Awareness and Capacity Building in Sustainable Energy (ACBSE-2010)

IIC, New Delhi, 6 August 2010

Proceedings

Programme Coordinator

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Jawahar Lal Nehru University
New Delhi - 110 067

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Preface

Future economic development strategy for India is expected to lead to an accelerated growth in the energy demand. In this context, a review of technology capabilities in the clean energy sector is of vital importance. Renewable energy development is receiving a new thrust in the National Action Plan on Climate Change 2008. At the same time clean energy development also requires application of strategic knowledge about carbon management, in view of dominance of coal in India's energy in the foreseeable future.

I convey my sincere thanks to India International Centre for sponsoring the Brainstorming Session on Awareness and Capacity Building in Sustainable Energy. The objective is creating awareness on the need to develop technology R&D imperatives for accelerating low carbon energy growth.

I convey my profound gratitude to Prof. P. N. Desai, Shri V. S. Verma and Dr. V. K. Garg for their whole hearted support and encouragement for organizing the ACBSE-2010. It would not have been possible but for the assistance from Council of Scientific and Industrial Research, which has facilitated the proceedings.

What is unique about this conference is that renewable energy and carbon sequestration are discussed on the same platform. We have to depend on both renewable and non-renewable energy resources to meet our energy requirements and both offer challenges in fulfilling the needs for a sustainable energy future. I would like to express my special thanks to Shri Pradeep Chaturvedi, Dr D. M. Kale, Dr S. N. Charan, Prof T. Satayanarayana, Dr. A. K. Singh, Dr P.S. R. Prasad, and Dr Chhemendra Sharma for their valuable contributions and taking out time from their busy schedule.

It is hoped that report is a positive step in the direction of clean energy policy and stimulates further debate on R&D strategies.'

Dr (Mrs) Malti Goel
Programme Coordinator and CSIR Emeritus Scientist

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Awareness and Capacity Building in Sustainable Energy (ACBSE-2010)

Sustainable development is development that satisfies the need of the present generation without jeopardizing the abilities of future generation to satisfy their needs.

--- World Commission on Environment and Development

1. Global warming is greatest environmental challenge in the current century before us. In the future economic development strategy, India is heading towards an accelerated growth in the energy demand. In this context, a review of technology capabilities in the clean energy sector is of vital importance. Fossil fuels are predominant having a share of 69% in the total installed capacity of electricity generation. There are concerns for increasing CO_2 emissions and impending climate change. In view of dominance of coal in India's energy in the foreseeable future, clean energy development would require application of strategic knowledge about carbon management. Three sustainability goals for an energy technology strategy in the context of climate change could be following.

   i. Cost and Economics
   ii. Materials and Resources
   iii. Environment and Safety

2. The energy resource base anywhere can be classified into two categories: namely (i) renewable and (ii) non-renewable. Quantum of renewable energy resources at a place is determined by the amount of sun-light received. The Indian subcontinent being in the tropical bell is endowed with a reasonably high amount of renewable energy resource. In the non-renewables, India is having about one eighth share resources base of coal. The oil resources are comparatively meager and these as well as gas reserves are still under exploration. In order to meet the basic energy needs of people, there is urgent need to bridge the gap and develop technology strategies which can introduce environmental sustainability with competitive techno-economic feasibility of thermal power generation. The third category for energy resource is nuclear energy, which is free from CO_2 emissions and in this manner is sustainable energy.

3. In this background the Awareness and Capacity Building in Sustainable Energy (ACBSE – 2010) was held in collaboration with **India International Centre, Council for Scientific** and **Industrial Research** and **Centre for Studies in Science Policy, JNU**. The increasing accumulation of CO_2 emissions in the atmosphere and the projections for the future has led to IPCC predictions and evidence of Global Warming. The CO_2 sequestration initiative as a multinational geo-modeling programme of Department of Energy, USA having two components, IS^3 and GS^3 offers an opportunity to carry out scientific studies and address R&D challenges for carbon management for fossil fuel based economics.

ACBSE-2010

4. The Awareness and Capacity Building in Sustainable Energy (ACBSE – 2010) has following goals.

Objectives

(i) Create awareness on renewable energy technology and sustainable energy options.

(ii) Capacity building in Carbon Capture and Storage for mitigating and adopting to climate change impacts.

(iii) To discuss competitive technology strategies of various sources of energy.

5. The programme was split into two technical sessions.

i. Technical Session I - **Climate Change and Sustainable Energy**

ii. Technical Session II - **Beyond Carbon Capture: Science of Geo-modeling Studies**

In climate related energy technologies, Carbon Capture and Storage (CCS) is emerging as a CO_2 mitigation option. The CCS is characterized by three main technologies. First is capture technology where CO_2 is separated from the flue gas of a large power plant or a heavy industry. The second is safe transportation of captured CO_2 to a place of its disposal. The third is CO_2 storage technology for its removal from the atmosphere, which requires its injections in suitable geo-environment. In the context of Enhance Oil Recovery (EOR) and Coal Bed Methane (ECBM), CO_2 sequestration offers value addition but at the same time many R&D challenges.

6. Dr. V. K. Garg, Chairman, Joint Electricity Regulatory Commission delivered by Inaugural Address and highlighted the importance of economic feasibility of a resource as a crucial step towards deployment of a technology.

7. Prof. P. N. Desai, Chairman, Center for Studies in Science Policy, presided over the Session 1: Climate Change and Sustainable Energy and delivered the Welcome Address. He said that bridging the gap between science & society through public participation is a critical phase of policy making.

8. Sh. V. S. Verma, Member, Central Electricity Regulatory Commission chaired the Session 2: Beyond Carbon Capture: Science of Geo-modeling Studies. He said ' Footprints in power sector are targeted to reduce as schemes like mandatory Renewable Purchase Obligations become coal based generation, Central Flechmists Regulatory Authority has a and structured programme with increase in energy efficiency of coal based power generation, through super-critical and ultra supercritical technology, have been advised the CO_2 . Recommendations were made for future course of action.

2.1 SIGNIFICANT HIGHLIGHTS

Technical Session 1- Climate Change and Sustainable Energy

9. Three invited presentations were made in the Session 1;

i. Overview of Sustainability Energy and Geo-modeling Studies - **Dr. (Mrs.) Malti Goel, Emeritus Scientist, Center for Studies in Science Policy.**

i. Nuclear Energy Programme in India and Underground Waste Disposal. - **Dr. Pradeep Chaturvedi, Chairman, IAAS**

ii. Climate change and Greenhouse gas emissions - **Dr. Chhemendra Sharma, National Physical Laboratory**

iii. Bio-energy as Renewable Energy Resource: Problems and Prospects. - **Prof. T. Satyanarayana, University of Delhi.**

10. Dr. Malti Goel said predictions of atmospheric temperature rise are made from Global Circulation Models (GCMS). Data in vast terrain in space and time are needed for these calculations. New priorities of sustainable development and climate change are emerging in favour of Renewable energy sources like solar, biomass, wind, ocean and geothermal. Both land and materials challenges need to be addressed for success of these. In India. Jawahar Lal Nehru National Solar Mission has been launched for achieving 20,000 MW power by 2022 in 3 stages. This mission comprises one of the eight missions under Indian National Action Plan on Climate Change 2008. On the other hand, fossil fuels like coal oil and gas constitute almost 3/4 of total CO_2 emissions. Coal is dominant energy sources in India and contributes almost 70% of the generation. The problem of increasing CO_2 in the atmosphere can be addressed through CO_2 sequestration technology - carbon capture and storage (CCS). Role of Geo-modeling in CO_2 sequestration, properties of super critical CO_2 and trapping mechanisms inside the earth need to address for understanding CCS technology. The CCS enabling technologies are not an important issue for India yet, because of their high cost.

11. Dr. Pradeep Chaturvedi said that on this day i.e. 6^{th} August 1945 the first demonstration of nuclear energy had caused tremendous devastation, but it was soon decided that nuclear energy should be under civilian domain. Thereafter, peaceful uses of nuclear energy were encouraged and it became a source of electricity worldwide. India has a three stage Nuclear energy development programme which began in the 1950's. India is among the 33 countries having nuclear power generation capabilities with expertise in nuclear reactor design and construction. He enlightened the participants about the early policies, recent efforts to upgrade fuel and the current debate on nuclear liability issues. Under the new plan of action a nuclear capacity of 35,000 MW has been targeted by 2020. He drew attention to challenges of radioactive waste management and its geological disposal.

12. For taking actions on control, mitigation or adaptation at a place greenhouse gas inventory is the first step. Dr. Chhemendra Sharma said that Indian national greenhouse gas inventories of anthropogenic emissions by sources and sinks have been prepared by NATCOM. Sectoral GHG emission data base has been created in *India Greenhouse Gas Emission 2007* (report by Ministry of Environment & Forests) using IPCC methodology and three tier approach. He described studies undertaken for utilization of data namely, (i) reduction of uncertainties in methane emission inventories, (ii) calculation of GHG emissions from agriculture residue & landfills and (iii) climate change modeling. He concluded by saying that future climate change and its impacts are carried out using GCMs and GHG inventories, hence it is desirable to have a robust database.

13. Bioenergy is renewable energy made available from materials derived from biological sources. It includes biomass, the biological material used as the source of energy, and therefore, the biomass is the fuel and the bioenergy is the energy contained in the fuel. Prof. T. Satyanarayana, University of Delhi described factors like economical, environmental and geopolitical issues that drive current interest in renewable energy sources. Biomass is any organic material which has stored sunlight in the form of chemical energy. As a fuel it may include wood, wood wastes, straw, manure, sugar cane and many other byproducts from a variety of agricultural and forestry operations. The energy derivable from biomaterials include bioethanol from ligniocellulosic residues, biodiesel from non edible plant oils *and algae as well as methane and hydrogen which can be produced using microbial fuel cells.* Indian co. are getting interested in biodiesel and public-private partnership is necessary in basic research and developing technologies.

Technical Session 2 - Beyond Carbon Capture: Science of Geo-modeling Studies

14. The invited presentations made in the Session 2 included;

i. Carbon Capture & Sequestration **- Dr. D. M. Kale, Director General, ONGC Energy Centre**

ii. Modeling Studies on Storage in Coal Seams and CO2 ECBM. - **Dr. A. K. Singh, Head Methane Group, CMMFR, Dhanbad**

iii. Aqueous Mineral Carbonation and CO2 reaction in Basalts for forming Mineral Carbonates **- Dr. S. N. Charan, NGRI, Hyderabad**

iv. Sequestration Carbon Dioxide into Clathrate Hydrates - **Dr. P. S. R. Prasad, NGRI, Hyderabad**

15. Dr. D. M. Kale (Director General, ONGC Energy Centre, Delhi) explained trends in CO_2 emissions in the atmosphere as a consequence of human activities. According to International Energy Agency (IEA) projections, CO_2 emissions business-as-usual are expected to become 62 Gt in 2050, from 28 Gt in 2005. He explained various possible reduction approaches and the role of CCS technologies. He said that from sequestration of CO_2 in depleting oil reservoirs, additional production of oil is one of the ways to synergize the process. Basic concepts in CO_2 storage, International operational research projects, R&D challenges and other problems faced were highlighted. International Energy Agency, Weyburn project is particularly relevant as it intends to demonstrate that CO_2-EOR is economically viable, environmentally and socially acceptable. He concluded by saying that no oil field is large enough in India to store life-time emissions from a medium sized power plant.

16. Coalification results in large amount of methane and other gases. Dr A. K. Singh said that worldwide efforts are being made for recovery of methane gas as a fuel and India ranks 5^{th} in exploration and production of Coal Bed Methane (CBM). Like oil fields, coal fields can also sequester excess CO_2. Dr. Singh described how coal matrix responds to CO_2 gas and the studies conducted on stronger affinity of CO_2 to coal molecules in comparison to methane. Basic research has been started. Modeling studies are being carried out for reservoir simulations, transport of CO_2 in coal beds and coal matrix reactions. Important parameters for simulation studies of CO_2 sequestration were explained.

17. Among the CO_2 storage options, geological sequestration is considered large scale disposal option by mineral trapping for safe storage. Dr. S. N. Charan said that flood basalts occupy more than 1million km^2 of the Earth's Surface and the Deccan Flood Basalt Volcanic Province in India is rich in reactive Fe-Mg-Ca and Na-bearing silicate mineral assemblage. In order to generate knowledge base on how CO_2 reacts with minerals and how one can compute the rate of carbonate formations, laboratory-scale experiments have been carried out. The science behind them is not yet fully understood. The research initially began in collaboration with Pacific North-West National Laboratory (PNNL), USA. He also said that PNNL is planning to carry out CO_2 injection studies in basalts in Columbia region. Simulation studies of rocks and results of simulated mineral carbonation were presented.

18. Laboratory studies on novel concepts in Glacial CO_2 Storage and storage in biogenic methane were presented by Dr. P. S. R. Prasad. Using advanced spectroscopy tools he described the studies carried out on the kinetics of carbonation reaction, structural changes and simulation of Clathrate Hydrate structures. Role of water interacting in CO_2 storage and trapping of gas molecules in hydrates has been investigated. He said that interesting results have been achieved in a research project supported by Department of Science & Technology.

19. Interactive discussions followed on nuclear energy perspectives, economic sustainability of new energy sources, future of bio-energy fuels and importance of CO_2 sequestration.. Dr. Meenakshi Dhote, Head, Environment Planning Division, School of Planning & Architecture said that this conference provided valuable insights on the concerns of energy and on aspects of bio-energy from a different perspective. Greenhouse gas inventorization is a mammoth task and in environmental planning projects land use, land use changes and their impact of GHG emissions is a major concern before urban planners.

20. Sh. V. S. Verma in his concluding remarks congratulated the organizers and said that research interest in carbon sequestration must be sustained. It should become a meeting point with power industry in the long run. He opined that clean energy and sustainable energy are very important for the coming decades. The programme of CO_2 fixation is being pursued in research mode for enhanced oil recovery and enhanced coal bed methane. He advised that recommendations should find place in the government.

2.2 RECOMMENDATIONS

1. The ACBSE-2010 has provided a meeting of experts from different disciplines. Teachers and students from academic institutions found it very enlightening as it gave an insight into recent developments.

3. Real-time issues in search of technology competitive solutions from both renewable and non-renewable sources were addressed. The conference helped in creating awareness and giving insights into the concerns of sustainable energy.

4. The following recommendations have emerged.

   (i) A Renewable Energy Policy is needed for achieving the sustainability goals.

   (ii) Understanding CO_2 capture and geological storage are important aspects of maintaining fossil fuel energy options.

   (iii) We need to keep the economics of energy supply, water shortage, food shortage and land constraints in view, while selecting a technology.

   (iv) A stakeholders' workshop on Sustainable Energy should be organized in the near future with the participation of national and international experts.

   (v) There are rapid developments taking place and the discussions should aim not only to enrich our knowledge for a technology strategy, but also to expand social science research network in the country and provide a policy support.

ACKNOWLEDGMENTS

The conference ended with a vote of thanks to all esteemed speakers. The facilities for the conference arranged by the India International Center, Delhi were excellent and gratefully acknowledged.

Presenation

3.1 Sustainable Energy and Geo-modeling Studies for CO_2 Storage

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The Awareness and Capacity Building in Sustainable Energy (ACBSE – 2010)

- ❖ One day Brainstorming Session organized in collaboration with **India International Centre and Center for Studies in Science Policy**
- ❖ Awareness on clean energy technology options and capacity building are targeted.
- ❖ Reduction of greenhouse gas emissions for mitigating and adopting to climate change impacts.

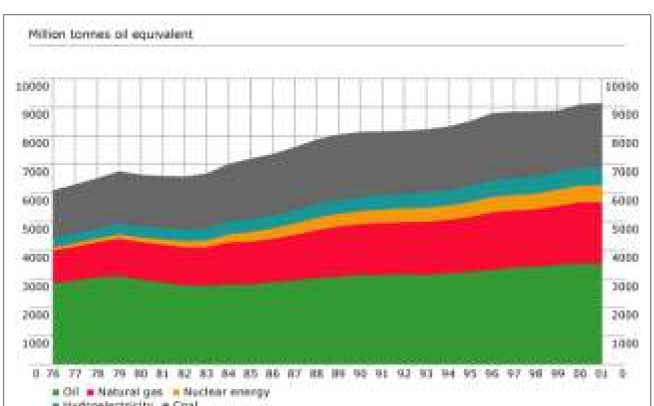
Sustainable Energy Goals?

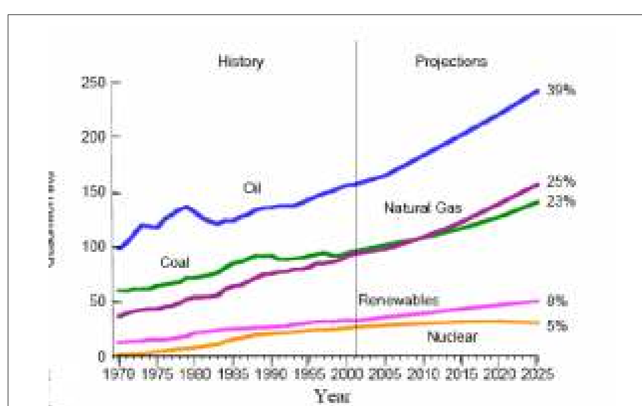
- Cost and Economics
- Materials and Resources
- Environment and Safety

Energy Resource Base at a Place

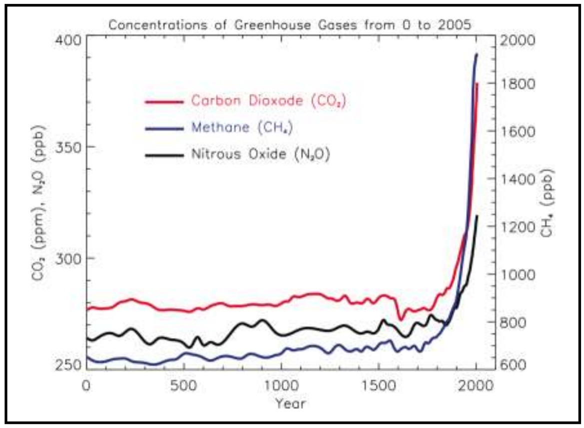
- ❖ **Renewables**
  - Solar, Wind, Hydro, Ocean, Geothermal energy
- ❖ **Non- renewables**
  - Coal, Oil, Gas, Nuclear

World Energy is Dominated by Fossil Fuels





Technical Session I

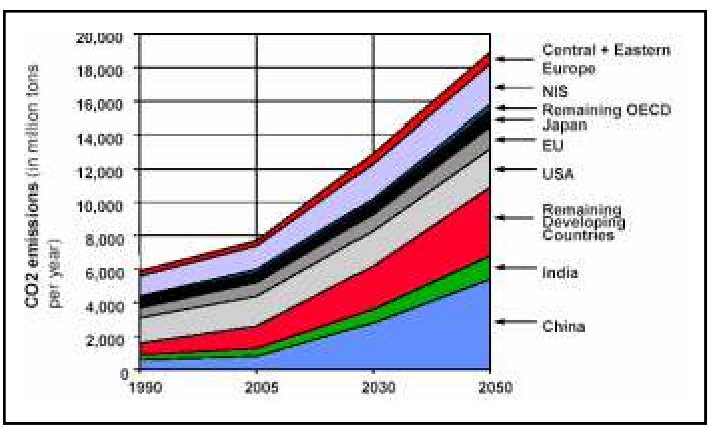


Increasing concentration of Greenhouse Gases

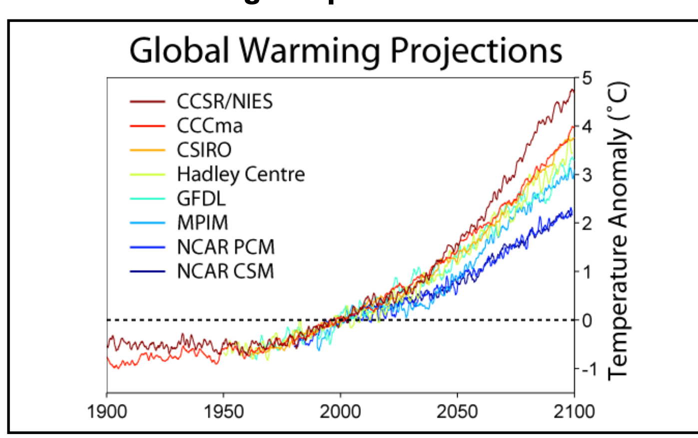
Climate Change and Sustainability

Focus on greenhouse gas emission scenario, the developments in renewable energy, nuclear energy & safety issues and recent developments including carbon capture for coal based power generation.

Global CO_2 Emissions and Projections



Earth's Increasing Temperature



Source- IPCC

India's Energy - Solar Energy

- ❖ Jawaharlal Nehru National Solar Mission launched on 11th January 2010
- ❖ Three phases
  - First Phase (2009-2012) - 1000MW
  - Second Phase (2012-2017) - Developments in Solar thermal (15 million sqm collector area)
  - Third Phase (2017-2022) - 2 0,000MW

Bio- energy

- ❖ Energy from Plants, which make use of solar chemical energy.
- ❖ Energy technologies include
  - Thermo-chemical Conversion of Biomass
  - Bio-chemical Conversion of Biomass
- ❖ Bio Energy share in 2031 for India is estimated to reach 500BkWh (2.5%)
- ❖ Competing demands from land for Agriculture

Nuclear Energy

- ❖ **Nuclear Fission**
  - Electricity generation from controlled nuclear reaction has become a target of many nations
  - 436 Nuclear plants are operational in 34 countries having over 350 GW capacity

Wind Energy

- ❖ Forecast for 2020 –World- 1,60,000 MW

  - India - 25,000 MW
- ❖ Wind Energy Potential in India - 48,000 MW
- ❖ Wind Energy installed capacity - 10,904MW
- ❖ Indigenous capability in manufacturing of wind machines of capacity 3 MW and more

Fossil Fuels

- ❖ Nearly 40% of world's energy comes from coal
- ❖ Coal is dominant energy resource in India contributes almost 70 % of the generation
- ❖ Coal, Oil and Natural gas account for almost three fourth of total emissions

Clean Energy from Fossil Fuels

- ❖ Natural gas as replacement of coal and oil for reducing CO_2 emissions
- ❖ Further reduction in CO_2 emissions can be through carbon management such as carbon capture and storage

Technical Session II

Beyond Carbon Capture: Science of Geo-modeling Studies

In the context of global warming, CO_2 sequestration - carbon capture and storage (CCS) is widely acknowledged as an emerging technology to address the problem of increasing carbon dioxide (CO2) in the atmosphere.

Carbon Capture and Storage

The Carbon Capture and Storage (CCS) technologies are emerging for CO_2 mitigation. The CCS is characterized by three main technologies.

- **CO_2 Capture -** Capture from the flue (waste) gas of a large power plant or a heavy industry.
- **CO_2 Fixation -** Fixation of CO_2 in terrestrial environment using biological methods. It can also be converted into useful products.
- **CO_2 Transportation & Storage -** Safe transportation of captured CO_2 to a place of its disposal and its injections in suitable geo-environment for its removal from the atmosphere.

Where do you Store CO_2?

- Deep saline formations. These are porous and permeable reservoir rocks containing saline water in their pore spaces.
- Depleted or partially depleted oil fields – either as part of, or without, enhanced oil recovery (EOR) operations.
- Coal seams (= coal beds) – either with or without enhanced coal bed methane recovery (ECBM) operations

Properties of Super Critical CO_2

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

Underground Trapping Mechanisms

- Solution trapping
- Residual gas trapping
- Mineralogical trapping
- Large-scale geometric trapping

Role of Geo-modeling studies

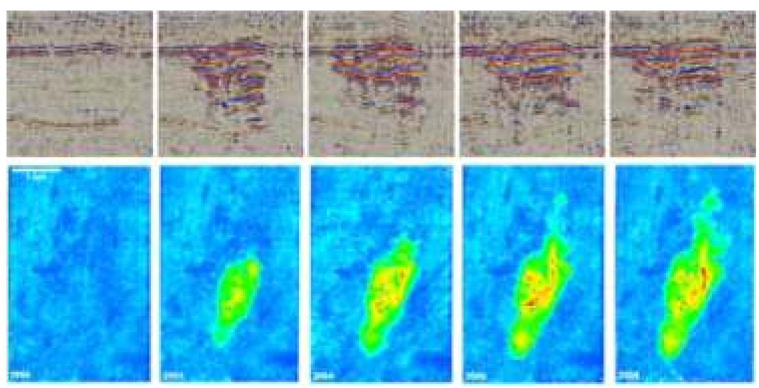
- Geo-modeling studies are needed to model the dynamics of reservoir in terms of its various parameters such as depths, size cap rock characteristics as well as CO_2 behavior in the reservoir.
- Reactive transport modeling integrates the geochemical, hydrological, and mechanical processes that characterize dynamic geologic systems.

What Models can Do?

- A number of issues can be addressed in numerical modeling of CO_2 sequestration
- A range of models have been developed to study CO_2 geochemistry, leakage pathways and trapping mechanism, like STOMP, FEHM, PNLCARB and TOUGH.
- STOMP-CO_2 is numerical multiphase CO_2 flow and transport simulator for modeling behavior at CO_2 of indifferent geo-environments.
- PNLCARB adopted a semi-analytical modeling framework to simulate deep-well injection of CO_2 for geological sequestration.

CO_2 Sequestration Initiative

- CO_2 sequestration multi-national geo-modeling programme has two components
  - In Situ Supercritical Suite [IS3)
  - Geological Sequestration Software Suit (GS3).



