plants which drive or will drive India's energy future. The CO_2 in the atmosphere is also partially released through automobile exhaust. Several protocols, mechanisms and fora have come into force for CO_2 mitigation, including the Kyoto Protocol, Clean development Mechanism (CDM), Carbon sequestration Leadership Forum (CSLF), UN Framework Convention Treaty on Climate Changes (UNFCC) and Asia Pacific Partnership on Clean Development and Climate (AP6). India signed the Kyoto

Protocol in 2003 but is not obliged to reduce emissions by 2012 as the per capita emission is very low (<1 metric ton /year). India is also member of CSLF, CDM, AP6, and also stands by UNFCC.

The world's primary energy consumption is based on coal as the most widely used fuel with consumption of ~ 11,000 million tons of oil equivalent. Although coal remains the world's leading energy source, it has lost market share to oil and natural gas in the past decade. The energy scenario in India is driven by coal, oil & gas, hydroelectric, nuclear and renewable resources. The present power generation capacity of India is about 135,000 MW out of which 64% is thermal (53 % from coal, 11 % from oil and gas), 25 % hydro, 3 % nuclear and 8 % from other sources.

India's per capita contribution to global greenhouse gas (GHG) emissions is relatively low at present i.e. 0.97 as compared to global per capita carbon emissions of 3.89, European Union of 8.41 and US of 19.66 (IEA, 2006). Assuming sustained GDP growth of 8-9%, the energy requirements in India are expected to grow at 5-6 % per annum over the coming years.

This paper discusses the R&D efforts in India towards carbon management with special reference to geological CO_2 storage and development of alternate resources of fuels, namely coal bed methane and oil shale.

Geological CO_2 Storage

Carbon capture & sequestration (CCS) is the injection of nearly pure CO_2 gas (around 80%) captured from point sources and separated from flue gases into geological formations such as depleted hydrocarbon reservoirs for enhanced oil or gas recovery (EOR), unmineable coal seams for enhanced coal bed methane (ECBM) recovery, saline aquifers and flood basalts for sequestration. CO_2 is stored either in mineral, miscible and/or immiscible fluid phases and, depending upon the sequestration medium selected, the storage security varies from high to low.

The CO_2 is preferably injected in the super critical state in which it has physico-chemical properties between those of liquid and gas. 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. Three main trapping mechanisms by which the CO_2 is stored in the geological formations are hydrodynamic, solubility and mineral trapping. In hydrodynamic trapping the CO_2 is stored as a separate phase and has lower storage integrity. In solubility trapping, the CO_2 is dissolved in the formation fluids, providing a better trapping efficiency.

$$CO_2\ (gas) + H_2O \longrightarrow H_2CO_3\ (aq)$$

The most effective means is mineral trapping, in which the CO_2 reacts with the formation minerals and is converted to geologically stable mineral carbonate, as, for example:

$$CO_3^{-2}\ (aq) + Ca^{+2} \longrightarrow CaCO_3\ (solid)$$

Storage of CO_2 in Depleted Oil Reservoirs

Storage of CO_2 in depleted oil reservoirs is an economically viable option because the cost of CO_2 capture and transport is adjusted against the enhanced recovery of oil. CO_2 injected for EOR can be stored either in a miscible or immiscible phase and depends primarily on the pressure of the injection gas into the reservoir.

In the miscible phase, CO_2 mixes with the crude oil causing it to swell and reducing its viscosity, while 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. In the immiscible phase, the CO_2 is used to re-pressurize the reservoir and as a sweep gas, to move the oil towards the production well.

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

(Kumar M.S et al., 2007). The CO_2 is planned to be injected @ 600,000m^3/d and is sourced from ONGC gas processing complex at Hazira. 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.

Storage of CO_2 in Unmineable Coal Seams

CO_2 sequestration in unmineable coal seams serves the dual purposes of CO_2 storage and ECBM recovery. Coal beds typically contain large amounts of methane rich gas which is adsorbed onto the surface of the coal. The injected CO_2 efficiently displaces methane as it has greater affinity to the coal than methane in the proportion of 2:1 and is preferentially adsorbed, displacing the methane sorbed in the internal surface of coal layers.