IS2

- The In Situ Supercritical Suite or IS3 is a group of instruments to probe geochemical reactions inside the earth under supercritical pressures and temperatures.
- It uses advance optical spectroscopy, nuclear magnetic resonance, atomic force microscopy and high pressure XRD instruments to study supercritical CO_2

GS3

- The Geologic Sequestration Software Suite, GS^3, is designed for modeling of geological sites for sequestration using advance scientific programming
- It is an extensible, dynamic and integrated computing environment using data, scientific software, analytical tools, and computing resources.

Summing Up

Bridging the Gap between Science & Society

- A Renewable Energy R&D Policy is needed for achieving the sustainability goals
- Understanding CO_2 capture and geological storage are an important aspect of maintaining fossil fuel energy options

3.2 Nuclear Energy Programme in India and Underground Waste Disposal

Pradeep Chaturvedi
Chairman
Indian Association for the Advancement of Science

India's nuclear power programme has always maintained a long term focus. A very conscious decision has been made to utilize India's limited Uranium resources and still make a large contribution to nuclear power development. Keeping that in view India has developed a three stage nuclear power development programme. Technological development is taking place at a fast pace and to keep abreast of these technologies, it is necessary for India to maintain a rapid pace in R&D and its deployment.

The Expert Committee on Integrated Energy Policy, in its report in August 2006, emphasized on nuclear power contributing significantly to India's energy supply. Even realizing the constraints and the small quantity of nuclear power in the over all scenario, the Expert Committee took a very conscious decision to highlight that the nuclear power contribution has to be raised. In its Report it studied the lean Uranium resources in the country and the possibility of developing nuclear energy through different routes and its definite contribution by the year 2030 and 2050.

The Expert Committee was informed that India's available Uranium supply can fuel only 10,000 MW of the pressurized heavy water reactors (PHWRs). Further, India is extracting Uranium from extremely low grade ores (as low as 0.1% uranium) compared to ores up to 12-14% Uranium in certain resources abroad. This would make Indian Nuclear fuel two to three times costlier than international supplies. The substantial thorium reserves can be used but that require fertile Thorium to be converted to fissile material. In this context, a three stage nuclear power programme is envisaged. This programme consist of setting up of Pressurised Heavy Water Reactors (PHWRs) in the first stage, Fast Breeder Reactors based on the Uranium 233-Thorium 232 cycle in the third stage. It also envisaged that in the first stage, of the programme, has been capacity addition will be supplemented by electricity generation through Light Water Reactors (LWRs), initially through import of technology, but with the long-term objective of indigenization. PHWR technology was selected for the first stage as these reactors are efficient users of natural Uranium for yielding the plutonium fuel required for the second stage FBR programme. The FBRs will be fuelled by plutonium and will also recycle spent Uranium from the PHWR to breed more plutonium fuel for electricity generation.

The first stage programme of PHWR technology has reached maturity, though much later than was initially expected. A beginning has been made in the introduction of LWRs with the inter-governmental agreement between India and the Russian Federation for cooperation in setting up of 2x1,000 Megawatt Electrical (MWe) LWRs at Kudankulam, Tamil Nadu. A 40 MWe Fast Breeder Test Reactor (FBTR) was set-up in 1985 at Kalpakkam to gain experience in the technology under the second phase. This has been followed by progress in the development of technology for the first Prototype Fast Breeder Reactor (PFBR) of 500 MWe capacity. Such a plant is currently under construction. Research and development on the utilization of thorium is also in progress.

FBR technology is critical to developing stage two of India's nuclear power programme. Without developing the wide-scale use of FBR technology, India will find it difficult to go beyond 10,000MWe nuclear capacity based on known indigenous Uranium resources. Use of FBR technology would enable indigenous Uranium resources to support a 20,000 MWe nuclear power programme by the year 2020. Such a FBR programme is critical to developing the Thorium-based third stage of India's nuclear power programme. The Bhabha Atomic Research Centre (BARC) is also engaged in R&D activities to develop an Advanced Heavy Water Reactor of 300 MWe capacity that would provide industrial scale experience necessary for the Thorium-based Stage Three of India's nuclear power programme. Table shows the potential of nuclear energy with domestic resources in the country.

The pace of development of nuclear power is constrained by the rate at which plutonium can be bred and Thorium converted to fissile material. If India is able to import nuclear fuel, the process can be accelerated. Two possible growth paths of nuclear power are summarized in the Table1.

Table 1: The Approximate Potential Available From Nuclear Energy

Particulars	Amount	Thermal Energy		Electricity	
		TWh	GW-Yr.	GWe-Yr.	MWe
Uranium -Metal	61,000-t				
In PHWR		7,992	913	330	10,000
In FBR		1,027,616	117,308	42,000	5,00,000
Thorium-Metal	2,25,000-t				
In Breeders		3,783,886	431,950	1,50,000	Very large

Waste Management

A multi-barrier approach is followed in the disposal of radioactive solid wastes. The overall safety against migration of radionuclide is achieved by proper selection of waste form, suitable engineered barriers, backfill materials and the characteristics of the geo-environment of the repository site. Based on the nature and type of the radionuclide present in the solid waste and its concentration the repository could be near-surface or in deep geological formations. Operation of various Near Surface Disposal Facilities (NSDF) has led to considerable expertise in this field. India's programme on site selection & hot rock characterization is under evaluation for deep geological disposal.

Disposal of Radioactive Waste

Disposal as a final step in the management of radioactive waste involves confinement or isolation of these wastes from biosphere in the repositories. Based on the longevity and concentration of the radionuclide present in the waste, the repository could be either near-surface or in deep geological formation.

India has extensive and varied experience in the operation of near surface disposal facilities (NSDFs) in widely different geohydrological and climatological conditions. Over the years, considerable expertise has gone in refining and improving the design and construction of these NSDFs. A system of multiple barriers employed in these NSDFs ensures isolation and release of radionuclides below permissible limits to the environment. This is ensured by regular monitoring and periodic performance assessment of these NSDFs.

Disposal of long-lived and high level waste in deep underground geological formation is one option which has received world-wide attention. In this context, our programme of site selection and host rock characterization for an Underground Research Laboratory is under evaluation.

Near Surface Disposal

As a national policy, each nuclear facility in India has its own Near Surface Disposal Facility (NSDF). There are seven NSDFs currently operational within the country. These NSDFs in India have to address widely varied geological and climatological conditions.

The performance of these NSDFs is continuously evaluated to enhance the understanding of migration, if any and to adopt measures for upgrading the predictability over a long period of time.

Backfills and Buffers for Geological Disposal

Backfills and buffers constitute the most important components of multi-barrier scheme adopted in a geological disposal system in hard rocks. These layers are placed between the waste overpack and the host rock mainly to restrict the groundwater flow towards the waste form and to retard the migration of radionuclides in the event of their release from the overpack. Swelling bentonitic clays predominantly composed of smectite mineral have emerged as preferable choice for such use due to their very low hydraulic conductivity and high retardation for radionuclides. Besides, their swelling property adds in sealing the fractures in the host rock.

Finland's Nuclear Waste Solution

Here on Olkiluoto Island, the forest is king. Elk and deer graze near sun-dappled rivers and shimmering streams, and humans search out blueberries and chanterelle mushrooms. Weathered red farmhouses sit along sleepy dirt roads in fields abutting the woods. Far beneath the vivid green forest, deep in the bedrock, workers are digging the labyrinthine passages and chambers that they hope to somebody pack with all of Finland's spent nuclear fuel.

Posiva, the Finnish company is building an underground repository here, says it knows how to imprison nuclear waste for 100,000 years. These multimillennial thinkers are confident that copper canisters of Scandinavian design, tucked into that bedrock, will isolate the waste in an underground cavern impervious to whatever the future brings: sinking permafrost, rising water, earthquakes, copper-eating microbes, or oblivious land developers in the year 2050. If the Finnish government agrees a decision is expected by, 2012 this site will become the world's first deep, permanent repository for spent nuclear fuel.

There is more at stake here than the interment of 5500 metric tons of spent Finnish fuel. More than 50 years after the first commercial nuclear power plants went operational in the United Kingdom and the United States, the world's 2,70,000 metric tons of spent nuclear fuel remain in limbo. After it gets swapped out of a reactor, utilities put it in specially designed pools, where chilled, circulating water absorbs the initial heat and radioactivity. After about five or six years, the fuel has cooled considerably, enabling utilities with limited pool space to load it into huge, million-dollar steel casks that are lift to sit on concrete pads within guarded compounds.

So far, Posiva has carved out nearly 5000 meters of tunnels and shafts, excavated more than 100,000 cubic meters of rock, and collected rock samples from 53 deep boreholes. Over the next three years, it will try to prove to the government that its canisters and deep chambers will contain radioactive waste no matter what happens to Finland. If Posiva succeeds, the repository will open for business in 2020. A hundred years later, the final canister will be buried, and the tunnels will be filled in, covered up, and artfully abandoned to a cover of pine needles and mushrooms. Finland's first nuclear era will be over.

Onkalo's underground tunnels won't even begin to address the global situation. But they will do the next best thing. This project, estimated to cost 3 billion ($4.5 billion), will either demonstrate that the technical, social, and political challenges of nuclear waste disposal can be met in a democratic society, or it will scare other such countries away from the repository idea for decades to come.

The waste will emit harmful levels of radioactivity for thousands of years to come, and the casks are expected to last for a couple of hundred years, at most. The lack of a more permanent option is one of the biggest problems facing the global nuclear-power industry, which has been stalled for decades. But concerns about climate change have revived the prospects for nuclear power's future growth, daring the industry to hope for a rebirth.

#####

3.3 Climate Change and Greenhouse Gas Emissions

Chhemendra Sharma
Radio and Atmospheric Science Division
National Physical Laboratory

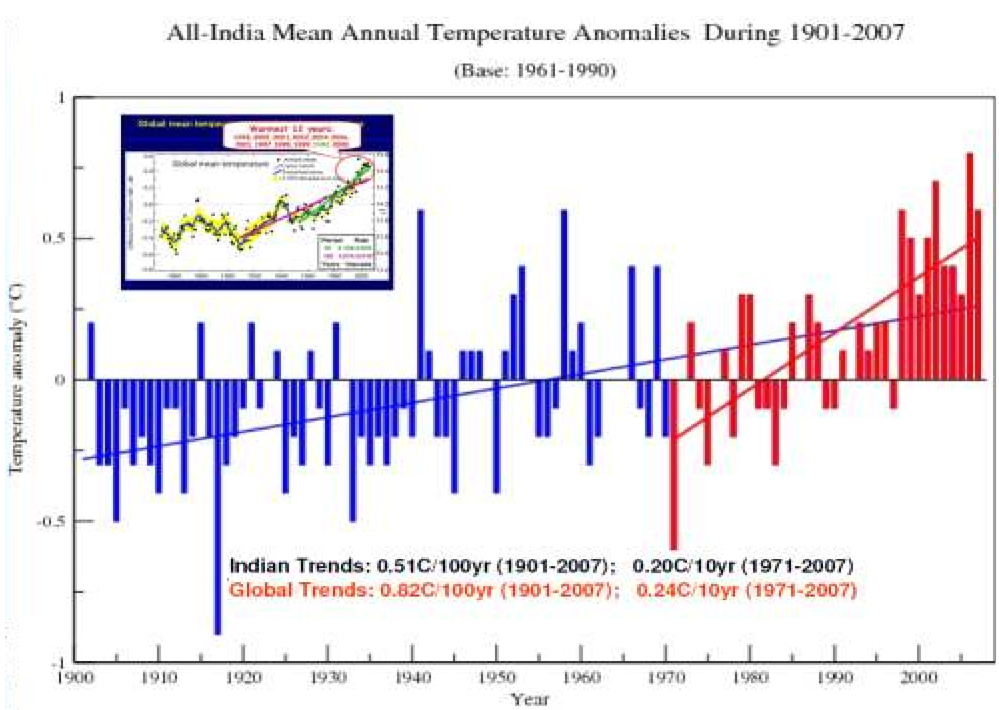
Layout of presentation

- GHG Emission Inventories
- Efforts for Reduction of Uncertainties
- Emission Inventories and Climate Change Modeling

Direct Observations of Global warming

- **Warming** of the climate system is **unequivocal**, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

(IPCC AR4)



Source: Krishna Kumar, NATCOM 2009

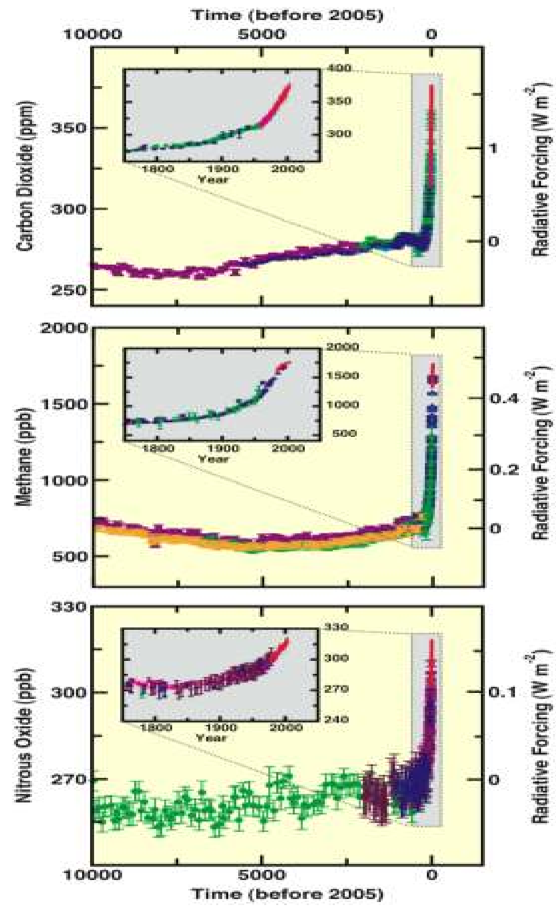
Human and Natural Drivers of Climate Change

CO$_2$, CH$_4$ and N$_2$O Concentrations

- far exceed pre-industrial values
- increased markedly since 1750 due to human activities

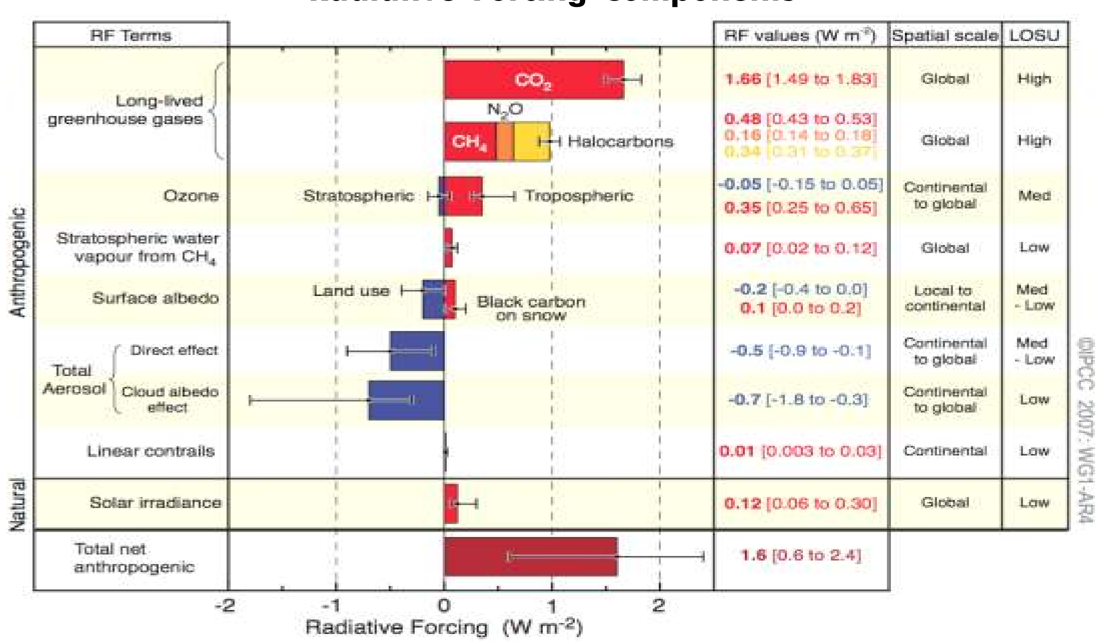
Relatively little variation before the industrial era

IPCC AR4



Global-average radiative forcing estimates and ranges

Radiative Forcing Components



Climate Change Assessments in Retrospect

GLOBAL

- ❖ Emergence of climate change as an issue, 1988
- ❖ United Nations Framework Convention on Climate Change, 1992
- ❖ IPCC Assessments
  - Science
  - Impacts, Vulnerability & Adaptation
  - Mitigation
  (1992, 1997, 2002, 2007)

INDIA

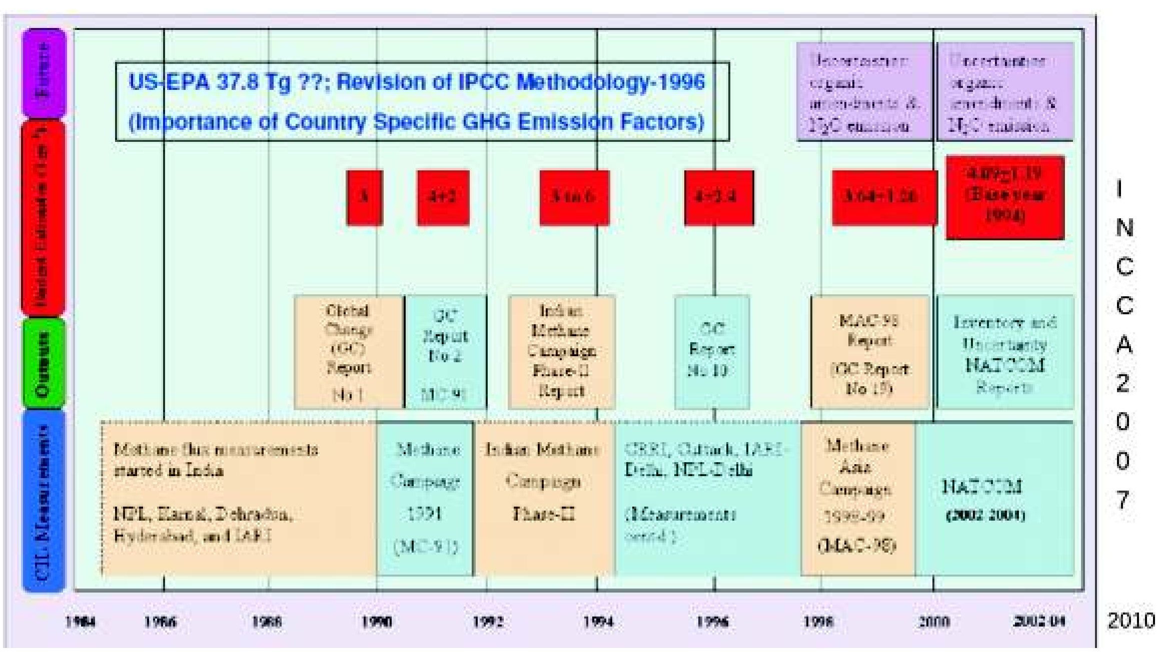
- ❖ ADB study, 1994 & 1998

  Focus - Impacts of Climate variability & Observed Climate on agriculture & sea level rise, GHG inventory 1990 & Project based assessments of Mitigation potential.
- ❖ NATCOM I, 2007

  Focus - Climate change scenarios, CC impacts at sectoral levels, GHG inventory for base year 1994 & development of country specific EFs.
- ❖ Other isolated studies by researchers.

Greenhouse Gas Emission Inventories

Data Quality and International Traceability through NMI-CH_4 from Rice example



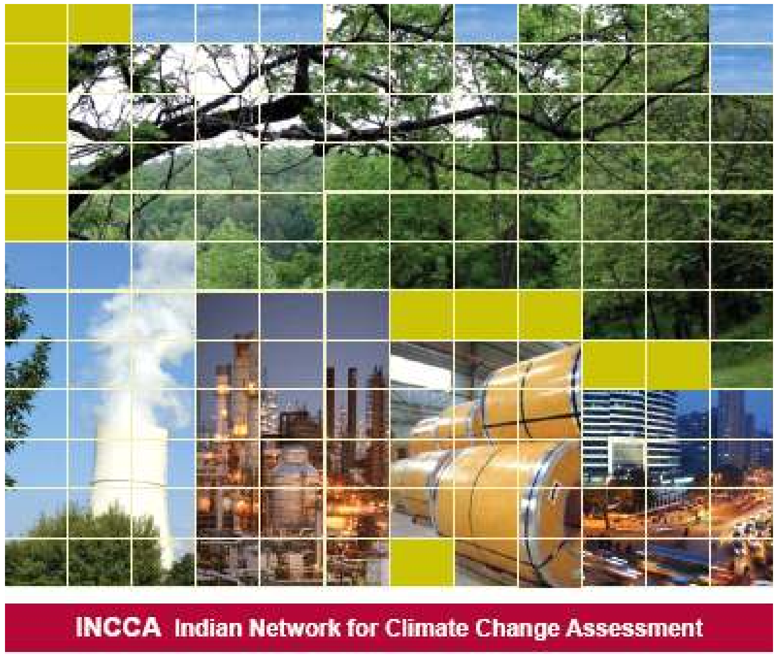
Chronology of measurement of methane emission from rice fields in India, reports and budget estimates

Initial National greenhouse gas inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol NATCOM I

GHG source and sink categories (Gg per year)	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO_2 eq. emissions*
Total (Net) National Emission	**817023**	**23533**	**18083**	**178**	**1228540**
1. All Energy	**679470**		**2896**	**11.4**	**743810**
Fuel combustion					
Energy and transformation industries	353518			4.9	355037
Industry	149806			2.8	150674
Transport	79880		9	0.7	80286
Commercial/institutional	20509			0.2	20571
Residential	43794			0.4	43918
All other sectors	31963			0.4	32087
Biomass burnt for energy			1636	2.0	34976
Fugitive Fuel Emission					
Oil and natural gas system			601		12621
Coal mining			650		13650
2. Industrial Processes	**99878**		**2**	**9**	**102710**
3. Agriculture			**14175**	**151**	**344485**
Enteric Fermentation			8972		188412
Manure Management			946	1	20176
Rice Cultivation			4090		85890
Agricultural crop residue			167	4	4747
Emission from Soils				146	45260
4. Land use, Land-use change and Forestry*	**37675**	**23533**	**6.5**	**0.04**	**14292**
Changes in forest and other woody biomass stock		14252			(14252)
Forest and grassland conversion	17987				17987
Trace gases from biomass burning			6.5	0.04	150
Uptake from abandonment of managed lands		9281			(9281)
Emissions and removals from soils	19688				19688
5. Other sources as appropriate and to the extent possible					0
5a. Waste			**1003**	**7**	**23233**
Municipal solid waste disposal			582		12222
Domestic waste water			359		7539
Industrial waste water			62		1302
Human sewage				7	2170
5b. Emissions from Bunker fuels #	**3373**				**3373**
Aviation	2880				2880
Navigation	493				493

Not counted in the national totals.

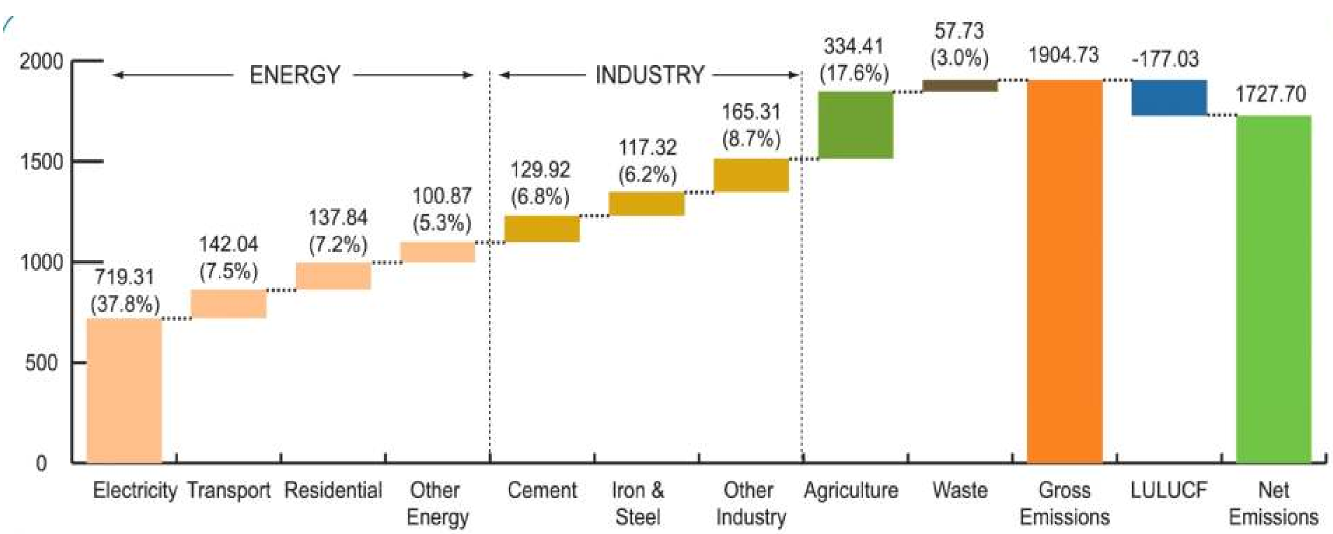
*Converted by using GWP indexed multipliers of 21 and 310 for converting CH_4 and N_2O respectively.