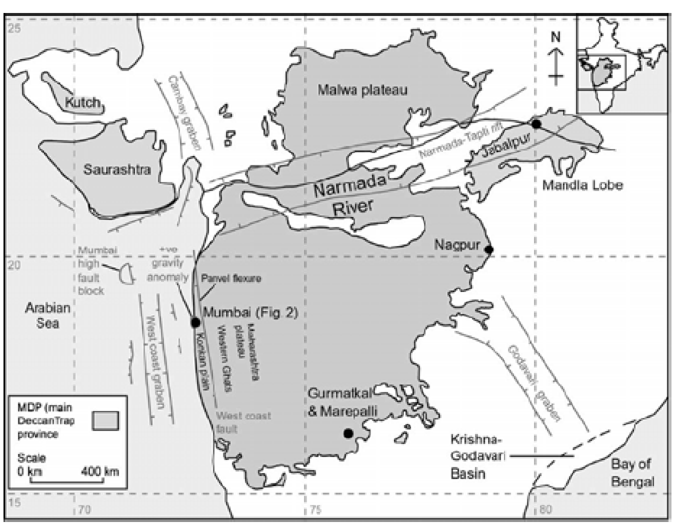
Storage of CO_2 in Basalt Formations

Basalt formations are the most viable options for environmentally safe and irreversible long time storage of CO_2 for India. The basalts are attractive storage media as they provide solid cap rocks and have favorable chemical compositions for geochemical reactions to take place between the CO_2 and the formation minerals, providing high level of storage security. The Intertrappean sediments between basalt flows also provide major porosity and permeability for injection.

Large Igneous Provinces like the Columbia River Basalt Group (CRBG) in the United States and the Deccan Traps of India are potential host media for geologic storage of CO_2. Lab study of the in situ reaction of CO_2 with basalt at Battelle Pacific Northwest National Laboratory (PNNL), Richland, USA (McGrail et.al. 2006) has shown fast mineralization reactions in terms of geological time scales (≤ 1000 days).

A pilot study for the evaluation of Basalt Formations of India for environmentally safe and irreversible long term storage of CO_2 has been initiated by National Geophysical Research Institute, Hyderabad jointly with the Department of Science & Technology, New Delhi, National Thermal Power Cooperation, India and Battelle PNNL, Richland USA. The Deccan traps with favorable geological, geophysical and geochemical features show promising option for carbon storage (Figure 1). The tectonically stable traps have intertrappean sediments in between the flows for providing sufficient porosity and permeability for CO_2 injection (Kumar, et al., 2005, 2007).

Deccan Basalts cover an area of 500 x 10^3 sq. km., and form one of the largest flood eruptions in the world. They are composed in most locations of > 40 flows. The



- Deccan Basalts cover an area of 500x10^3 sq. km. and form one of the largest flood eruptions in the world.
- Composed of typically > 40 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.

Figure 1: Out line map of Deccan Trap showing promising options for CO_2 storage (Out line map modified after Biswas, 1991)

thickness of basalt varies from few hundreds of meters to > 1.5 km. Basalts provide solid cap rocks and thus a high level of integrity for CO_2 storage. Basalts react with CO_2 and convert the CO_2 into mineral carbonates that provide a high level of security. Intertrappean sediments between basalt flows provide major porosity and permeability along with vescicular, brecciated zones within the flows. Tectonically the traps are considered to be stable. Geophysical studies have revealed the presence of thick Mesozoic and Gondwana sediments below the Deccan Traps.

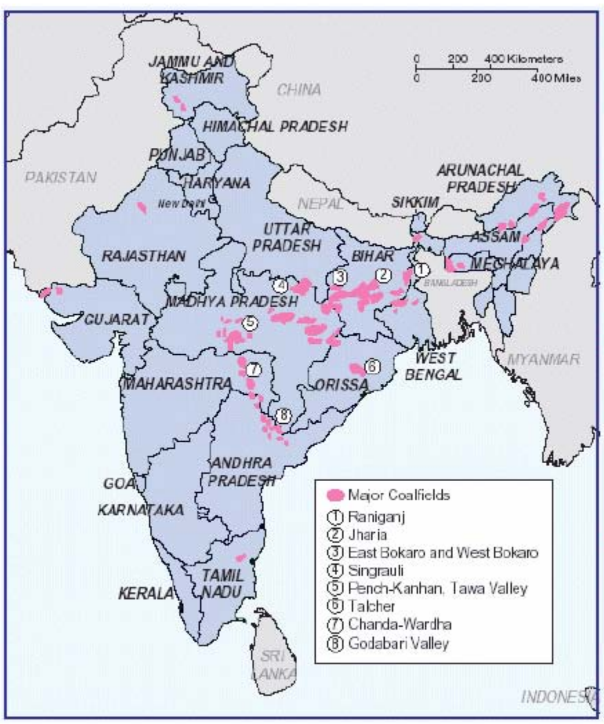
Storage of CO_2 in Saline Aquifers

Saline aquifers at depths of ≥800 m also provide viable options for the storage of CO_2, which can be stored in the miscible and/or mineral phase. The potential storage capacity is vast and is estimated to be ~ $1x11^{13}$ tons of CO_2. The high porosity and permeability of the aquifer sands along with low porosity cap rock such as shale provides suitable conditions for CO_2 storage. Over time, CO_2 gets dissolved in the brine and also reacts with the pore fluids and minerals to form geologically stable carbonates.