India: Greenhouse Gas Emissions 2007 - http://www.moef.nic.in

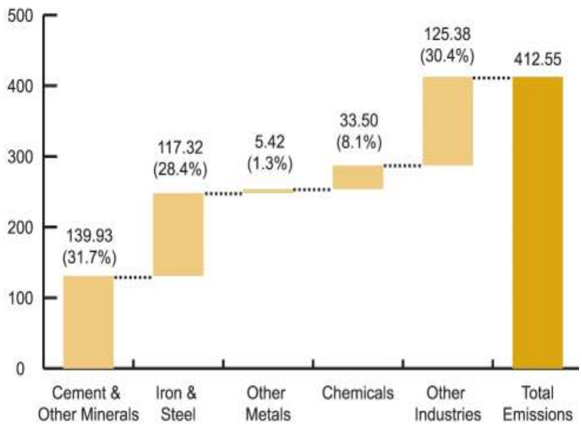
GHG Emissions by Sector 2007

(million tons of CO_2 equivalent)



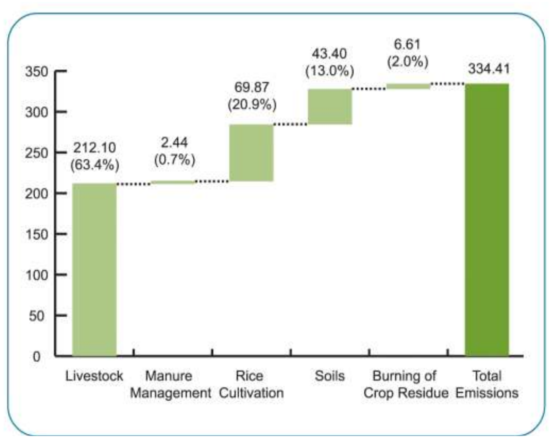
GHG emissions from Industry

(million tons of CO_2 equivalent)



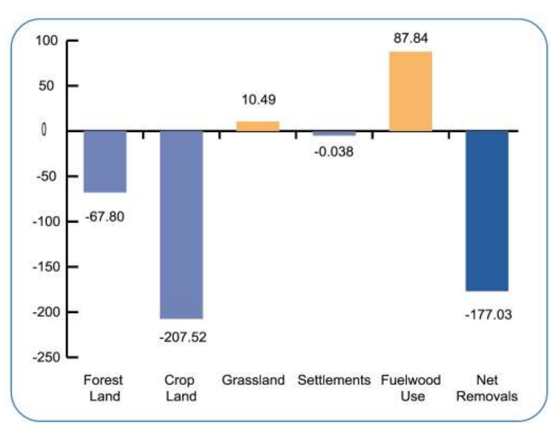
GHG emissions from the Agriculture sector

(million tons of CO_2 equivalent)



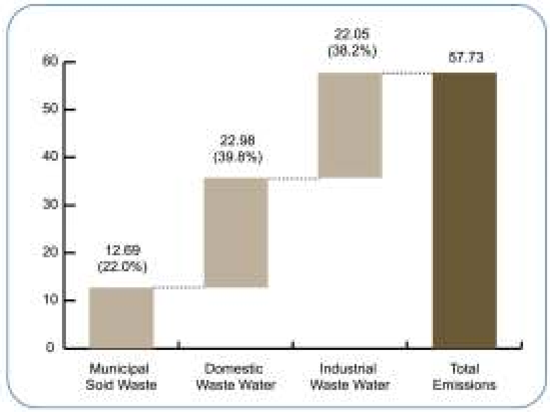
GHG emissions from the LULUCF sector

(million tons of CO_2)



GHG emissions from Waste sector

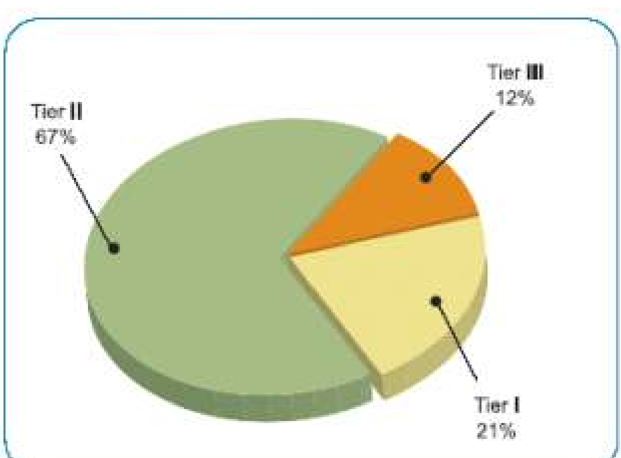
(million tons of CO_2 equivalent)



Key Results

- The total net Greenhouse Gas (GHG) emissions from India in 2007 were 1727.71 million tons of CO_2 equivalent (eq) of which
  - CO_2 emissions were 1221.76 million tons;
  - CH_4 emissions were 20.56 million tons; and
  - N_2O emissions were 0.57 million tons
- GHG emissions from Energy, Industry, Agriculture, and Waste sectors constituted 58%, 22%, 17% and 3% of the net CO_2 eq emissions respectively.
- Energy sector emitted 1100.06 million tons of CO_2 eq, of which 719.31 million tons of CO_2 eq were emitted from electricity generation and 142.04 million tons of CO_2 eq from the transport sector.
- Industry sector emitted 412.55 million tons of CO_2 eq. LULUCF sector was a net sink. It sequestered 177.03 million tons of CO_2.
- India's per capita CO_2 eq emissions including LULUCF were 1.5 tons/capita in 2007.

Tiers of methodology used for 2007 GHG emission profile



Tier I : approach employs activity data that are relatively coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics, and global land cover maps.

Tier 2 : use the same methodological approach as Tier 1 but applies emission factors and activity data which are defined by the country.

Tier 3 : approach uses higher order methods are used including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by disaggregated levels.

Efforts for reduction of uncertainties in emission inventories - Examples

❖

Assessment of trace gases, carbon and nitrogen emissions from field burning of agricultural residues in India.

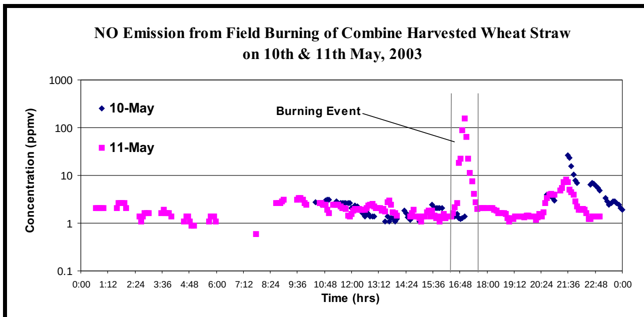
❖

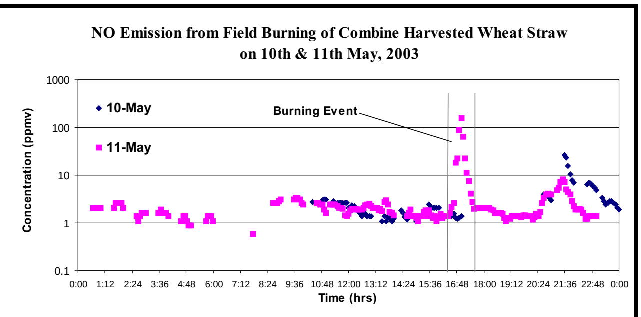
Sahai et. al., Nutrient Cycling in Ago-ecosystem, (In press - 2010)

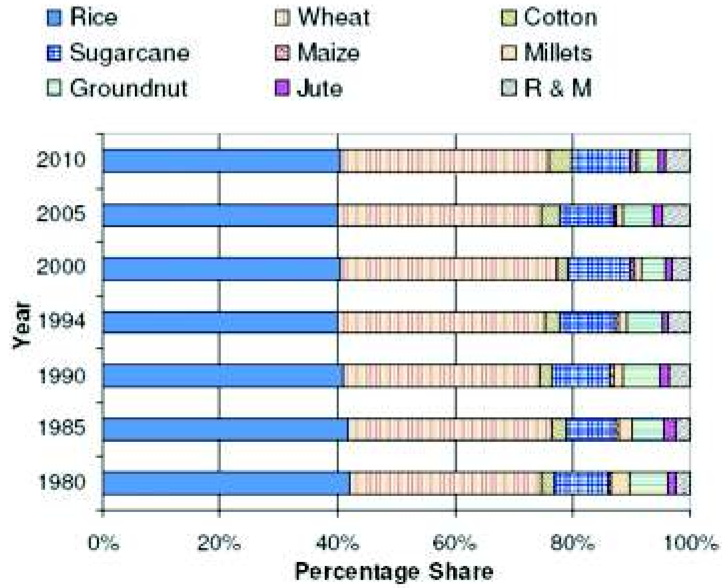
Agricultural Residue Burning in the Farms of G B Pant University of Agriculture & Technology (Pantnagar)

Wheat Straw Burning May 2003

Rice Straw Burning November 2003

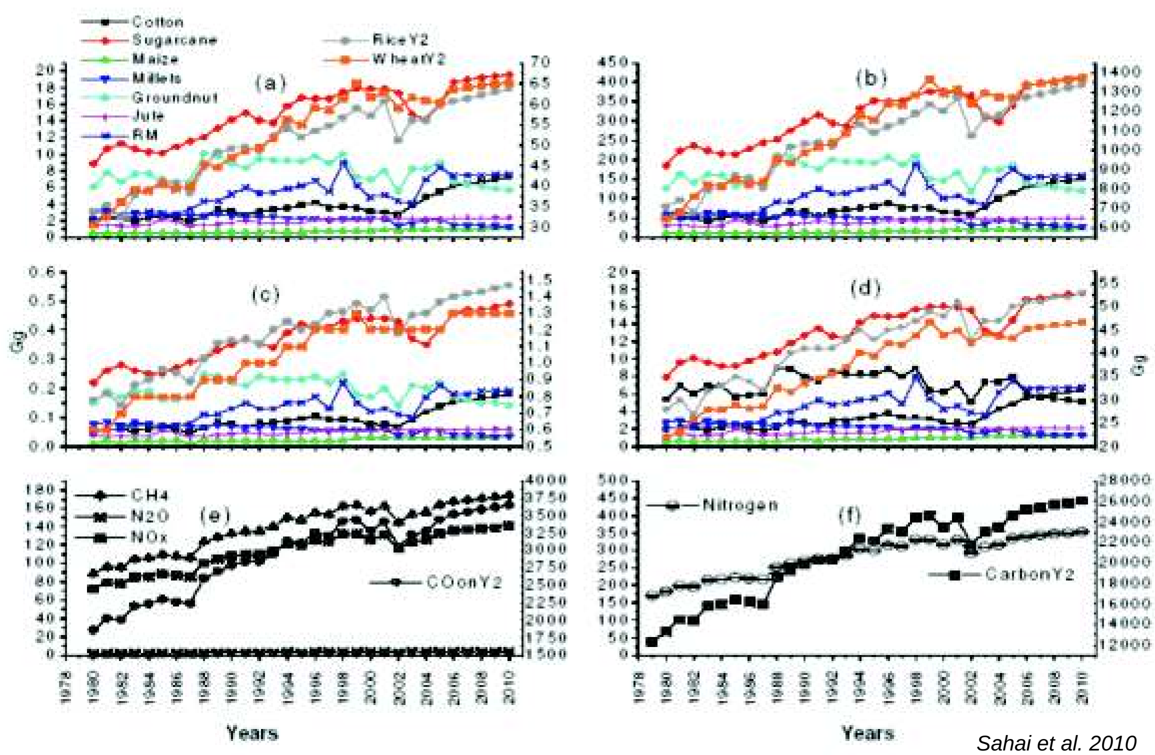




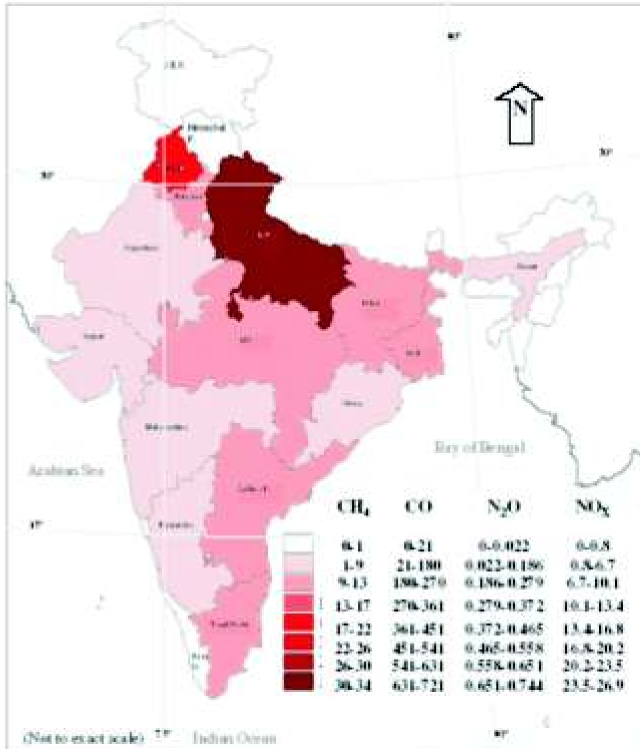


Sahai et al. 2010

Figure 1: Shares of different crops in dry residue generation



Crop-wise emission variation of (a) CH_4 (b) CO, (c) N_2O, (d) NO_x (a, b, c & d have same legends and emissions for rice and wheat are shown on Y2 axis); (e) trace gases emission from total of all crops; and (f)total nitrogen and carbon from all crops, between 1980 and 2010 from FBCR (Gg)



Sahai et al. 2010

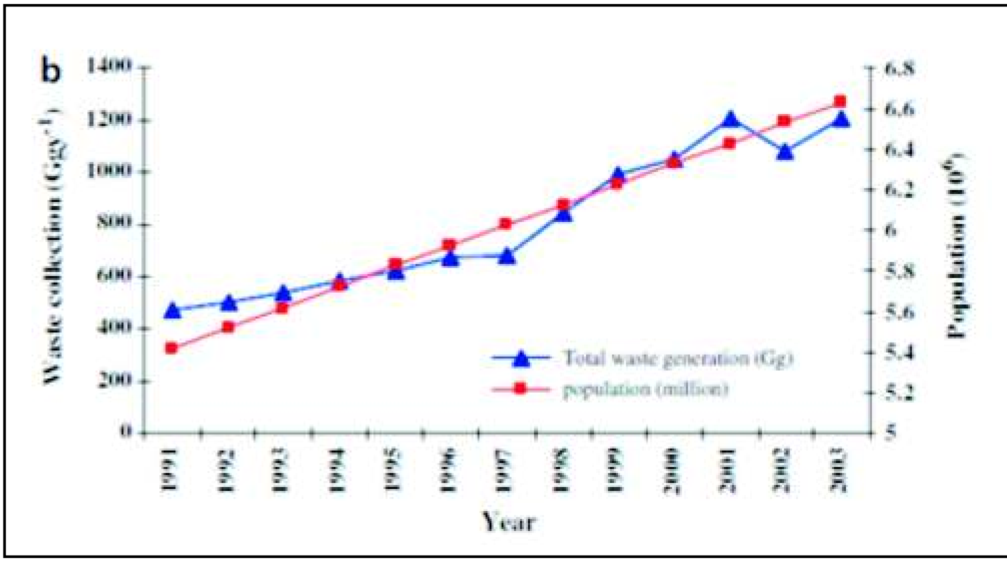
Figure 4: State-wise emission distribution of CH_4, CO, N_2O and NO_x from FBCR in India for the year 1994 (in Gg)

Greenhouse gas Emissions from landfills

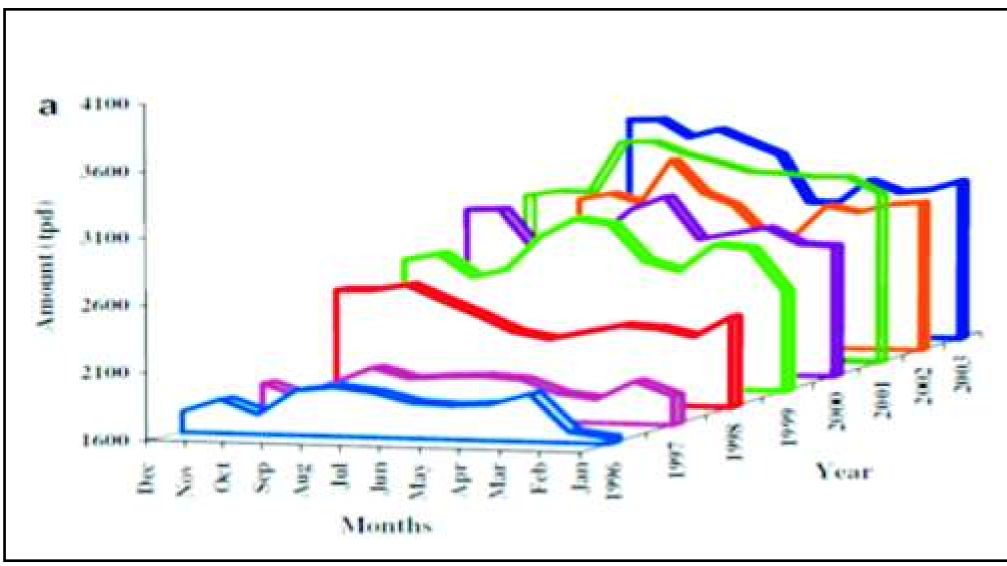
Scenario of municipal solid waste in four mega cities

Parameter	Year		Year			
			Chennai	Delhi	Kolkata	Mumbai
Area (km_2)	1981		174.0	148.4	187.33	437.71
Population (million)	1991		4.28	6.22	4.13	8.23
	2001		5.42	8.42	11.02	12.6
	1994		6.56	12.87	13.2	16.43
	1999		0.66	0.48	0.32	0.44
	1999		0.61	1.1	0.55	0.52
Garbage pressure (tons /km_2)	1999		17.529	4.042	16.548	13.708
Waste collection (Gg per day)			1999	3.124	5.327	3.692 6
Mode of disposal (%)	Landfilling		100	93	100	91
	Composting		-	7	-	9

Increase in MSW and population growth in Chennai. (Source: Jha et al. 2008)



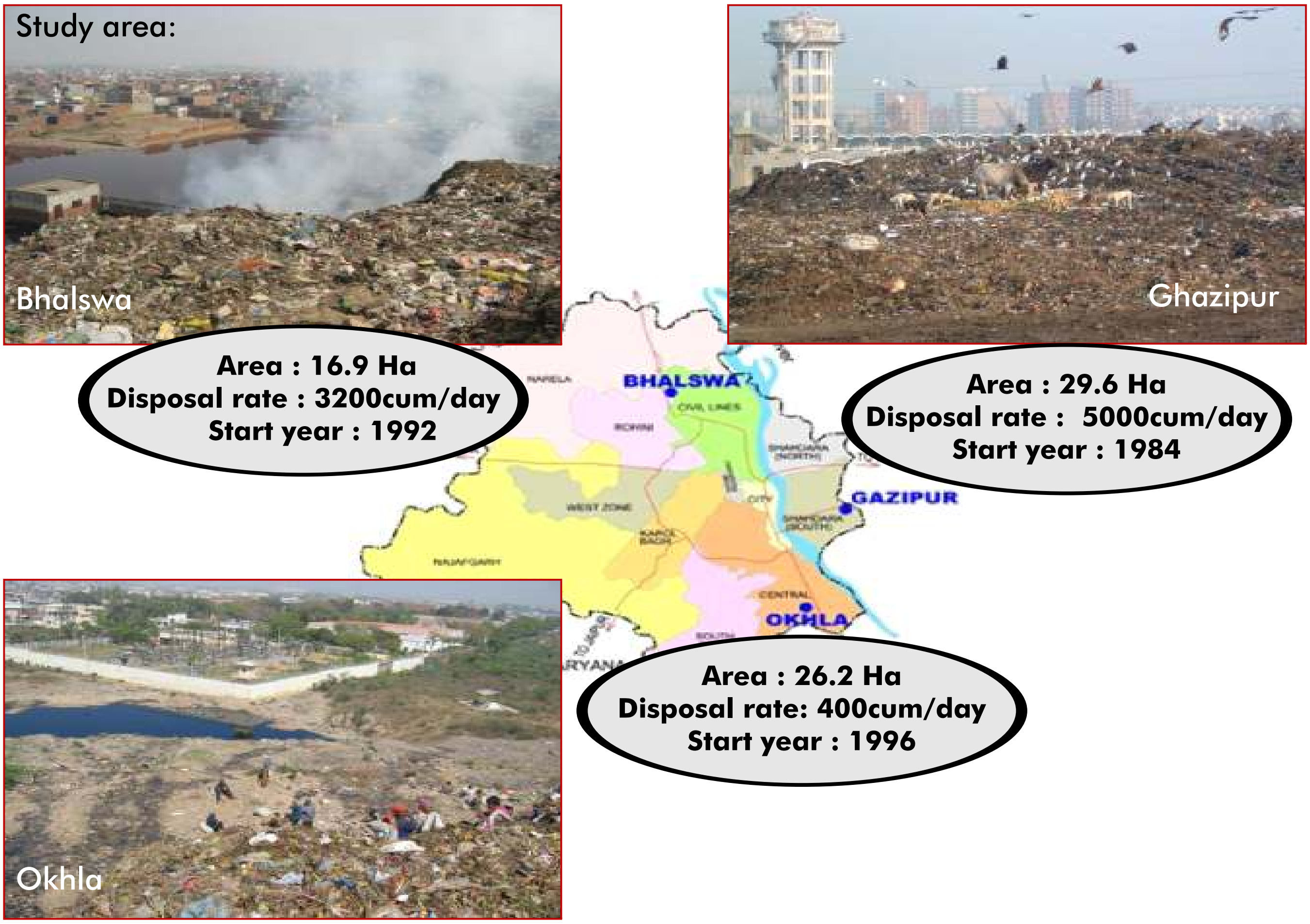
Variation in the daily MSW collection in different months from 1996–2003 in Chennai (Source: Jha *et. al.,* 2008)



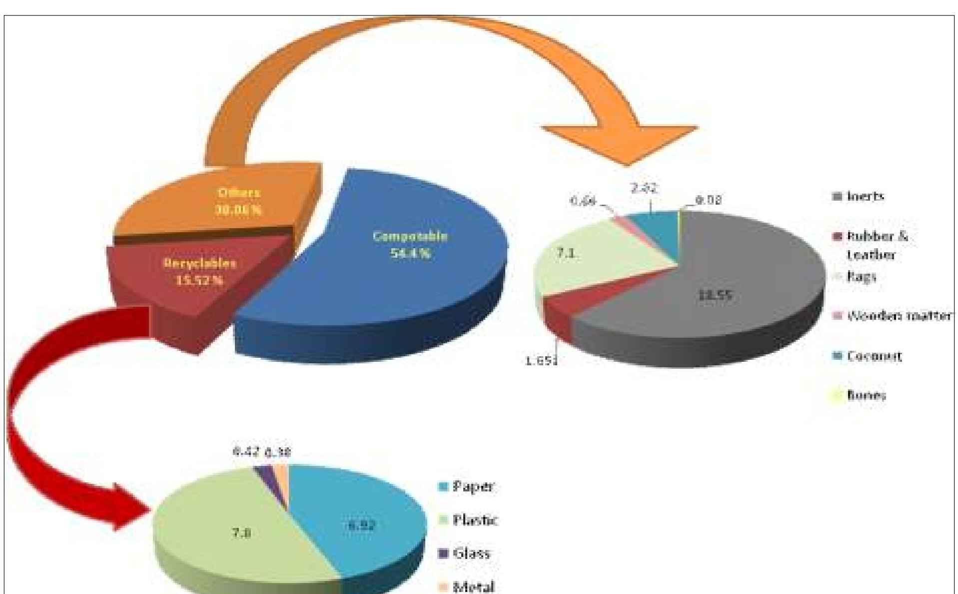
Study at Delhi Landfills: Objectives

- The present emission inventory estimates for Indian waste sector has mostly used IPCC default values, that may not be representative of the Indian scenario. For realistic values for Indian conditions, detailed study is required to generate country specific emission factors.
- Assessment of temporal and spatial variation of GHG emissions.
- Reduction of uncertainties in trace gas emission inventories from the waste sector.
- Potential role of limiting factors (like, organic carbon, nitrogen, hydrogen, oxygen etc.) in influencing the GHG emissions from landfills.