The Department of Science & Technology, India has initiated studies aiming at identification of deep underground saline aquifers and their suitability for CO_2 sequestration. The Central Ground Water Board and the 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 also shown the presence of saline aquifers at depths of 800m and beyond, around Palwal and Tumsara (Bhandari et al., 2007).

Coal Resources of India

Coal is the most abundant fossil fuel in India and accounts for 51% of India's energy need. Coal production in India grew to more than 328 million tones in 2001-02 rendering India as the third largest producer of coal with the present estimates of coal reserves of 247.85 billion tons (Figure 2). In 2005-06, the total coal production in the country was around 405.2 MMT.



State	Coal Resources in Million Tonnes			
	Proved	Indicated	Inferred	Total
Andhra Pradesh	8263	6079	2584	16926
Arunachal Pradesh	31	40	19	90
Assam	279	27	34	340
Bihar	0	0	160	160
Chhattisgarh	9373	26191	4411	39975
Jharkhand	35417	30439	6348	72204
Madhya Pradesh	7513	8815	2904	19232
Maharashtra	4653	2309	1620	8582
Meghalaya	117	41	301	459
Nagaland	4	1	15	20
Orissa	15161	30976	14847	60984
Uttar Pradesh	766	296	0	1062
West Bengal	11383	11876	4554	27813
Total	92960	117090	37797	247847

Formation	Proved	Indicated	Inferred	Total
Gondwana Coals	92528	116984	37428	246940
Tertiary Coals	432	106	369	907
Total	92960	117090	37797	247847

Figure 2: Coal resources of India (www.indiacore.com/coal)

With 10% of the world's coal and at current rates of production of over 92 billion tonnes, India has enough coal for the next 217 years. Coal has been recognized as the most important source of energy for electricity generation and about 75% of it is consumed in the power sector.

Coal is largely mined in the eastern and the central regions of the country. The coal resources of India mostly occur in the sedimentary rocks of Gondwana formations of peninsular India and Tertiary formations of Northeast India. The Gondwana coals account for 99% of total reserves. With the abundance of these coal reserves , coal is likely to remain the mainstay of the Indian energy sector making the development of advanced clean coal technology a central concern.

Due to its reliance on coal to the major extent presently and in near future, energy production in India is and is going to be very carbon intensive. Introduction of clean coal technology and low carbon technology coupled with capture and sequestration of carbon, and policies that can mitigate carbon emissions are therefore very important for carbon management. Low carbon technology with capture and storage may play an important potential role in addressing these challenges.

Alternate Sources of Energy

Coal Bed Methane

Coal bed Methane (CBM) represents an important alternate source of energy and refers to large volumes of natural gas, sourced and stored in coal seams. India has the sixth largest proven coal reserves in the world and unmineable coal contains varying amount of CBM depending on the rank of the coal, depth of burial and geotectonic settings of the basins . The coal bed methane potential of India is about 1,000 bcm (Raju & Ahmad, 2006).

Unmineable coal seams in India occur in most of the Gondwana and Tertiary coal fields. The Gondwana coal of India is bituminous in rank and have large CBM potential, whereas the Tertiary coal is sub bituminous in rank and is considered to be unsuitable for coal bed methane exploitation. In India, the Directorate General of Hydrocarbons (DGH), New Delhi has taken an initiative for the exploration and exploitation of CBM. The results are very encouraging with significant finds of CBM in Eastern and Central India.

CO_2 - ECBM can be advantageously used for exploiting the coal bed methane resources of India. The development and application of this technology is still at an early stage in the country. DGH, New Delhi has planed to initiate CO_2 - ECBM technology in some selected Gondwana coal fields.