Existing landfills in Delhi



Average Physical Composition of Municipal Solid Waste of Delhi, 2004- 2005



Sampling & Analysis of LFGs

Thermometer for monitoring box temperature

DC fan for homogeneous mixture

Sampling with syringe

Perspex box

Water column for isolation

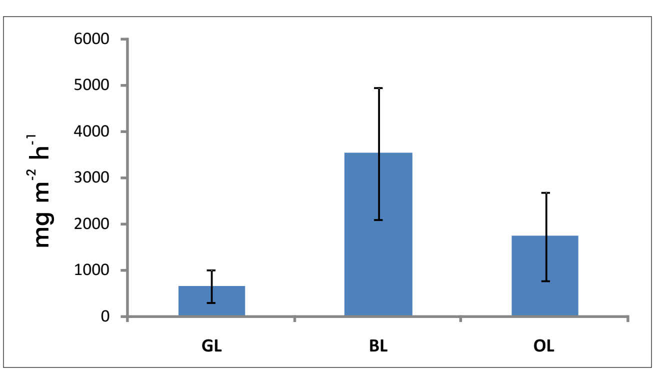
Aluminum base

LFG sampling at Okhla dumping site

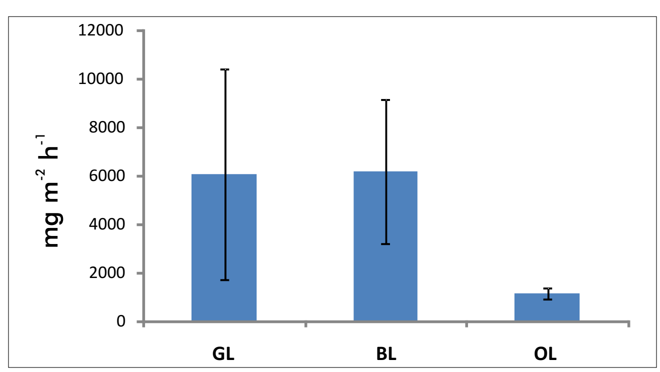
CH_4 & CO_2 gas standards

Gas chromatograph

Gas cylinders attached with GC

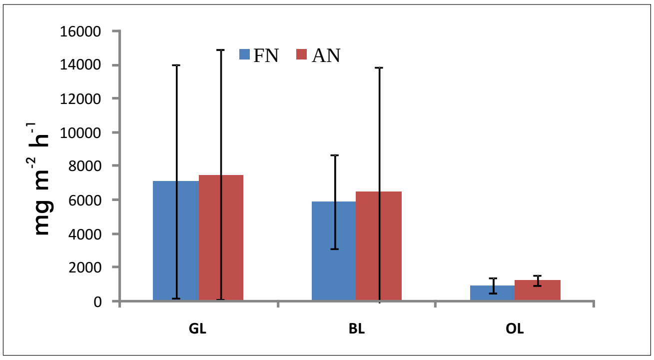


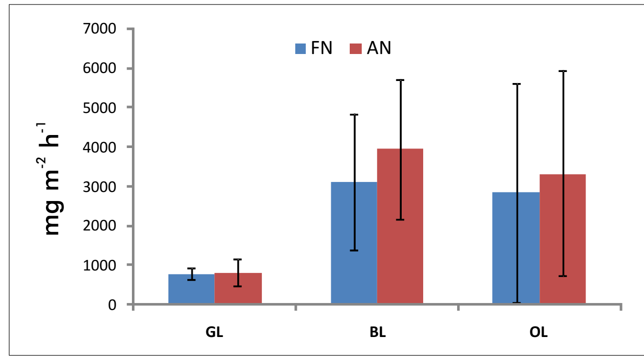
Methane emission flux comparison from three landfill sites in **winter season** in Delhi.



Methane emission flux in **summer season** from three respective landfills in Delhi.

Sampling & Analysis of LFGs





GHGs emission from landfills in Chennai :

Sampling site (Chennai)		Kodungaiyur (KDG)		Annual Average (ton/y)	Perugundi (PGD)		Annual Average (ton/y)
Year of Study		Dec. 2003	Sep. 2004		Dec. 2003	Sep. 2004	
Study of Methane	CH_4 flux range ($mgm^{-2}h^{-1}$)	2.4 -23.5	1.0 - 10.5	13.8	0.90 - 9.94	1.8 - 433	101.6
	CH_4 Emission (ton /y)	17.9±9.9	9.7±3.6		7.27 ± 2.7	196 ± 145	
Study of Carbon dioxide	CO_2 flux range ($mgm^{-2}h^{-1}$)	39 -906	106 -242	627.0	102 to 544	12.3 to 964.4	533
	CO_2 Emission (ton /y)	924.0 ± 358.0	330.0 ± 67		0.506 ± 0.123	0.560 ± 0.435	
Study of Nitrous Oxide	N2Oflux range ($mgm^{-2}h^{-1}$)	142 - 384	6 - 460	0.49	15 - 155	2.7 -1200	0.49
	N2OEmission (ton /y)	0.65 ± 0.17	0.32 ± 0.02		70.20 ± 0.05	0.78 ± 0.52	

Source: Jha *et. al.*, 2008

GHG Emission Inventories and Climate Change Modeling

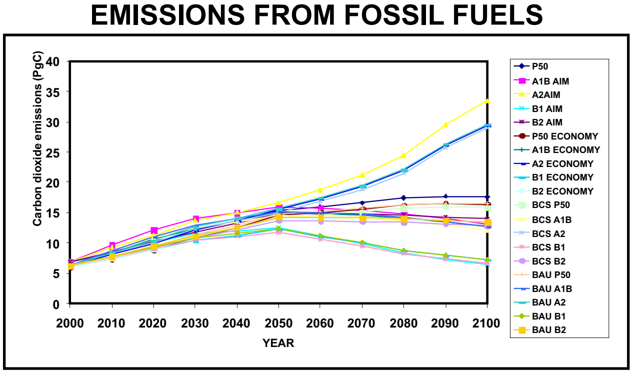
MAGICC/SCENGEN 4.1Based Assessment of Impacts of Indian Emissions on Future Climate Scenarios

MAGICC (Model for the Assessment of Greenhouse gas Induced Climate Change) is one-dimensional model of climate which estimates the changes in global mean temperature and sea level rise. It uses a series of reduced-form models to emulate the behaviour of fully three-dimensional, dynamic GCMs.

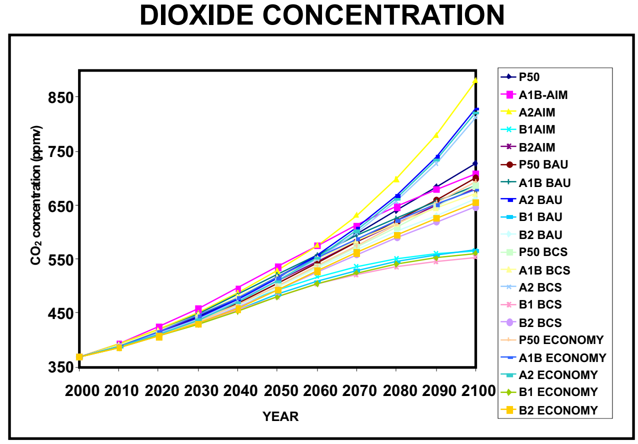
SCENGEN (SCENario GENerator) in turn uses the global-mean temperature output from MAGICC to scale up the results from 17 transient GCMs to give global and regional output of temperature and precipitation on a 5° by 5° grid.

Involves development of emission inventories of Greenhouse Gases and other trace gas species for MAGICC/SCENGEN 4.1 model runs

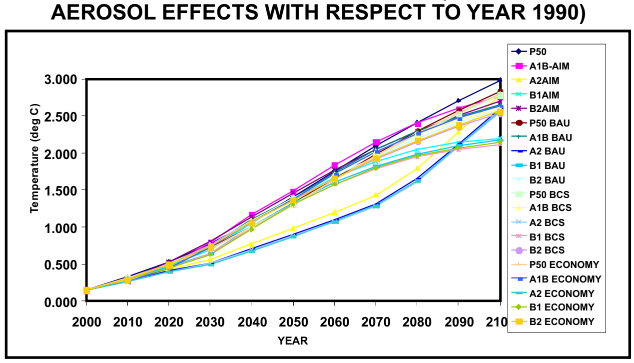
GLOBAL CARBON DIOXDE EMISSIONS FROM FOSSIL FUELS



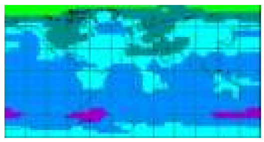
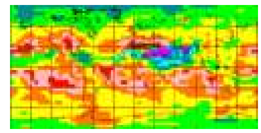
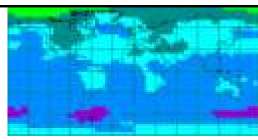
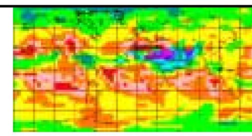
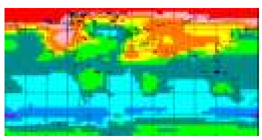
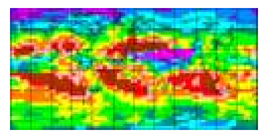
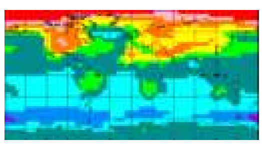
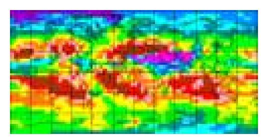
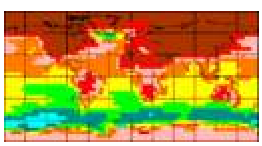
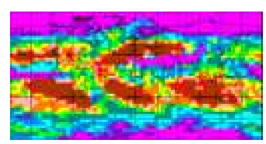
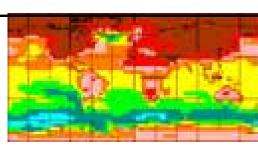
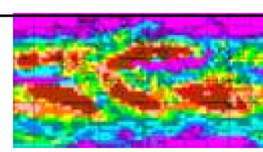
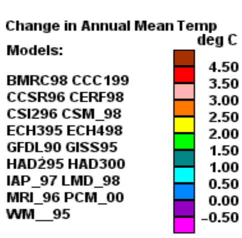
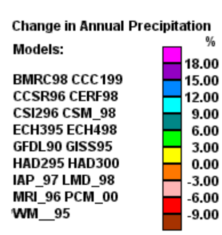
GLOBAL CARBON DIOXIDE CONCENTRATION



GLOBAL MEAN TEMPERATURE CHANGE (INCOROPRATING AEROSOL EFFECTS WITH RESPECT TO YEAR 1990)



SCENGEN Output for Annual Mean Temperature and Annual Mean Precipitation under Default and BCS Scenario

Scenario	Change In Annual Mean Temperature	Change In Annual Mean Precipitation
Default P50 2020		
BCS P50 2020		
Default P50 2050		
BCS P50 2050		
Default P50 2100		
BCS P50 2100		
		

To conclude:

Robust GHG Emission Inventories are need of the hour for understanding the Future climate change and its impact

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3.4 Bioenergy as Renewable Energy Resource: Problems and Prospects

T. Satyanarayana
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Introduction

Energy is extremely important for the well being of people as well as for commercial and industrial development. The demand for energy has been growing steadily worldwide. Over the last 200 years, most of the energy needs of the world have been derived from burning finite sources of fossil fuels, mainly coal, oil, and more recently gas, and thus fossil fuels account for 80% of the global energy demand. Current fluctuation in oil supplies and prices have further ignited widespread interest in alternative energy sources. The factors that revolve around economical, environmental, and geopolitical issues are central to the current interest in renewable energy sources. Bioenergy is renewable energy made available from materials derived from biological sources. In a broader sense, it includes biomass, the biological material used as the source of energy, and therefore, the biomass is the fuel and the bioenergy is the energy contained in the fuel.

Biomass is any organic material which has stored sunlight in the form of chemical energy. As a fuel it may include wood, wood wastes, straw, manure, sugar cane and many other byproducts from a variety of agricultural and forestry operations.

The energy derivable from biomaterials include bioethanol from lignocellulosic residues, biodiesel from non edible plant oils *and algae, methane,* H_2 *and that which can be produced using microbial fuel cells. In this article, an attempt has been made to review developments in bioenergy, and to summarise problems and prospects.*

Bioethanol

Henry Ford had been quoted to have said in 1925 that ethanol would be the 'fuel of the future' and it would come from apples, weeds, saw dust almost any vegetable matter that can be fermented. Today the significance of the futuristic vision of Hendry Ford can be easily understood. The major components in lignocellulosic biomass are cellulose, hemicellulose and lignin. Cellulose and hemicellulose can be hydrolyzed using acid/enzymatic methods into constituent sugars, which can be fermented to ethanol using yeasts (*Saccharomyces cerevisiae*, *Candida shehatae, Pichia stipitis*) and/or bactreria (*Zymomonas mobilis*, *Clostridium thermocellum*, *Thermoanaerobacterium thermosaccharolyticum*).

Improvements are needed in bioethanol production technologies like the pretreatment of biomass, the use of cellulolytic enzymes for depolymerisation of carbohydrate polymers into fermentable constituents and the use of robust fermentative microorganisms for ethanol production. The ethanol production process is energy-intensive requiring distillation to separate ethanol from aqueous fermented medium. Verenium Corporation, USA is constructing a commercial plant at Mexican city that will commence producing cellulosic ethanol ($36x10^6$ gallons per year) from 2012. The plant will have 85% biomass conversion, and the process is energy positive. The lignin will be utilized for generating energy. The pilot plant of Enerkem in Westbury (Canada) is expected to produce $1.5 x10^6$ gallons of cellulosic ethanol annually from creosoted urban wood.

Ethanol represents closed CO_2 cycle because after burning ethanol, the released CO_2 is recycled back into plant material, since plants use CO_2 to synthesize cellulose during photosynthesis cycle. Ethanol production process uses energy from renewable energy sources, and no net carbon dioxide is added to the atmosphere, making ethanol an environment-friendly beneficial energy source. Furthermore, the toxicity of the exhaust emissions from ethanol is lower than that of petroleum sources. Ethanol derived from biomass is the only liquid transportation fuel that does not contribute to the green house gas effect.

Biodiesel

The oil is extracted from the fruits of *Jatropha curcas* or *Pongamia pinnata*, and it is converted to biodiesel by catalytic trans-esterification. *Jatropha* plantations of 11 m ha can produce about 12 mt of biodiesel. Given that India has about 33 m ha of cultivable waste lands, this target appears achievable. The process also generates modest quantities of glycerine and oil cake. The bio-diesel properties are similar to those of fossil diesel. Its cetane number is 4860, comparable to diesel. The sulphur content is less than 15 ppm. Experiments with bio-diesel have resulted in lower emissions of CO and particulate matter, but reportedly higher NO*x* emissions. Biodiesel has higher viscosity, and it has to be warmed before injection to avoid gum deposition, especially in colder climates. This is not a major issue in many parts of India. Engines can operate totally on biodiesel or with varying blends of biodiesel and conventional diesel. Because of these properties, biodiesel has caught the imagination of scientists and policy makers.

The present market price of biodiesel is around ₹3255 per gallon, which is well above the present retail price of 'conventional' diesel. This could be due to lack of maturity in technology and varying oil content in the seeds. The biodiesel purchase policy of the Government specified that the oil marketing companies purchase biodiesel at ₹25/L from 1 January 2006. Given the uncertainty in biodiesel cost, it is not clear whether this price is attractive to biodiesel producers.

The main advantages of biodiesel are that it is almost carbon-neutral and could potentially create about 30 million unskilled to skilled jobs, mainly in rural areas. However, given constraints in the availability of land for cultivation, it may be difficult to produce more than about 12 mt of biodiesel. Hybrid (gasoline-electric) vehicles offer interesting possibilities for improved fuel consumption, especially for passenger vehicles in urban and semi-urban environments. In a hybrid, the electric motor adds additional thrust, allowing a smaller sized gasoline engine, and the brakes regenerate electricity to be stored in batteries. The most successful hybrid vehicle, the Toyota Prius36, achieves urban fuel efficiency of 60 miles/gallon or 25.5 km/l.

Algae can also be as a biodiesel feedstock. An advantage of using algae for biodiesel production is that the resource requirements are less intensive as compared to other crops and plants. Algae require only a few basic resources for cultivation: CO_2, water, sunlightand nutrients. Furthermore, algae such as *Botryococcus braunii*, *Dunaliella primolecta and several others can be oil-rich. Oil content typically ranges between 20 and 50 % depending on the species. In comparison with terrestrial crops such as corn, soybean, and palm plants, algae are far more oil rich and offer higher yields of oil per unit of land in a year. Open ponds and closed photobioreactors can be used for the cultivation of algae. Long term indepth studies on microalgal cultivation are needed for biofuel production*.

Attempts are also being made to ferment glycerol, a byproduct of biodiesel manufacture, to biochemicals such as ethanol, butanol, 1,3-propanediol and propionic acid using Klebsiella planticola, Clostridium pasteurianum, C. bytyricum and *Propionibacterium acidipropionici, respectively.*

Biogas

Biogas refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas originates from biogenic materials, and thus, it is a type of biofuel. Biogas can be produced utilizing anaerobic digesters.

One type of biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant materials, and energy crops. This type of biogas contains mainly methane and CO_2. The other principal type of biogas is wood gas, which is generated by gasification of wood or other biomass. This type of biogas comprises mainly nitrogen, hydrogen and CO_2, with trace amounts of methane. The gases methane, hydrogen and carbon monoxide can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking. Biogas can be compressed like natural gas, and used to power motor vehicles. In the UK for example, it has been estimated to have the potential to replace around 17% of vehicle fuel. Biogas is a renewable fuel, and thus, it qualifies for renewable energy subsidies.

Domestic biogas technology is a proven and established technology in many parts of the world, especially Asia. Several countries in this region have embarked on large-scale programmes on domestic biogas, such as China and India. The Netherlands Development Organization, SNV supports national programmes on domestic biogas aimed at establishing commercially viable domestic biogas sectors in which local companies market, install and service biogas plants for households. In Asia, SNV is working in Nepal, Vietnam, Bangladesh, Cambodia, Lao PDR, Pakistan and Indonesia, and in Africa in Rwanda, Senegal, Burkina Faso, Ethiopia, Tanzania, Uganda and Kenya.

It is also possible to produce biogas from food processing industry wastes (eg. vegetable processing wastes, distillery wastes, press grape skins, brewer's grains and fats from skimming tanks) and industrial (glue, paper and pulp and rubber) effluents.

Hydrogen

Hydrogen is considered to be a non-polluting synthetic fuel which could replace oil, particularly for transport applications. Hydrogen would be a good transport fuel because:
*(1) it has the highest energy-to-mass ratio of any chemical, and thus used to propel rockets, (*2) hydrogen is carbon-free, non-toxic, and its thermal or electrochemical combustion with oxygen yields energy and water only, and (3) the main source is water, which is essentially an unlimited resource.

Splitting of water yields hydrogen, which requires energy (electricity/light/heat), and this, however, can be recovered when hydrogen is combusted. In order that hydrogen becomes a widely used fuel, three crucial steps are needed: (i) economically viable methods must be developed for producing large quantities of hydrogen, ideally using renewable energy sources, (ii) hydrogen distribution and storage systems are necessary, and (iii) development of technologies and devices for converting the chemical energy stored in hydrogen into more useful forms of energy. Hydrogen can yield thermal energy in a combustion engine or electrical energy in a fuel cell. It is essential to develop practical way of storage. Liquefaction yields hydrogen in an extremely energy-dense form, but the process requires temperature below 250 °C, which is expensive. Furthermore, liquefaction results in the loss of about 30 % of the chemical energy of gaseous hydrogen. Several methods of storing hydrogen using lanthanum-nickel hydrides, borohydrides and others are being developed. Hydrogen-powered buses in Germany and Japan have been successful, and about 50 prototype cars have so far been tested.

Extensive efforts are being made globally to produce hydrogen from renewable materials such as sugars, industrial and domestic wastes, organic residues such as dumped wheat, apple pomace and others. Microbes such as algae (*Chlamydomonas reinhardtii*, *C. mewusii, Chlorella, Scenedesmus, Porphyridium), Cyanobacteria (Anabaena cylindrica, Nostoc commune, Oscilatoria brevis, Calothrix scopulorum) and bacteria (Bacillus licheniformis, B. coagulans, Clostridium thermocellum, Rhodopseudomonas, Rhodospirillum, Ruminococcus albus, Selenomonas ruminantium) have been shown to produce hydrogen.*

Genetic as well as metabolic engineering approaches are being used for improving hydrogen production. Clostridium thermocellum has been shown to produce hydrogen from lignocellulosic material (corn stover).

Hydrocarbons from microbes

Several cyanobacteria such as Synechococcus elongatus, Anabaena variabilis, Nostoc punctiforme and *Gloeobacter violaceus*, whose genomes have been sequences, are known to have hydrocarbons such as pentadecane, heptadecane and others. Recently Schirmer and his coworkers have cloned acyl-acyl carrier protein reductase and aldehyde decarbonylase, which convert fatty acid metabolites into alkanes and alkenes, from *S. elongatus* in *Escherichia coli*. The recombinant *E. coli* secreted diesel-like fuel when cultivated in glucose containing medium. The biotechnology company LS9 based in South San Francisco, California is planning to produce the fuel using this recombinant.

Microbial fuel cells

Microbial fuel cells (MFCs) are devices, which use bacteria as the catalysts to oxidize organic and inorganic matter and generate current. Electrons produced by the bacteria from these substrates are transferred to the anode (negative terminal) and flow to the cathode (positive terminal) linked by a conductive material containing a resistor, or operated under a load (i.e., producing electricity that runs a device). Bacteria such as *Geobacter sulfurreducens*, *G. metallireducens*, *Shewanella oneidensis, Clostridium butyricum, Rhodoferax ferrireducens* and others have been used in microbial fuels. MFCs are being constructed using a variety of materials and in a variety of configurations.

By convention, a positive current flows from the positive to the negative terminal, a direction opposite to that of electron flow. The device must be capable of having the substrate oxidized at the anode replenished, either continuously or intermittently. Otherwise, the system is considered to be a biobattery. Electrons can be transferred to the anode by electron mediators or shuttles, by direct membrane associated electron transfer, or by so-called nanowires produced by the bacteria. Chemical mediators, such as neutral red or anthraquinone-2,6-disulfonate (AQDS), can be added to the system to allow electricity production by bacteria unable to otherwise use the electrode. If no exogenous mediators are added to the system, the MFC is classified as a 'mediator-less' MFC even though the mechanism of electron transfer may not be known. Microbially catalyzed electron liberation at the anode and subsequent electron consumption at the cathode, when both processes are sustainable, are the defining characteristics of an MFC. Systems that use enzymes or catalysts not directly produced *in situ* by the bacteria in a sustainable manner are considered as enzymatic biofuel cells.

One of the first applications could be the development of pilot-scale reactors at industrial locations where a high quality and reliable influent is available. Food processing waste waters and digester effluents are good candidates. To examine the potential for electricity generation at such a site, a food processing plant producing 7500 kg/d of waste organics in an effluent can be used as an example. This represents a potential for 950 kW of power, or 330 kW assuming 30% efficiency. At an attained power of 1 kW/m^3, a reactor of 350 m^3 is needed, which would roughly cost 2.6 M Euros, at current prices. The produced energy, calculated on the basis of 0.1 Euros per kWh, is worth about 0.3 M Euros per year, providing a payback time of 10 years without other considerations of losses or gains as compared to other (aerobic) technologies. Moreover, decreased sludge production could substantially decrease the payback time. In the long term, more dilute substrates, such as domestic sewage, could be treated with MFCs, decreasing society's need to invest substantial amounts of energy in their treatment. Several alternative applications could also emerge, ranging from biosensor development and sustained energy generation from the seafloor, to biobatteries operating on various biodegradable fuels.

While full-scale, highly effective MFCs are not yet within our grasp, the technology holds considerable promise, and efforts will be made to overcome major hurdles by engineers and scientists. The growing pressure on our environment, and the call for renewable energy sources will further stimulate development of this technology.

Conclusions

Although bioenergy in the form of bioethanol, biodiesel, hydrocarbons, biogas, hydrogen and microbial fuel cells hold a great promise to supplement the energy from the conventional fossil fuels, technological developments are needed to fully realize this dream. Concerted efforts are being made globally to develop technologies in order to utilize renewable biomaterials for generating usable forms of energy in a sustainable manner.

Further reading

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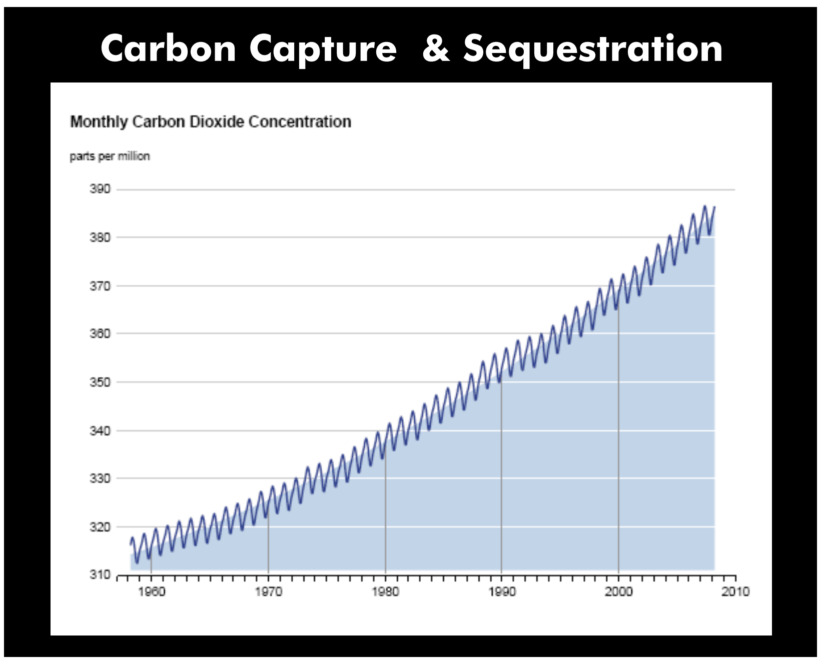
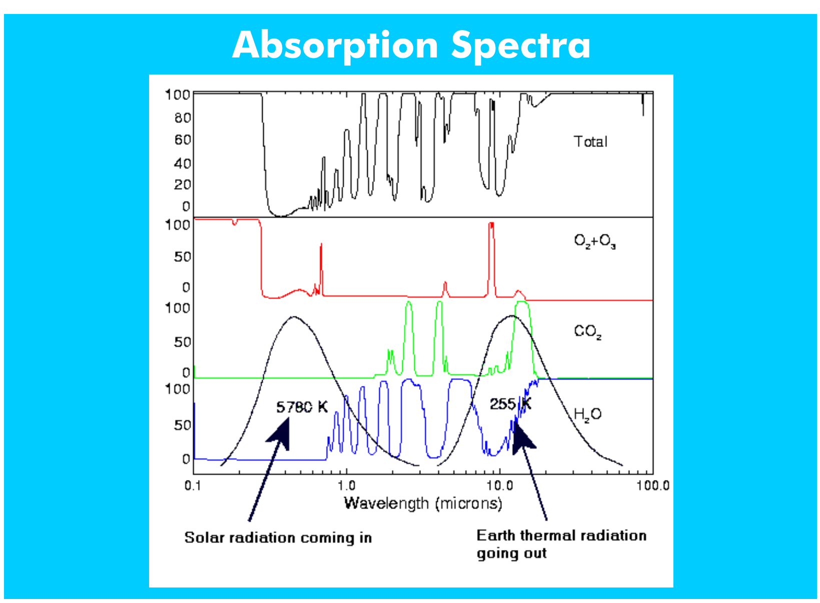
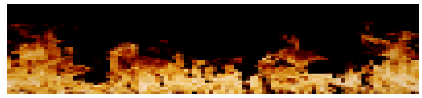
3.5 Carbon Capture & Sequestration

D. M. Kale
Director General, ONGC Energy Centre



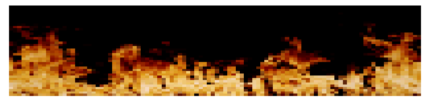




Carbon Capture & Sequestration
1 ppm is 8.08 billion tons CO_2.
Current CO_2 emission ~ 30billion tons
That amounts to 3.7 ppm
Of which 57% = 2.1ppm
Retained in the atmosphere

Carbon Capture & Sequestration
Power Plants
Transport
Industry
Cement, Iron and Steel
Petrochemicals
Natural Gas, Refinery
Residential

Carbon Capture & Sequestration
Vehicular pollution
A few Billion of mobile polluters wheezing
All over the place !



Carbon Capture & Sequestration
The current CO_2 emissions ~ 28 Gt
Business as usual projection to 2050
62 Gt
ACT plan 2050 =2005
Reduction by 35 Gt
BLUE plan 2050 =half of 2005
Reduction by 48 Gt

Carbon Capture & Sequestration
of this about 20% reduction to be achieved by CCS
7 to 10 GT CO_2 to be
Sequestered every year!

Carbon Capture & Sequestration
Enhanced Oil Recovery
Miscible displacement
Minimum Miscibility pressure
Immiscible displacement
Little Incremental Recovery

Active EOR projects in 2004

Country	**Number of active EOR Projects**				
	Thermal	**Gas**	**Chemical**	**Other**	**Total**
USA	56	83	4	-	143
Canada	16	32	-	-	48
China	18	-	18	2	38
Colombia	2	-	-	-	2
France	-	-	1	-	1
India	3	1	4	3	11
Indonesia	2	-	1	-	3
Libya	-	1	-	-	1
Mexico	-	1	-	-	1
Trinidad	8	5	-	-	13
Turkey	-	1	-	-	1
UAE	-	1	-	-	1
Venezuela	38	9	2	1	50
Total	**143**	**134**	**30**	**6**	**313**

Active Gas Injection EOR projects

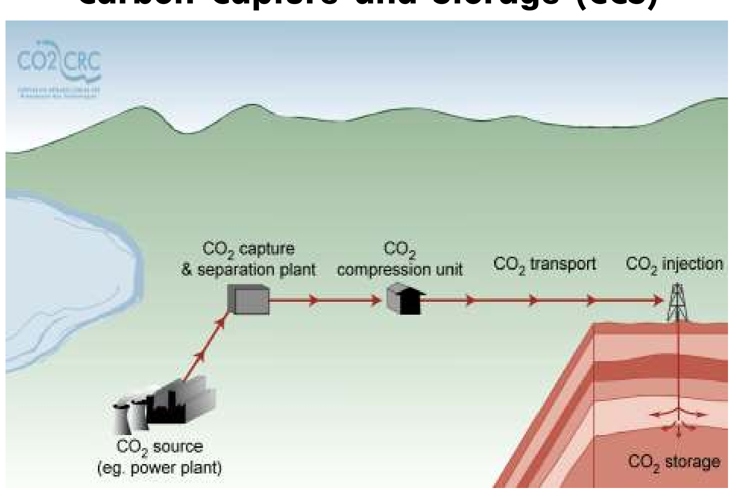
Country	Name of project		
	CO_2	HC	Others
USA	71	8	4
Canada	2	29	1
Libya	-	1	-
India	-	1	-
Mexico	-	-	1
UAE	-	1	-
Trinidad	5	-	-
Turkey	1	-	-
Venezuela	-	8	1
China	-	-	-
Colombia	-	-	-
Indonesia	-	-	-
Total	**79**	**48**	**7**

Carbon Capture & Sequestration
3% of total oil production from EOR
10% of that from CO_2
0.3% of total oil production by CO_2

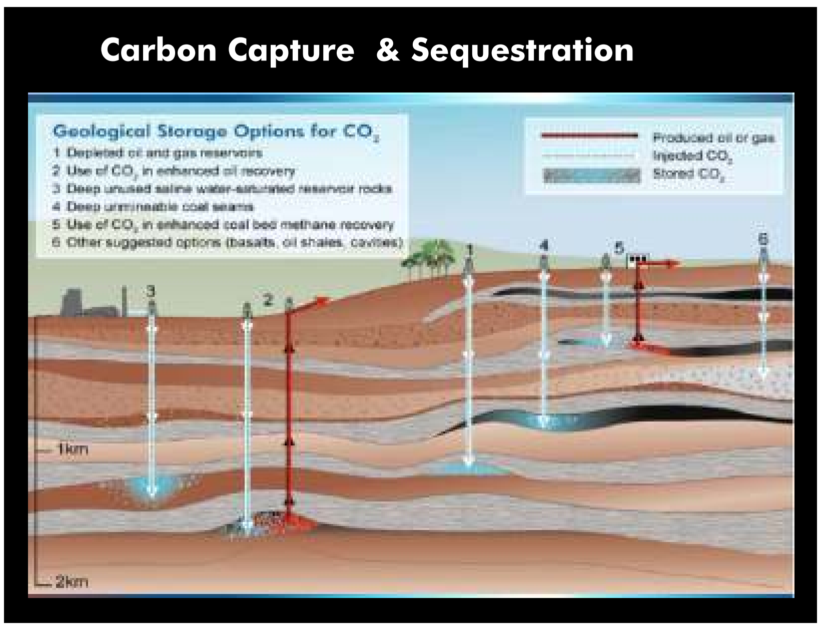
Carbon Capture & Sequestration
Potential for CO_2 EOR
200 billion barrels of extra oil
Will lead to storage of 70 to 100 Gt

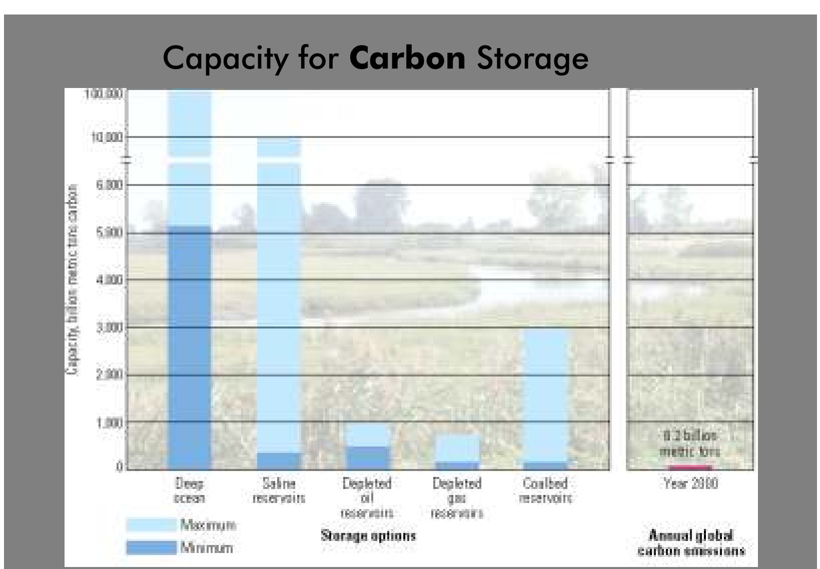
This is about the CO_2 emission from this Oil!
Do we do any net good?

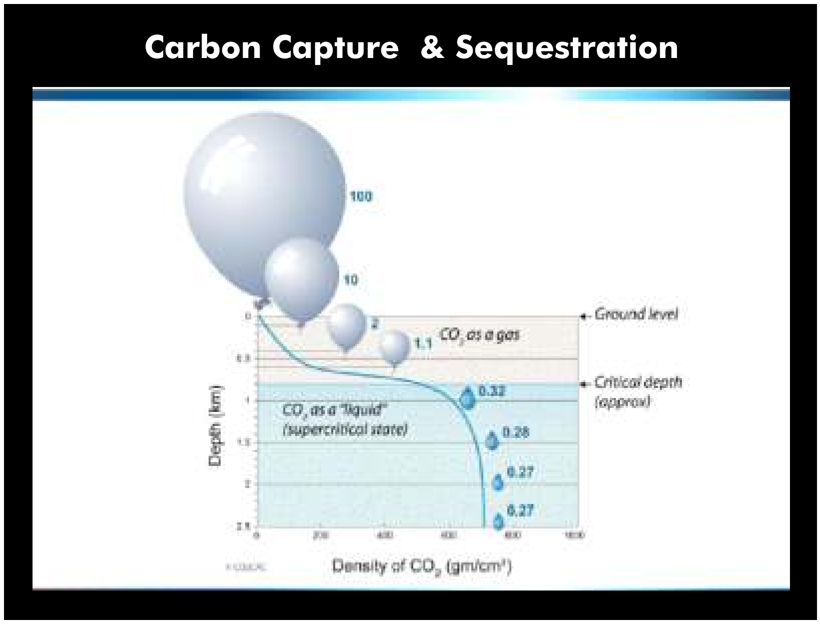
Geosequestration:
Carbon Capture and Storage (CCS)

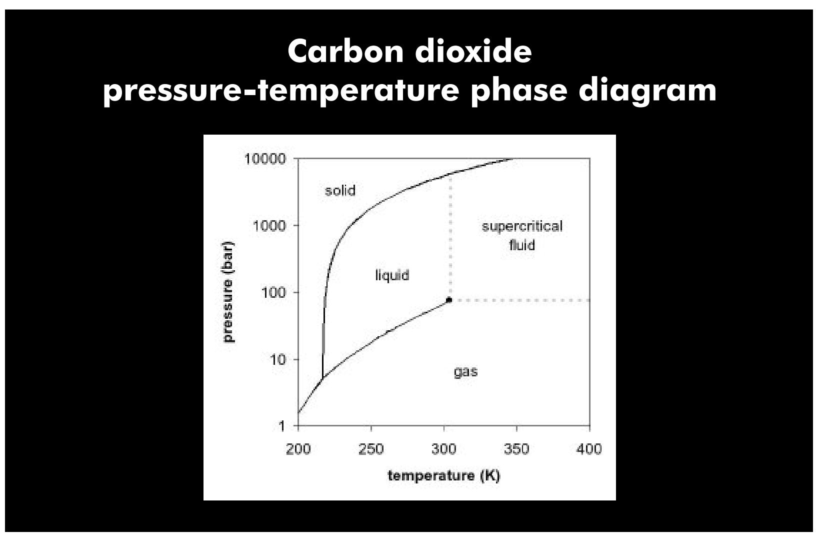


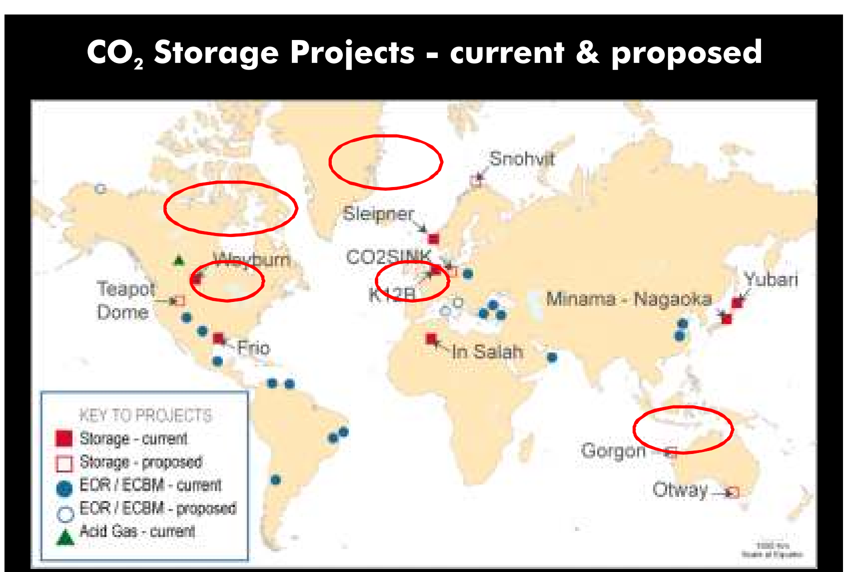
Geo-sequestration Concept





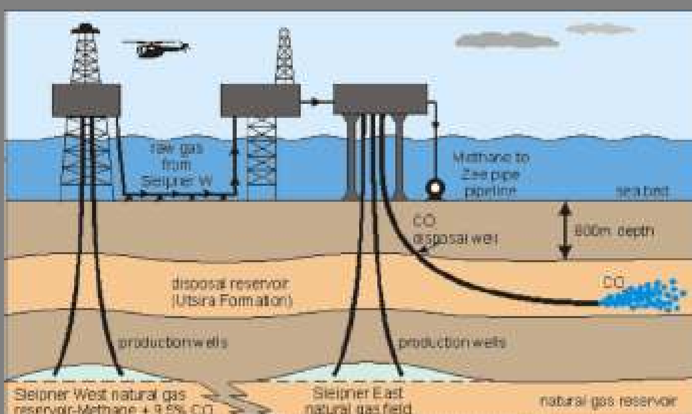

Carbon Capture & Sequestration
100
10
2
1.1
CO2 as a gas
Ground level
Critical depth
(approx)
0.32
CO2 as a "liquid"
(supercritical state)
0.28
0.27
0.27
Depth (km)
Density of CO2 (gm/cm3)


Carbon dioxide
pressure-temperature phase diagram
10000
1000
100
10
1
solid
liquid
supercritical
fluid
gas
pressure (bar)
200
250
300
350
400
temperature (K)


CO2 Storage Projects - current & proposed
Snohvit
Sleipner
CO2SINK
K12B
Weyburn
Teapot
Dome
Frio
In Salah
Minama - Nagaoka
Yubari
Gorgon
Otway
KEY TO PROJECTS
Storage - current
Storage - proposed
EOR / ECBM - current
EOR / ECBM - proposed
Acid Gas - current

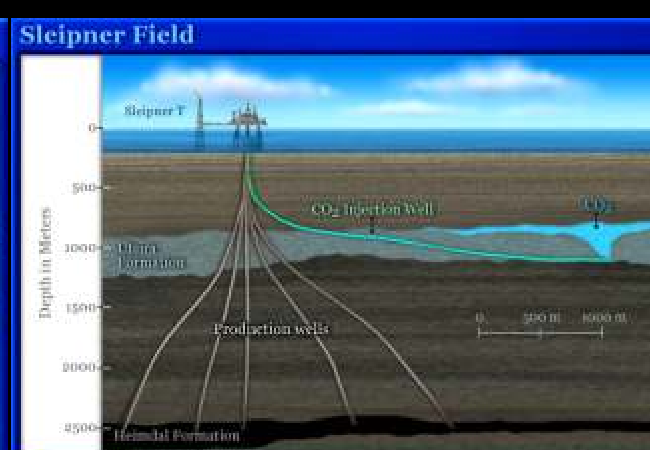
Carbon Capture & Sequestration
Largest project so far sequesters
1 million ton /annum of CO_2
Sleipner

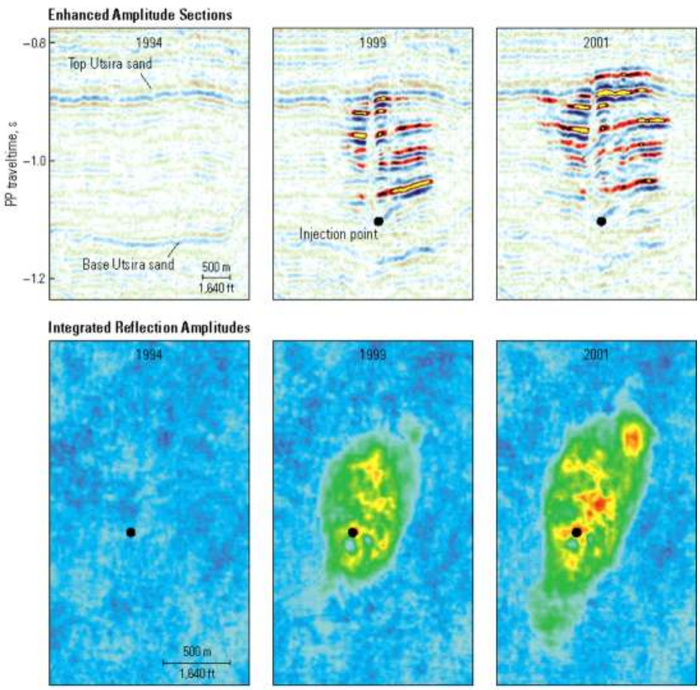
Sleipner (STATOIL)

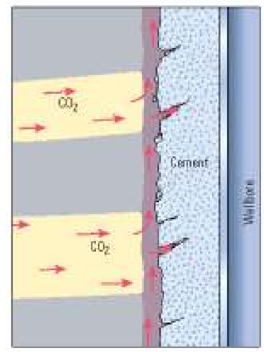


- ❖ 250 kilometres west of Norway in the North Sea
- ❖ Injection into Utsira Formation, a sandstone.
- ❖ P1 million tons CO2 per year since 1996

Sleipner (STATOIL)





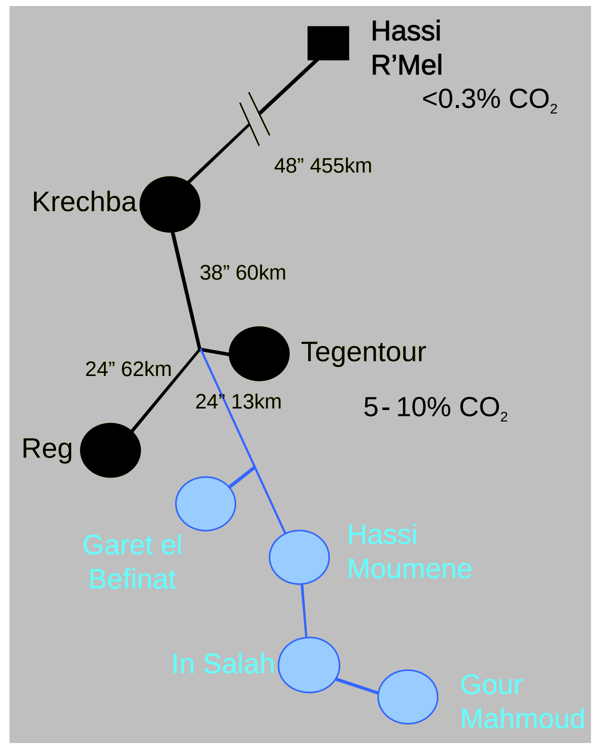


Main CO_2 pipeline enters Weyburn

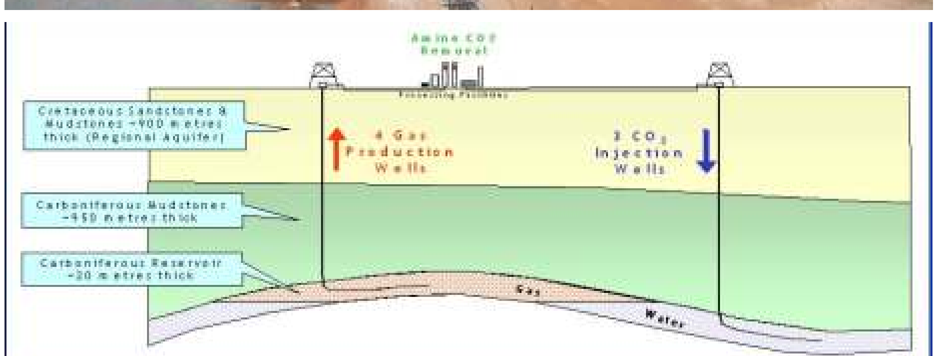
Weyburn CO_2 Project

- CO_2 Source: Dakota Gasification Company
- 95 mmscfd (5000 tonnes/day) injection rate
- CO_2 purity 95% (primary feed)
- Currently 26% recycle.

In Salah Gas Project



In Salah Gas Project

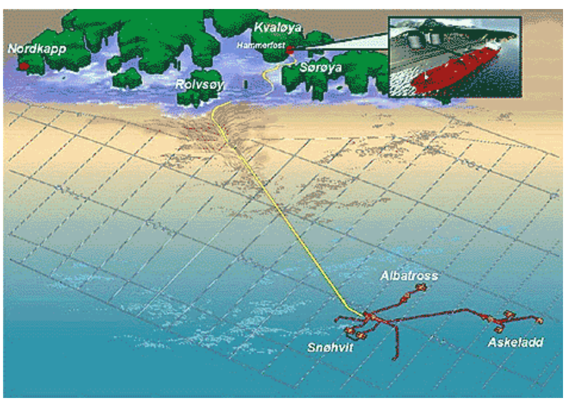


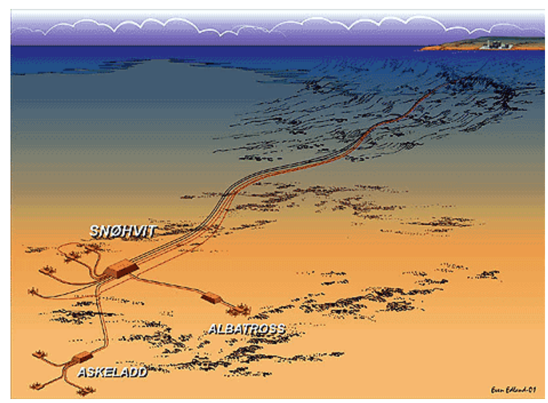
Carbon Capture & Sequestration

In April 2008, Statoil announced carbon storage had started on its Snøhvit field – Statoil is reinjecting Snøhvit's CO_2 emissions into the ground beneath the gas-bearing formation on the field. The process will reduce CO_2 emissions by 700,000t a year when Snøhvit is at full capacity, it is estimated. This is the equivalent of emissions from 280,000 cars.

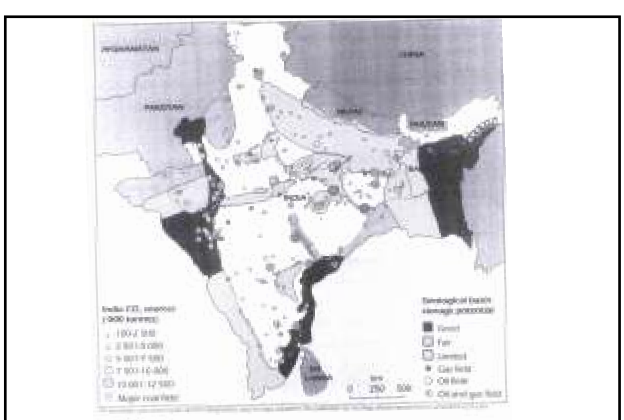
Natural gas is first pumped to a carbon capture plan at Melkøya. Here, 5% to 8% of CO_2 is removed from the gas and piped back to a 2,600m-deep sandstone formation at Snøhvit, where it sits under the seabed.

Snøhvit Project





India CO_2 Sources & Storage Potential



Carbon Capture & Sequestration INDIA

Storage Potential	500 to 1000 Gt
Off shore Deep Saline	300 – 500 Gt
Basalt Traps	200 – 400 Gt
Depleted Oil , gas fields	5 --10 Gt
Unminable Coal Seams	5 Gt

Carbon Capture & Sequestration INDIA

No field large enough to store life time emissions from a medium sized Power Plant

Saline Aquifer potential in Assam more than 1000 Km away from CO_2 sources

Carbon Capture & Sequestration

Largest project so far sequesters

1 million ton /annum of CO_2

We generate

30,000 million tons of CO_2 !

A Sleipner a day for 80 years!!!

Carbon Capture & Sequestration

What is left out ?