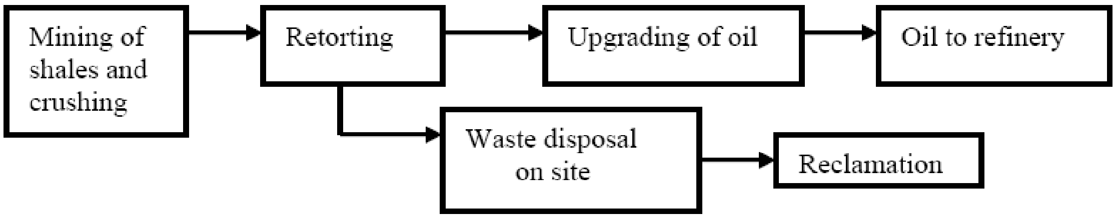
Oil Shale

Oil shale is one of the unconventional alternate resources of energy that has emerged as a possible means to supplement declining conventional hydrocarbon production. These are fine grained sedimentary rocks containing relatively large amounts of organic matter from which significant quantities of shale oil and combustible gas can be extracted. Oil shale ranges in age from Cambrian to Tertiary and the total world resources of oil shale are conservatively estimated at 2.6 trillion barrels.

Oil Shale Occurrences in India

In India, oil shale mostly occurs in the Northeastern part, interbedded with Tertiary coal. Carbonaceous shale of Oligocene age crops out in association with Tertiary Coal in Assam and neighboring areas of Arunachal Pradesh. The coal-shale unit occurs as outcrops towards south of the oilfields in a region called the Belt of Schuppen and it is part of the Barail and Disang formations. The presence of coal and organic rich shale has been recorded in the subsurface from wells drilled for oil. The coal-shale unit was probably deposited in a regressive phase in backwater lagoons or brackish water swamps on a prograding delta complex. The estimated in-place

Major steps in mining and surface retorting of oil shale



Steps for in situ conversion of oil shale to oil

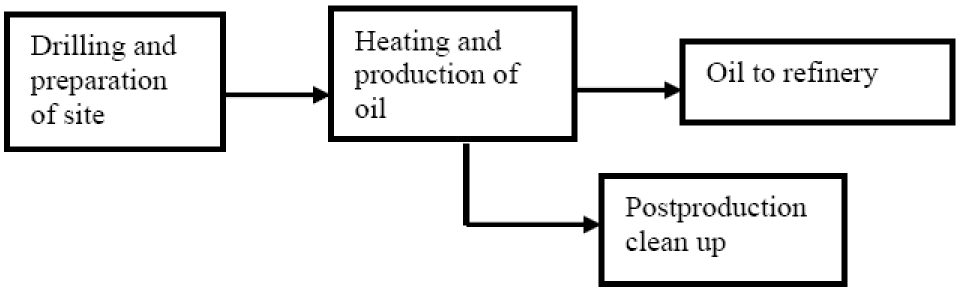


Figure 3: Schematic for oil shale retorting.

shale oil reserves are greater than 15 billion tons.

Salient Features of Oil Shale of North East India

Studies of shale samples from Upper Assam Valley resulted in a hydrocarbon potential of 81 mg/g, which compares favorably with yields known from oil shales elsewhere in the world. The characteristic features of Barail oil shale of Northeast India are:

- Average vitrinite reflectance in oil shale ranges from 0.5 to 0.7%;
- Rock-eval T_{max} values are less than 435 °C indicating low thermal maturity;
- The organic matter is predominantly type-II to type-III;
- Biomarker ratios indicate dominance of land plant derived kerogen with prevalence of C29 $\alpha\alpha\alpha$ 20R steranes with a high hopane/sterane ratio;
- Sulfur content is high (1.5 to 5%).

Oil Shale Retorting and Carbon Management

Oil from carbonaceous shale is produced by retorting, an energy intensive process in which the rock is heated in the absence of oxygen (Figure 3). It comprises surface retorting and thermally conductive in-situ conversion. Oil shale deposits usually contain carbonates and due to pyrolysis of kerogens and decomposition of carbonates, significant amount of CO_2 is released. Oil shale generally evolves several times more CO_2 during shale oil production than the same amount of petroleum does. This could be a serious defect from the viewpoint of global warming. Deep coal seams of North East India that are not commercially viable for coal production, could be used for permanent underground storage of CO_2 evolved from shale oil production. The CO_2 released from oil shale can also be used for EOR in depleted oil fields of North East India.

Summary

Carbon management and exploitation of alternate and renewable sources of fuel are the key to India's Energy Future. Coal Bed Methane and oil shale are very important alternate energy resources to meet the challenges of Indian energy demand.

India stands with the global community for accelerating R&D in CCS technologies for sustainable energy future. Initiatives for carbon capture research are in advanced stages worldwide; however the challenges are to develop cost effective methods. The CO_2 storage R&D in India is still in beginning stage and there is a need for developing programs on CO_2 – EOR, CO_2 - ECBM and geologic storage in saline aquifers and basalt formations etc.

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