Costs

Economics

Legal aspects

Regulatory frame work

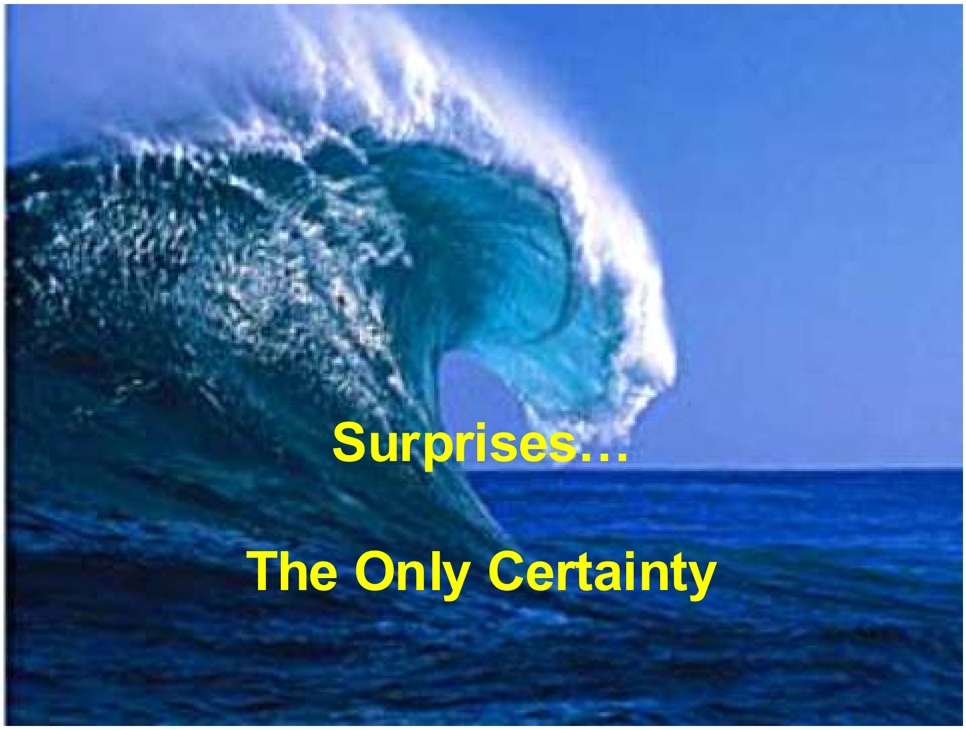
Monitoring , verification

Politics

Public Acceptance

Risk assessment , mitigation

Long term liability


Surprises…
The Only Certainty


What do you have to lose?

3.6 Modeling Studies on Storage in Coal Seams and CO_2-ECBM

Ajay Kumar Singh
Central Institute for Materials & Fuel Research

- Coal bed methane is natural gas.
- It is formed during coalification, the process in which plant material forms coal.
- Contained within the coal seams and surrounding rock strata, coal bed methane generally does not escape into the atmosphere unless exposed by coal mining activity.
- Released into the mines, the gas becomes Coal Mine Methane, which must be removed from a coal mine for safety reasons.

Volumes of Gases Generated During Coalification

❖ Methane	2,000 to 5000+ scf/ton (63 to 157 + m3/t)
❖ Carbon dioxide	177 scf/ton to 6,000+ scf/ton (6 to 188+ m3/t)
❖ Wet gases	100 to 1,000+ scf/ton (3 to 31 + m3/t)
❖ Nitrogen	250 to 500 scf/ton (8 to 16 m3/t)

Dual Porosity of Coal

Microscopic view of the
Micropores structure of coal

Fracture system, cleats in coal

Producible CBM

- ❖ Gas content and permeability appear to be the two most critical parameters.
- ❖ Most successful coal bed methane projects have greater than 100 cubic feet per ton.
- ❖ Coals which are fractured or have better cleat network, will have better permeability.
- ❖ Other factors which influence producibility are coal rank, thickness, dip of beds, cleat development, faults or secondary fractures, and depth of cover.

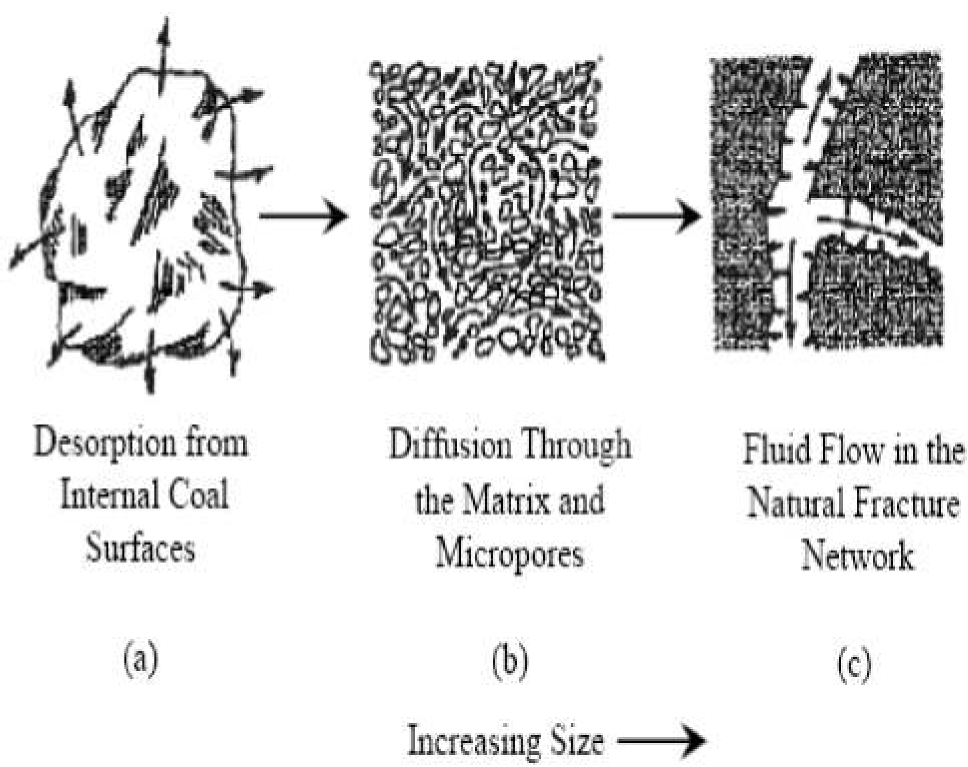
- ❖ USA tops in the CBM production.
- ❖ Australia ranks 2nd in the CBM production and development in the world.
- ❖ Canada ranks 3rd – 5 MMSCMD.
- ❖ China ranks 4th and producing – 2 MMSCMD.
- ❖ India ranks 5th in CBM activities.
- ❖ Indonesia have just started the drilling of CBM wells.

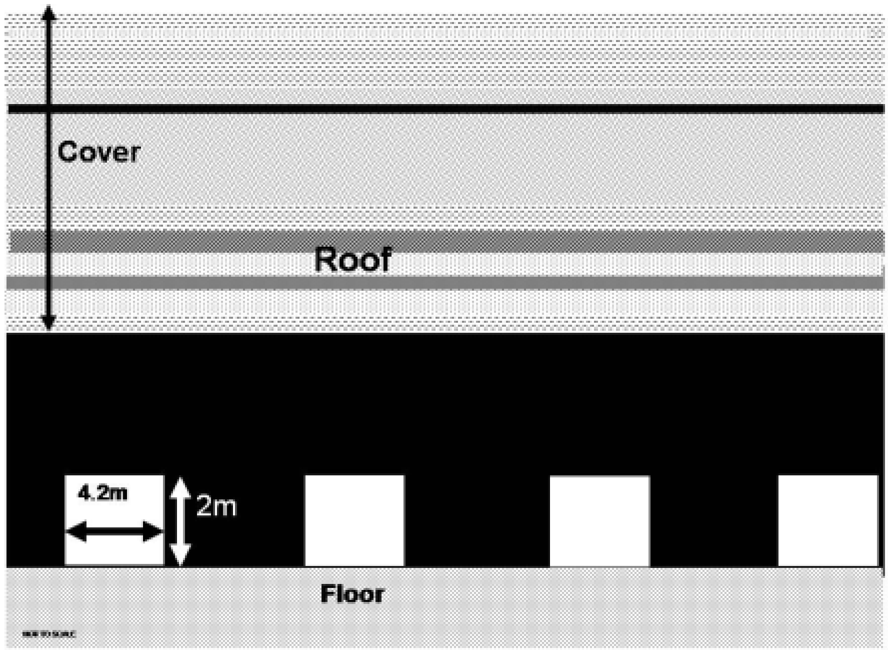
Note: 1 Million BTU = 1000 cu.ft = 28 m3 of gas.

INDIA RANKS 5TH IN THE EXPLORATION AND PRODUCTION OF CBM.

- GEECL- Production Capacity 1 Lakh m3/day from 23 wells.
  Producing – 30,000 m3/day. Selling 25MSCMD.
- ONGC – Production testing completed in Jharia and Bokaro. 1st well in Jharia produce 20 MCM/day and stabilizes at 7 MCM/day. Started drilling of 1st horizontal-multilateral CBM well in Jharia.
- RIL – Completed drilling of test wells in their Sohagpur East and West CBM blocks. CBM production from a cluster of 5 wells is about 22-25MCM/day.
- Other active players in CBM field are Essar Oil, Arrow-GAIL, RNRL- Geo-Petrol, Deep Industries-Coal Gas Mart and BP.

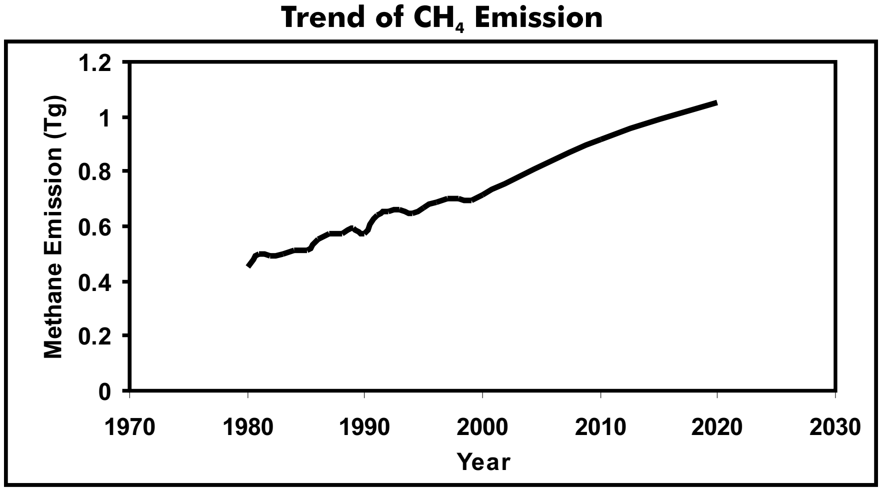
Transport of Gas





What about surface mines???

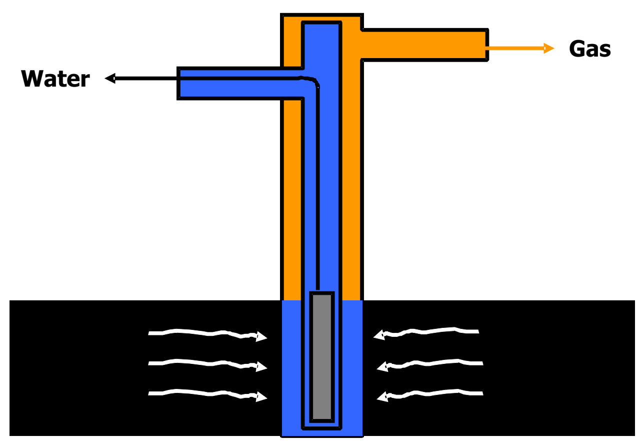
Trend of CH_4 Emission

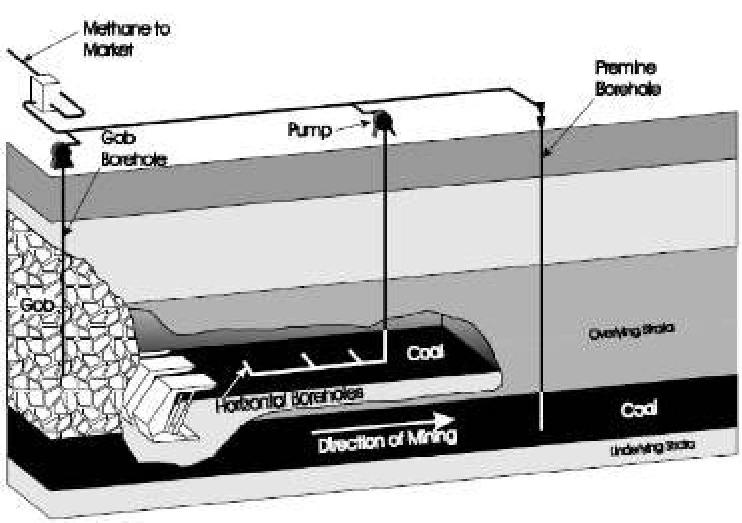


DIFFERENT CATEGORIES OF CBM

- **VCBM**
- **CMM**
- **AMM**
- **VAM**

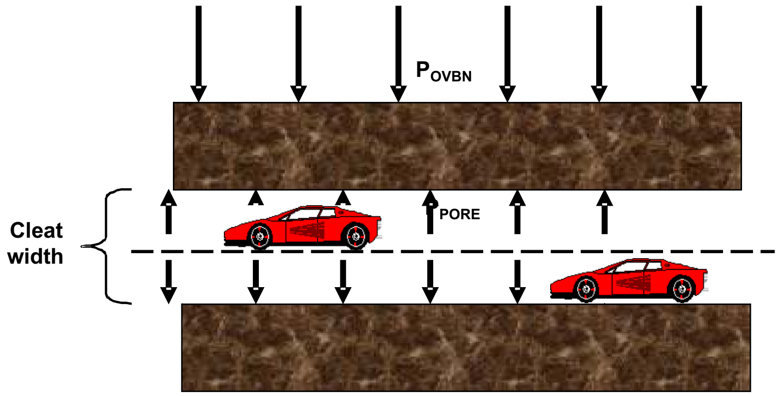
Typical VCBM Well in Production



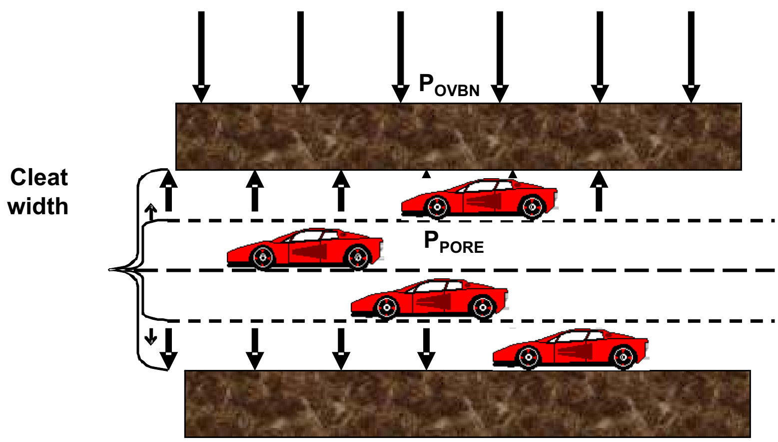


Types of gas drainage and capture techniques in coal mining Vertical Pre-Mining gob wells and Underground Horizontal wells

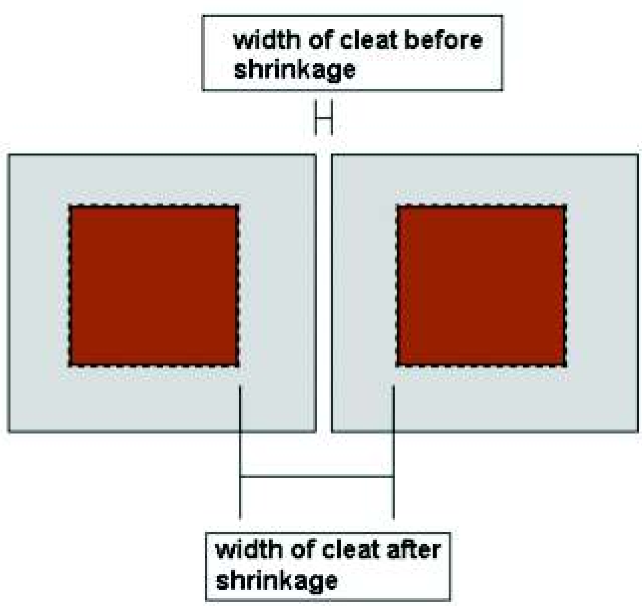
As pore pressure decreases, the net overburden pressure increases.



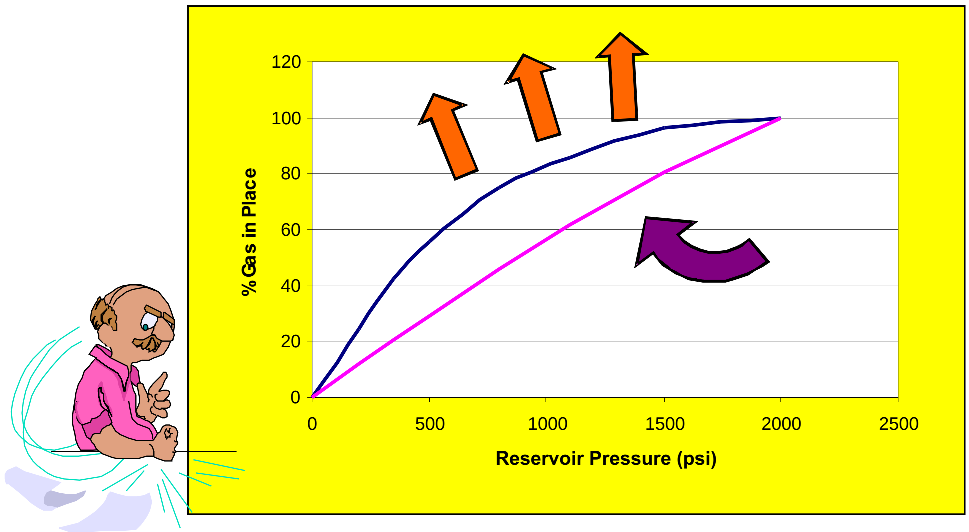
A mitigating factor is that as the pore pressure decreases, the desorbed gas will effectively shrink the volume of the coal. This tends to intensify the cleating in situ.



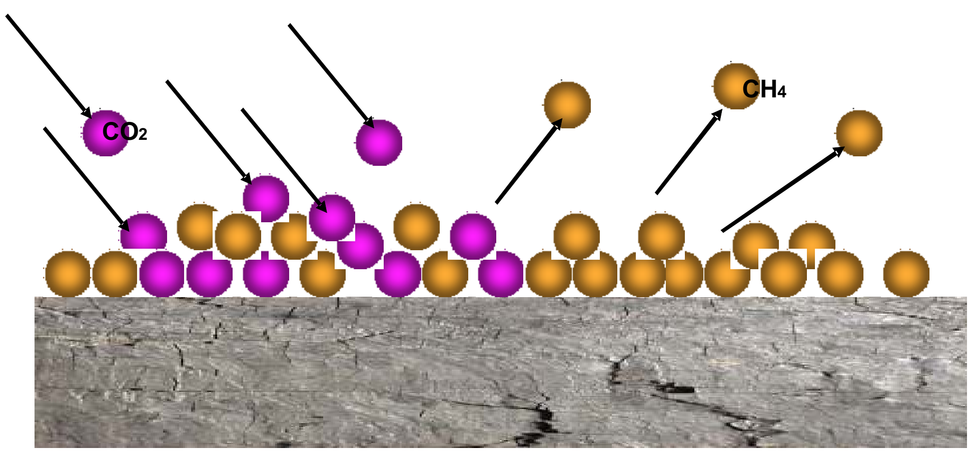
Coal matrix shrinkage



What about Enhanced Gas Recovery ?!?



Affinity of CO_2 Adsorption for Coal



Comparative Adsorption of CO_2 and CH_4

- Studies conducted so far support 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 at 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.

CBM Reservoir Simulation

- Three-dimensional; two phase; single, dual or triple porosity simulation for modeling gas and water production from coal seams.
- Generally a dual porosity model based on the idealization of fractured media by Warren and Root is considered.
- Two-phase flow of gas and water occurs in the cleat system.
- The cleat system is assumed continues and provides flow paths to producing wells.
- The two systems are coupled by use of a desorption isotherm at the matrix-cleat interface.
- Both Cartesian (x-y-z) and radial (r-?-z) coordinate system for multi-well problems.

Desorption and Diffusion Theory for Coalbeds

Comparative Adsorption of CO_2 and CH_4

- Desorption of pure gas is described by a Langmuir isotherms, which relates the coal cleat pressure, p, to the equilibrium matrix gas concentration, C (p), according to

  $C(p) = VLp/(PL+p)$

- Where VL is the maximum amount of gas that can be absorbed, and PL, a characteristic pressure, is measure of the residence time for a gas molecule on the surface.

Comparative Adsorption of CO_2 and CH_4

- The gas flow through the matrix, Qm is described mathematically by Ficks first law of diffusion expressed in the form

$$Qm = V_m/T[C - C(p)]$$

- Where C is the average matrix concentration, Vm is the bulk volume of a matrix element, T is thesorption time defined by

$$\tau = 1/D\sigma$$

- Where D is the diffusion coefficient and σ is the warren and Root shape factor which depends on the size of the matrix element. Alternately, a shape factor may be defined in terms of the surface area of a matrix element, Am , such that

$$\sigma = aAm/Vm$$

Dual porosity/single-permeability model for coalbeds

- Coalbed methane reservoir represents a well–defined dual porosity/single-permeability system. The basic equation governing fluid flow in the coal cleats (fractures) are mass conservation equations for gas and water:

Conservation of gas :

$$\nabla\left[b_g M_g(\nabla p_g + \nabla Z) + R_{gw} b_w M_w(\nabla p_w + \gamma_w \nabla Z)\right]_f + q_m + q_g = \frac{\partial}{\partial t}(\phi b_g S_g + R_{sw}\phi b_w S_w)_f$$

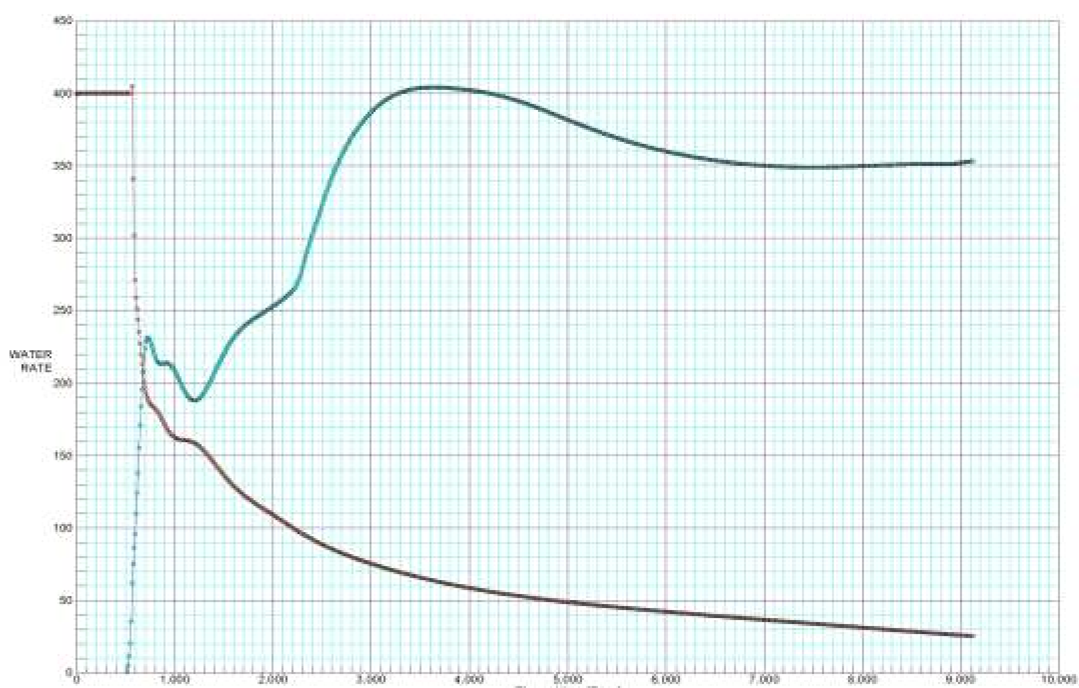
Conservation of water:

$$\nabla[b_w M_w(\nabla P_w + \gamma_w \nabla Z)]_f + q_w = \frac{\partial}{\partial t}(\phi b_w S)_f \quad where, M_n = kk/\mu_n$$

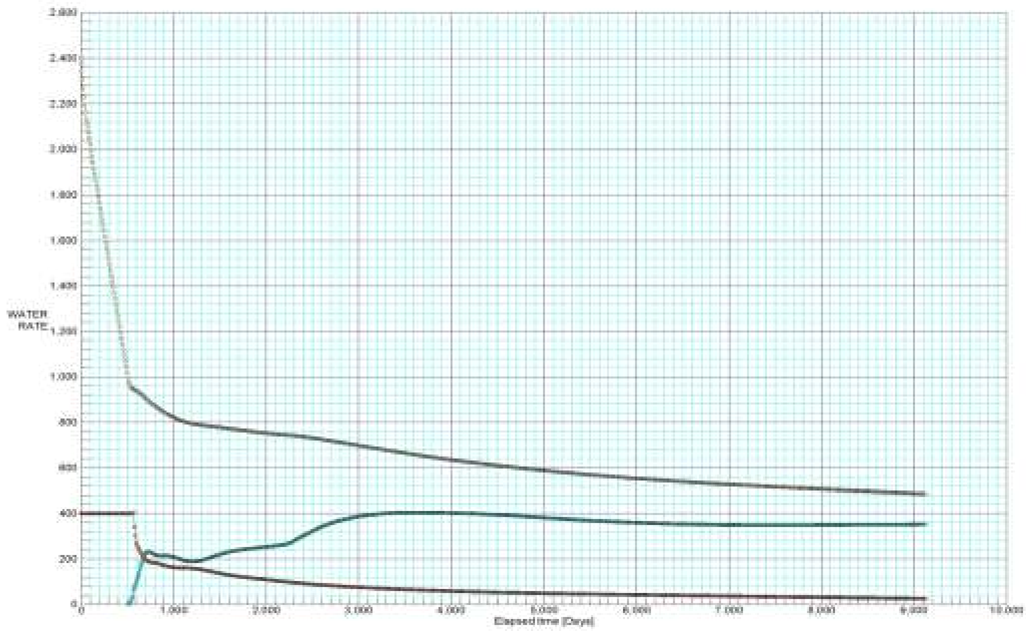
- Subscript f indicates fractured systems, bn (n= g or w) is gas or water shrinkage factors, n (n = g or w) is water and gas gradient, Rsw is gas solubility in water and Pg and Pw are related by the capillary pressure.

Parameters for CBM Reservoir Simulations and modeling				
S.NO	Parameters	1st Layer	2nd Layer	3rd Layer
	Lignite Seams	Kalol Seam	Sobhasan Top	Sobhasan Bottom
1	Geometry	XYZ		
2	Grid System	6 6 2		
3	Grid Spacing	1312 feet		
4	Average Reservoir Temperature	149^0 f		
1	No of days (TMAX)	9125		
2	No of time Steps	999		
3	Unit System	English		
4	Reservoir Phase (MCODE-1)	GAS-WATER		
5	Gas Composition	0.95% in fraction		
6	Dual porosity/Single permeability	YES		
7	Single Component (methane) System	YES		
8	Solution Gas	NO		
9	Gas readsorbed	YES		
11	Initial gas desorption pressure(PD1)	980 PSI	973 PSI	900 PSI
12	Langmuir Pressure (PL)	975 PSI	899 PSI	841 PSI
13	TAU1 and TAU2 (Sorption Time)	2 Days	2 Days	2 Days
14	Langmuir Volume (VL)	28.81	29.87	30.54
15	Water Rate Per day	400 STB/day		
16	Gas Content	14.4418 scf/cuft	15.5254 scf/ft	15.7875 Scf/cuft
17	Permeability (Kx;Ky;Kz)	15 15 2 md	15 15 2 md	15 15 2 md
18	Depth of well below sea level (EL)	4790 feet	4890 feet	4995 feet
19	Gas-Water Contact (GWC)	2654 feet		
20	Initial reservoir pressure below sea leavel (PWRIG)	1450 PSI		

Gas and water rate production at Mehsana



Falling Pressure with Gas and water rate production



Possible areas for Deeper (>300m) Level Coal Resource

- South Eastern part of Jharia Coalfield.
- Eastern part of Raniganj Coalfield.
- Western part of Ib-River & Talcher Coalfield.
- Westcentral 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

Summary

- CBM may be produced in pockets in India.
- CMM may also be produced in selected mines.
- ECBM may be initiated at few locations in deeper coal seams.
- This would reduce the load of atmospheric methane and store CO_2 in deep seated coal.

#####

3.7 Aqueous mineral carbonation and CO_2 reactions in basalts for forming mineral carbonates

S.N. Charan
National Geophysical Research Institute
(Council of Scientific & Industrial Research)

Preamble

- Present day atmospheric concentration of CO_2 ~ 320 ppm
- Environmentally safe permissible upper limit ~ 450 ppm
- Global CO_2 concentration risen by 25% over last 200 Yrs.

- **Excess usage of Fossil Fuels**
- **To meet ever growing Energy Demands**
  - Increase in atmospheric accumulation of CO_2
  - Triggering perceptible changes in Climate
    - Melting of Polar Ice Caps
    - Recession of Glaciers
    - Slow but inexorable rise in Sea Levels

What is Carbon Sequestration?

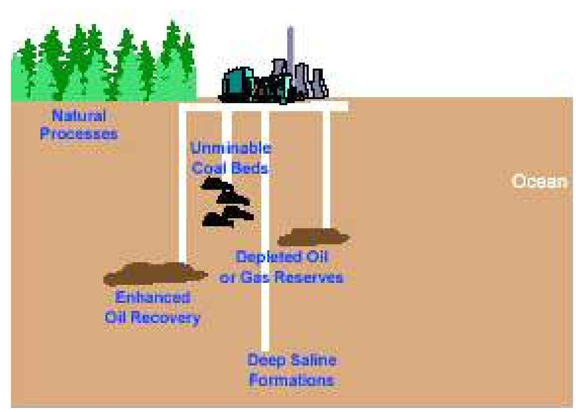
Capture and storage of CO_2 and other Greenhouse Gases that would otherwise be emitted to the atmosphere

Capture can occur:

- at the point of emission when absorbed from air.

Storage locations include:

- underground reservoirs.
- dissolved in deep oceans.
- converted to solid material.
- trees, grasses, soils, or algae



Storage Options- Geological (Best)

❖ Capacity & security for sequestering large quantity of CO_2 with economic benefits.

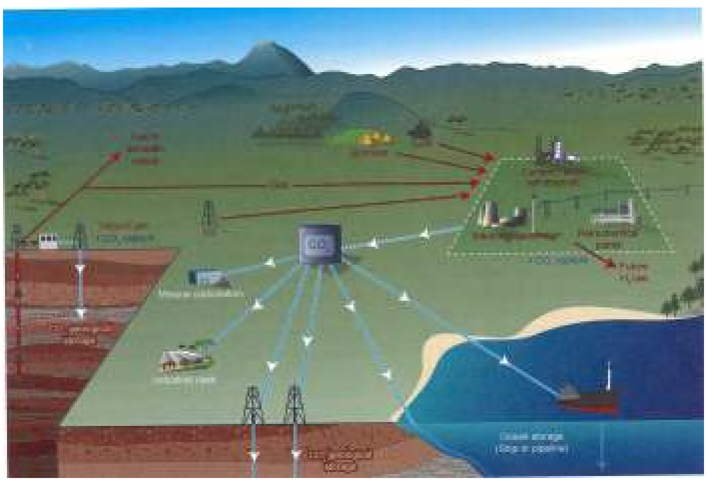
Potential Storage Sites

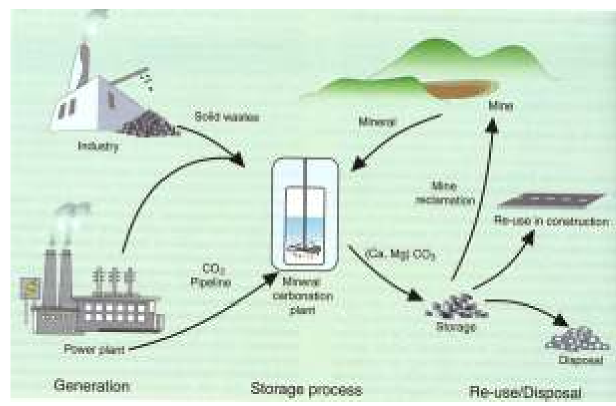
❖ Deep Saline Aquifers

❖ Basic/Ultrabasic Rock Formations (CFB, LC,GSB)

❖ Oil and Gas Fields (EOR)

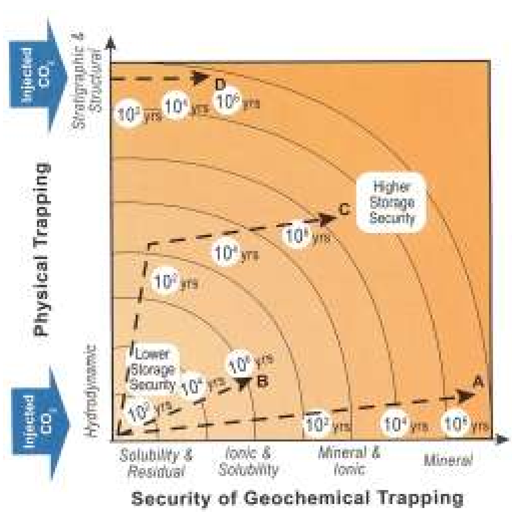
❖ Abandoned Coal Mines (CBM)



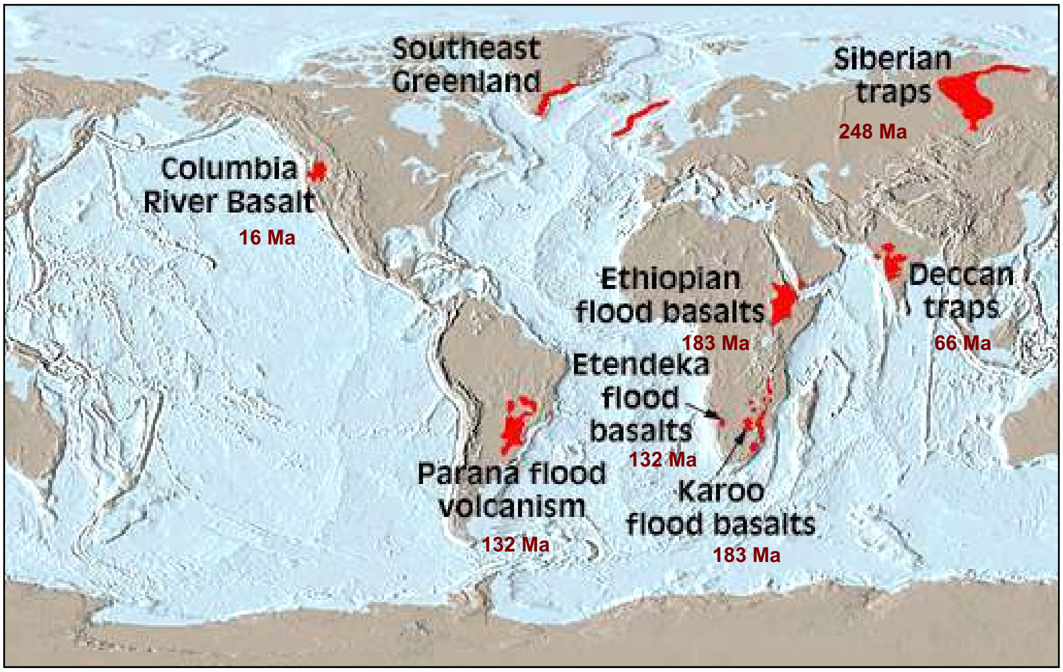


❖ Geological sequestration of CO_2 to be a practicable large scale disposal option, the injected CO_2 must remain safely underground for geological time scales.

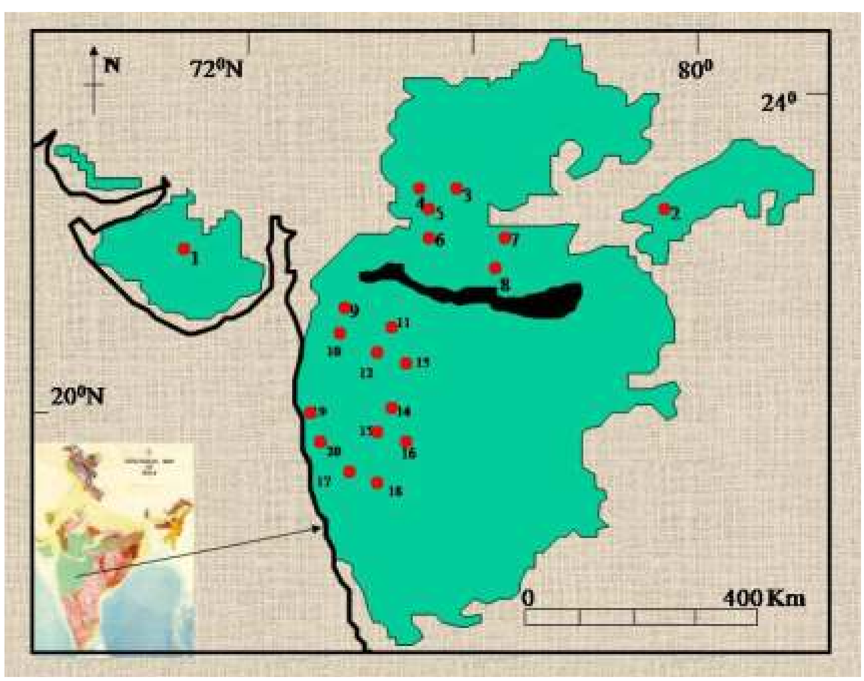
❖ Best achieved by *Mineral Trapping*, allowing the natural buffering processes sufficient time to reduce the global atmospheric CO_2 levels to environmentally safe and acceptable levels.



Flood basalts cover more than 1 million km^2 of the Earth's surface



Generalised Geology Map of Deccan Volcanic Province, India (Modified after Richa Sahu *et. al.,* 2003)



Why Deccan Flood Basalt Province ?

- Large and continuous aerial extent (500,000 Sq. Km.)
- Number of sequential basalt flows (av. >10)
- Favorable structural and interflow features.
- Reactive Fe-Mg-Ca and Na-rich silicate mineral assemblages
- Underlain at places by Mesozoic Sediments (SST)
- -- suggesting that the DVP can be a potential deep underground storage reservoir for CO2
- -- (to be proved by pilot scale studies)

Objectives

- To carryout laboratory scale aqueous mineral carbonation experiments under simulated conditions, using basalt-picrite, water and CO_2 (reactants) aimed at mineral carbonation and document the nature of carbonates (products).
- To document the reaction kinetics under varied P, T, pH conditions between CO_2, the primary silicate minerals in basalts namely olivine, pyroxene and plagioclase (reactants) and the secondary carbonates, serpentine and clay (products) and estimate the rate and extent of mineral carbonation.

Rationale

- Study: Knowledge base on how CO_2 reacts (its reaction kinetics as a function of T,P, porosity/permeability) through low to high-T experiments to better understand the dissolution kinetics & affinity of Ca/Mg/Fe-silicates for forming the secondary carbonates.
- Computing rate of carbonate mineral formation in basalt flows requires: (a) solution conc. of Ca/ Mg/ Fe required to precipitate stable carbonates and (b) the concentration of dissolved CO_2.

Deccan Basalt Province

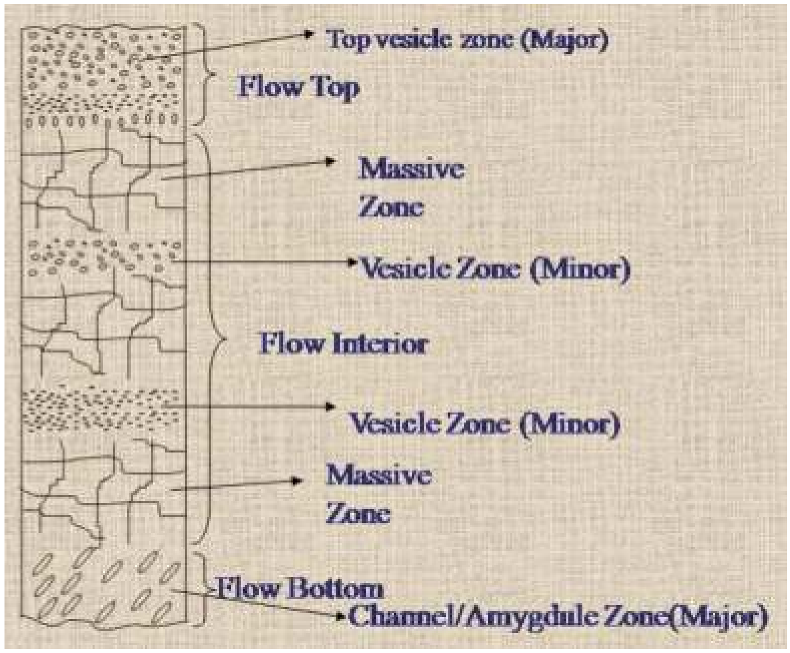
Favorable megascopic features in DVP

☞ Intertrapeans between basalt flows, Igatpuri (Ma)

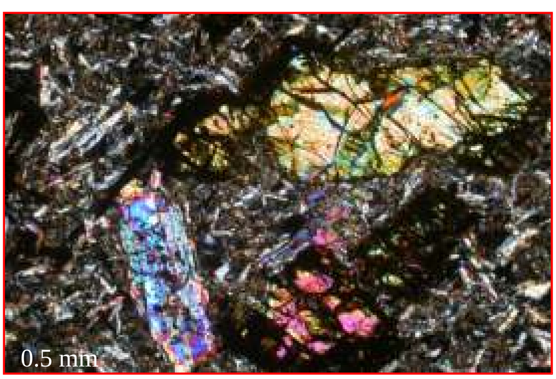
☞ Pipe vesicles in basalts, Igatpuri (Ma)

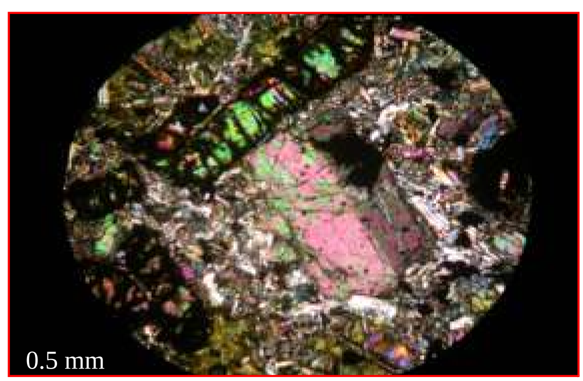
Amygdular basalt, Igatpuri (Ma) ☞

Interflow Features in a Basalt Flow Unit at Kalsubai Hill (Ma)



Mineralogy of Picrites





Mineralogy of Picrites

Simulation studies

- Preliminary Aq.Experiments using Picrite (Igatpuri Formation) & CO_2 (@1000 C, 60 bars CO_2 pressure) for 5 months—in 3 steps
  - CO_2 dissolved in an Aq.phase (CO_2+H_2O—H_2CO_3)
  - Fe/Mg/Ca leaching facilitated by protons (Fe/Mg/Ca-silicates(s)+2H+(aq) $(Fe/Mg/Ca)_2$+(aq)+SiO_2+H2O
  - Fe/Mg/Ca bearing sec. carbonates formed $(Ca/Mg)_2$+(aq)--(Ca/Mg) CO_3(s)+H+(aq).
- A general mineralization reaction scheme is:

  $CO_2\ (g) \rightleftarrows Kh\ CO_2\ (aq)\ (1)$

  $CO_2\ (aq) + H_2O \rightleftarrows K1\ HCO_3\text{-} + H+\ (2)$
- Where Kh=Henry's constant; K1=Equilibrium constant. Pressurization with CO_2 (g) produces Carbonic acid (CO_2 (aq)), bicarbonate anions and H+ via reactions (1 & 2) lowering the solution pH.

Causative exothermic mineral reactions

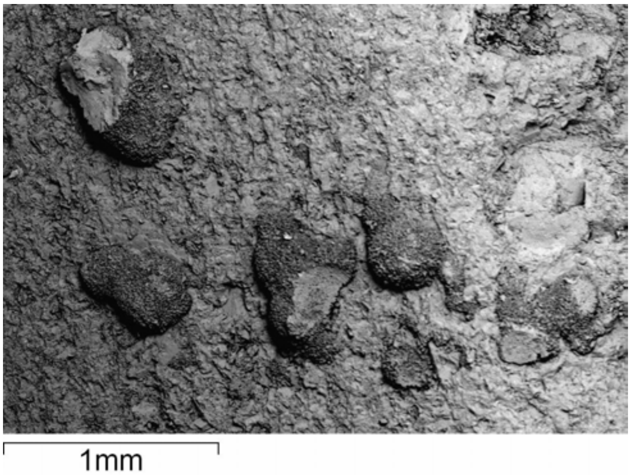
- 2Mg2SiO4(Ol) + 2H2O   Mg3SiO5(OH)4 (Serp) + MgCO3 (Mag).
- CaAl2Si2O8(Plag)+2H2O + CO2   CaCO3(Cc)+AlSi2O5(OH) (Clay).
- Both the above reactions are exothermic hence they releasing lot of heat energy during this process which can be trapped to generate electricity on a small scale.
- Computing the rate of carbonate mineral formation in the basalt flows requires:
- solution conc. of Ca, Mg, Fe and Mn required to precipitate stable carbonates
- release rate of Ca, Mg, Fe & Mn from the basalt
- the concentration of dissolved CO2.

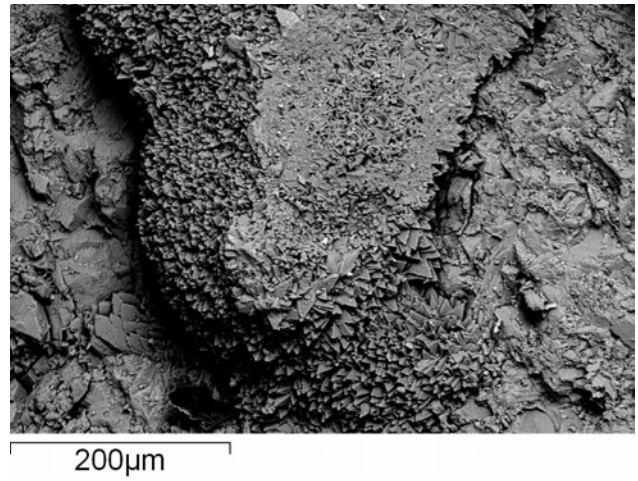
In-situ mineral carbonation

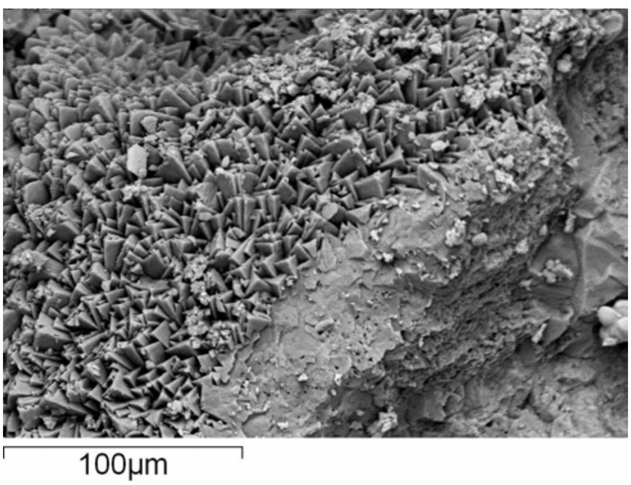
- $CaO+CO_2 \rightarrow CaCO_3+179$ kJ/mole.
  $MgO+CO_2 \rightarrow MgCO_3+118$kJ/mole.
- Carbonation reaction is thermodynamically favored –carbonates are at lower energy state—CO_2.
- $Mg_2SiO_4+_2CO_2 \rightarrow 2MgCO_3+SiO_2+95$kJ/mole.
  140 gms   88gms   168gms   60gms
- $2Mg_2SiO_4+CO2(g)+H_2O \rightarrow Mg_3Si_2O_5(OH)_4+MgCO_3+16.5$ Kcal
  280gms   44gms   36gms   276gms   84gms

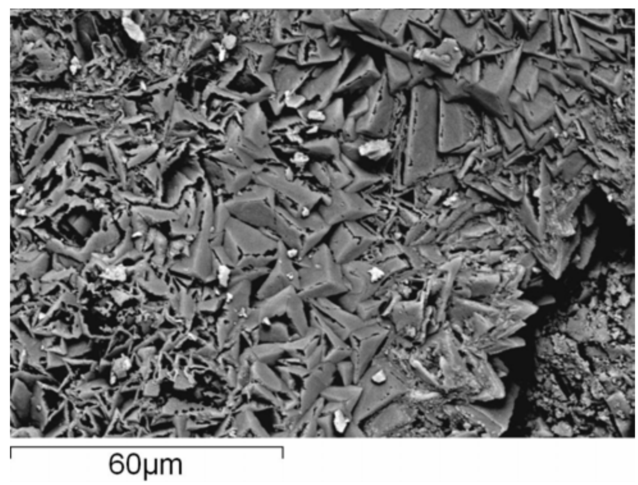
Laboratory Simulated Mineral Carbonation

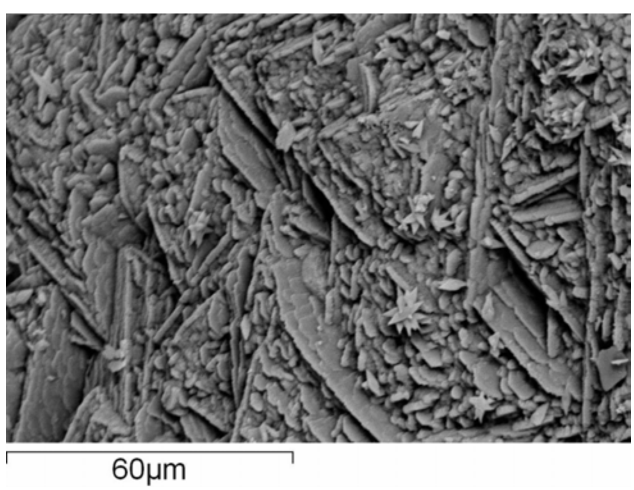
Secondary Ca/Mg/Fe carbonates formed by reacting CO_2 and Picrite (Western DVP)





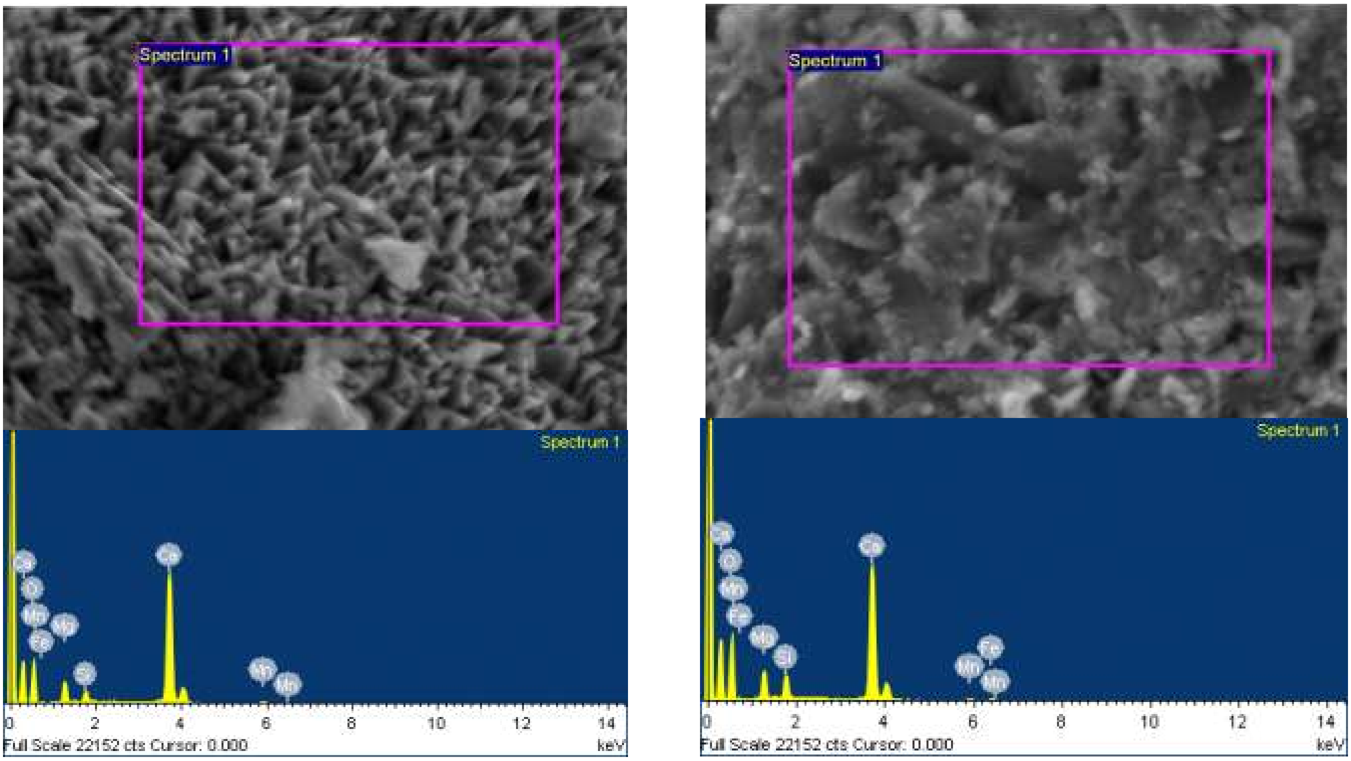




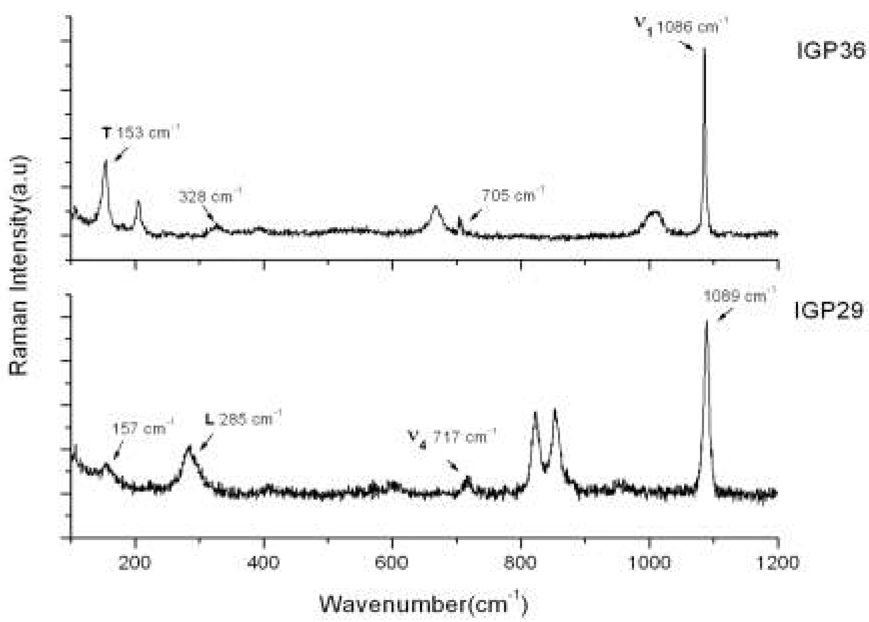


Scramming Electron Microscope picture of mineral carbonation

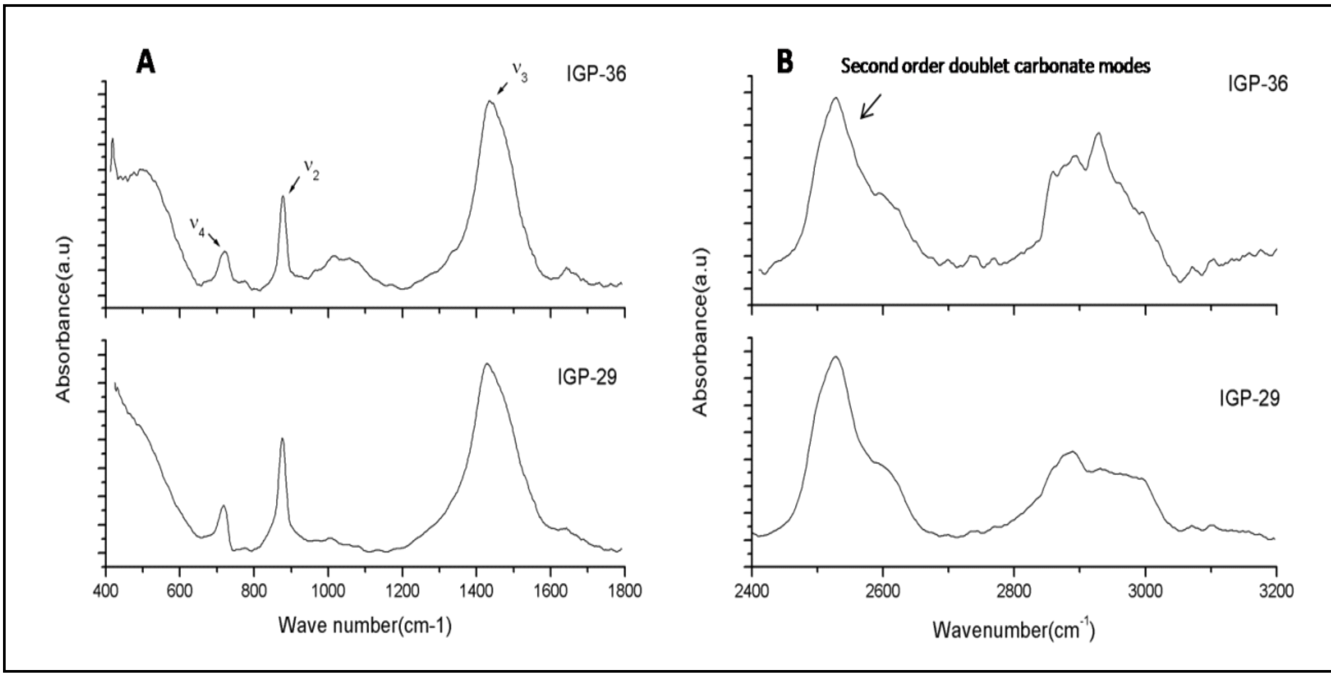
EDS Spectrum



Raman spectra of secondary carbonates



FTIR spectra of secondary carbonates



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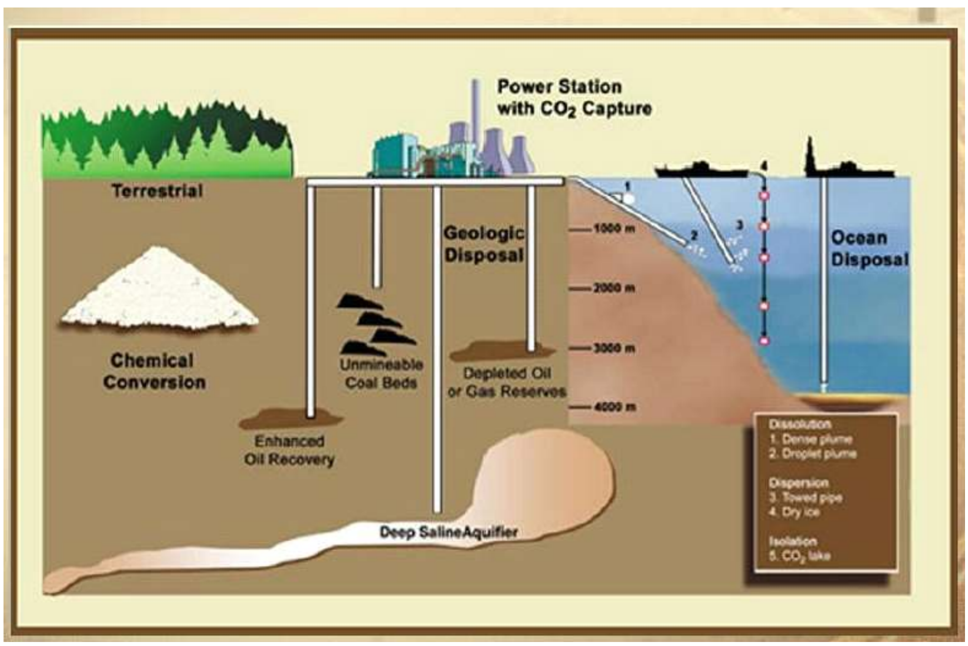
3.8 Sequestering Carbon dioxide into Clathrate Hydrates: Laboratory Studies

P.S.R. Prasad
Gas-hydrates Group
(Laser Raman & FTIR Laboratory)
National Geophysical Research Institute

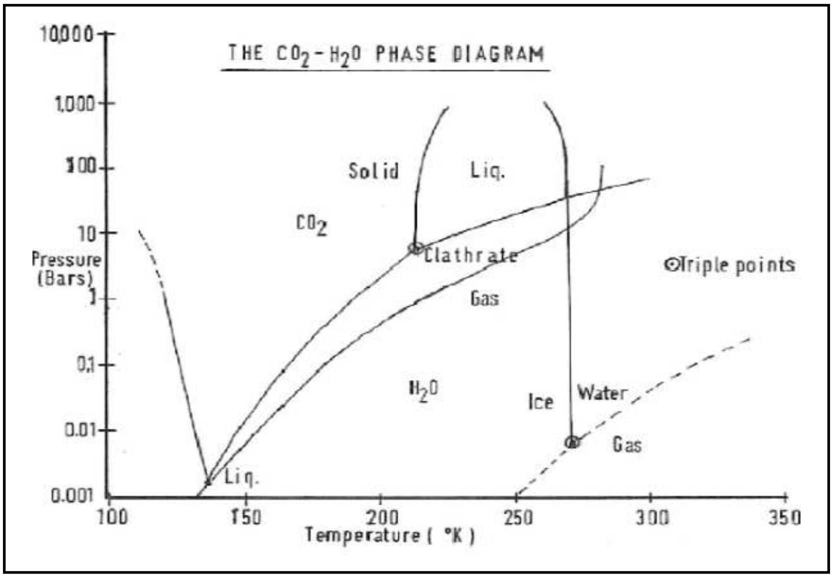
Current Sequestration Methods

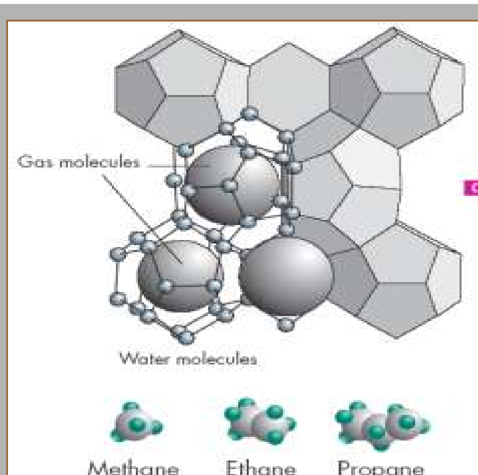


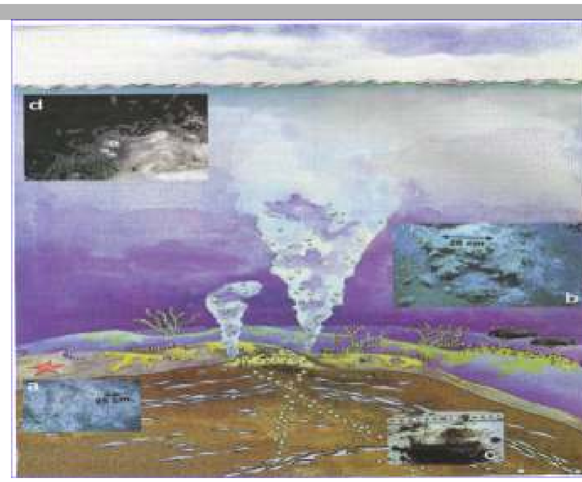
Novel Concepts

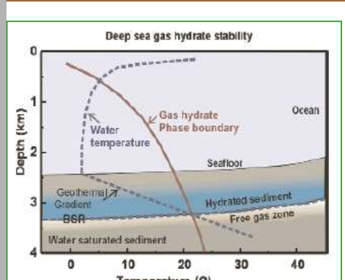
- ❖ Glacial Storage (Clathrates)
- ❖ Biogenic Methane
- ❖ Mineralization

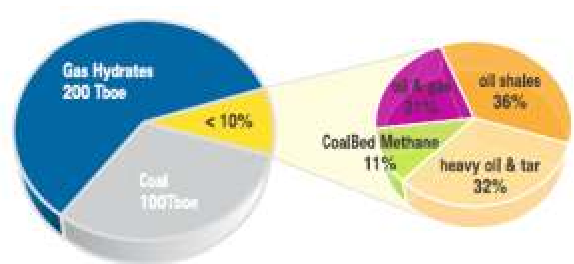
CO_2 – H_2O Phase Diagram





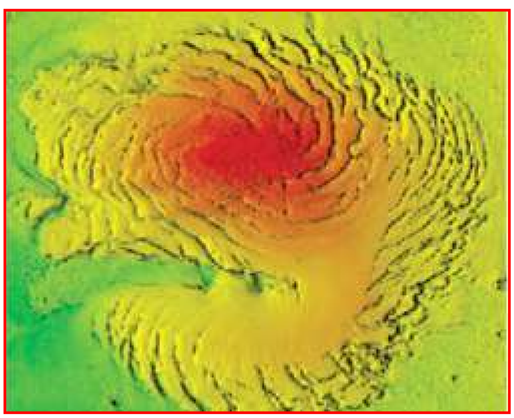


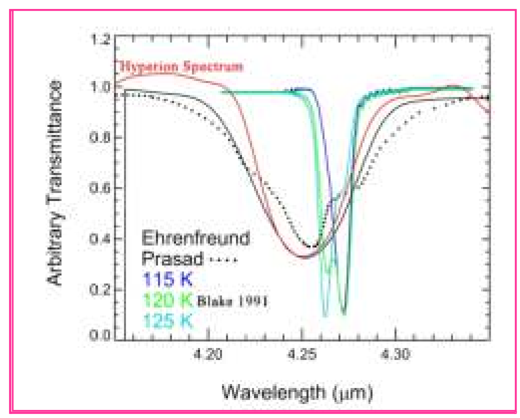


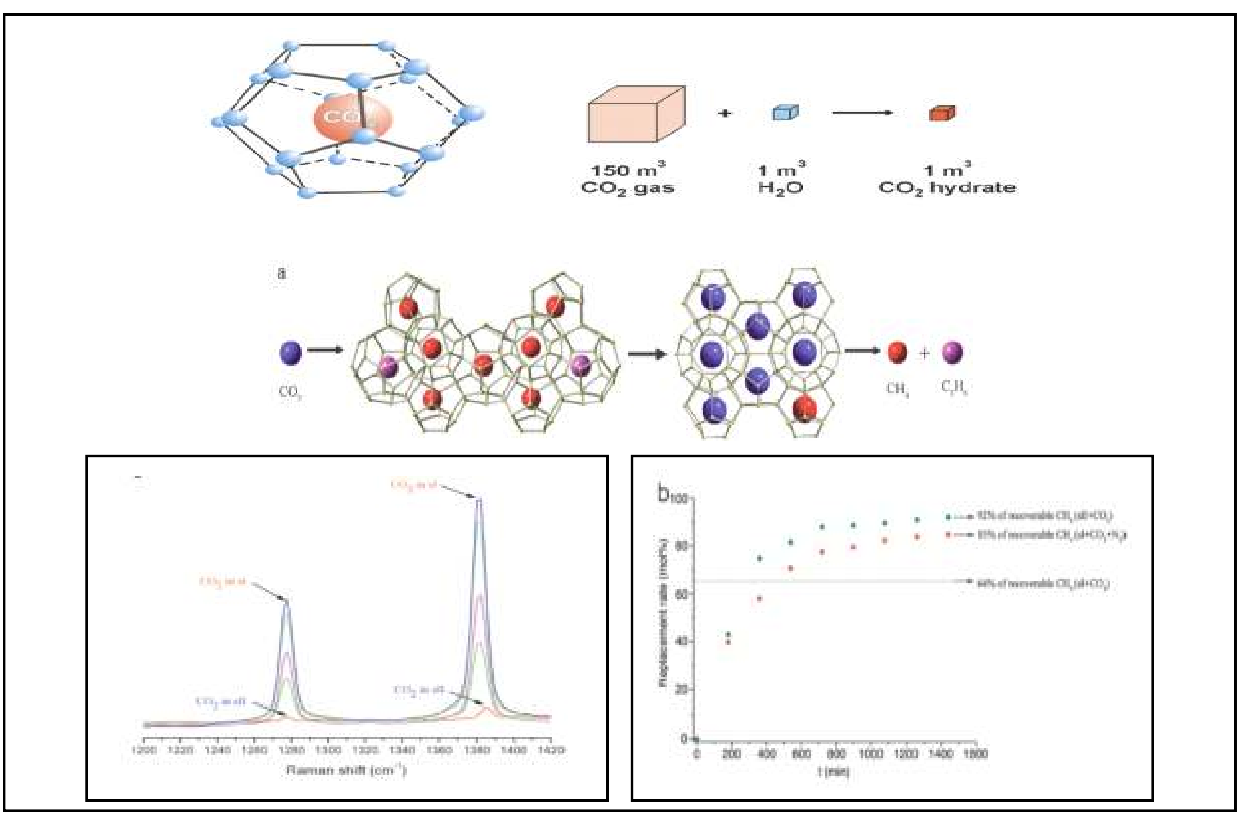


Glacial Clathrate Storage: a better carbon store

- Clathrates naturally form in Glaciers
- Storage times up to 1 million years
- Stability of Clathrates within Glaciers
- Practically unlimited storage of CO2
- Low environmental impact
- Low energy requirement to create store
- Stored carbon is recoverable







What are the issues related to the presence of Gas hydrates?

Deep offshore extraction

Extreme conditions encountered at these depths require an adaptation of the drilling muds. The range of temperature (down to - 1°C) and pressure (up to 400 bars) favor the formation of gas hydrates. The water contained in the drilling muds traps the gas molecules coming from the reservoirs. The plugging of the lines as well as the annular may cause interruption of the drilling operation and even destruction of the rig equipment.

Flow assured

The production, processing and distribution of gas is a high pressure operation. Under pressure, pipelines can be plugged with gas hydrate in the form of ice. Today every oil and gas company has a flow assurance department responsible for detecting and predicting the formation of gas hydrates in the pipelines and the processing equipment.

Natural gas hydrates

More and more countries are interested in the investigation of gas hydrates trapped in marine sediments and in permafrost. Gas hydrates occur abundantly in nature, both in artic regions and in marine sediments. Methane trapped in marine sediments as a hydrate represents a huge carbon reservoir. The worldwide amounts of carbon bound in gas hydrates is conservatively estimated at twice the total amount of carbon to be found in all known fossil fuels on earth. Methane hydrate is stable in ocean floor sediments at water depths greater than 300m.

Storage and transportation of natural gas

One way of reducing the cost of natural gas transport is to carry it as natural gas hydrates (NGH). The gas hydrate process reduces the volume of natural gas by about 169 times and stores the hydrates within a range of potential temperatures and associated pressures. Such transportation and storage are easier and safer than liquefied natural gas (LNG) handling. But more has to be known about the formation of gas hydrates to optimize the industrial process, and particularly their stability and conditions of safety during transportation and storage.

Global warming

The stability of gas hydrates and their effect on global warming may become an issue and needs to be investigated. Depending on the stability of the gas hydrates, a 1 or 2°C increase in the temperature of the ocean might possibly cause the release of methane into the atmosphere with all the ensuing impacts on climate changes.

CO_2 Ocean sequestration

CO2 ocean sequestration is one method being explored to control the build-up of CO_2 in the atmosphere. The formation of a CO_2 hydrate from fossil fuel CO_2 disposal with a solid hydrate as the sequestered form is evaluated. The success of the option of pumping liquid CO_2 into the oceans depends above all on the chemical stability of the CO_2 hydrate.

Cold Energy Storage

As gas hydrates show high latent heat during formation and dissociation, they are considered very interesting materials for cold energy storage.

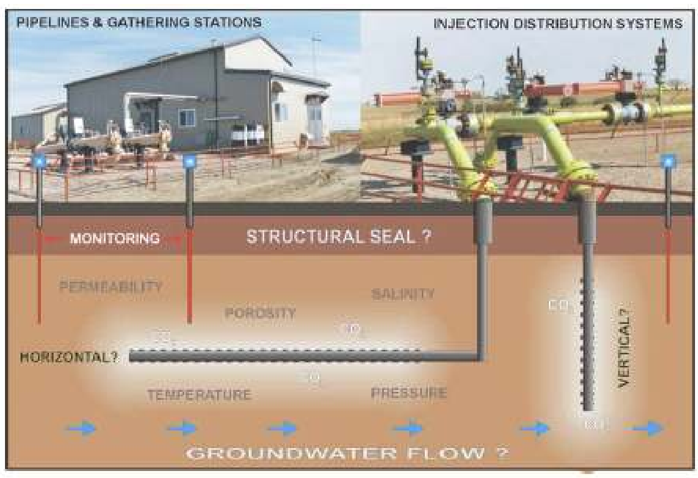
Desalination

Gas hydrate technology can be used to produce fresh water. Using an appropriate gas, water molecules go into a hydrate phase during hydrate formation from salt water, while minerals dissolve in the water concentrate.

For all the scientists working on the above mentioned topics, it is absolutely vital to have as much information as possible on gas hydrate formation / dissociation such as:

- **thermodynamic properties**
- **kinetics data with any type of mixture (even including solid particles)**

Conceptual diagram – (Geological)



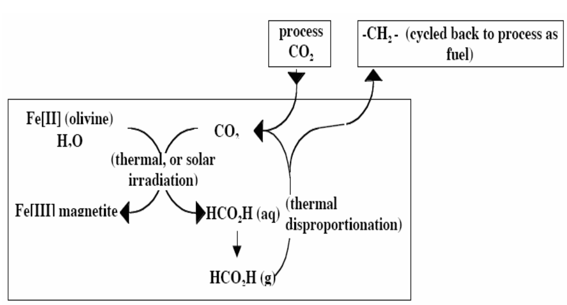
$$CO_2 + H_2O + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

$$Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2$$

(Olivine) (Magnesite)

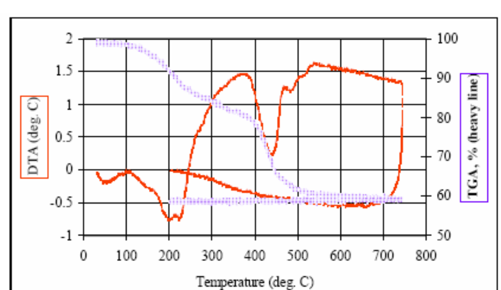
$$Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O$$

(Serpentine) (Magnesite)



$$0.75q\, Fe_2SiO_4 + CO_2(g) + (0.5q - 2)\, H_2O\,(l) \rightleftarrows 1/n\, C_nH_{2n+2}\,(aq) + 0.5q\, Fe_3O_4 + 0.75q\, SiO_2$$

where $q = 6 + 2/n$.



Hydromagnesite [3MgCO3.Mg(OH)2.3H2O]

Objective

- Firstly, to study the kinetics of carbonation reactions in laboratory test vessels by varying the parameters like temperature and pressures. The reactants & products will be analyzed in detail to estimate the over-all retention time of captured carbon dioxide.
- The second objective is to develop an understanding into guest - host interactions in gas hydrate system. Recovery of hydrocarbons from 'Gas hydrates' is a technological problem as the volume of gas released on dissociation of hydrates is exceedingly large.

Raman spectrometer

FTIR spectrometer

De-(Re) hydration induced structural modifications in Natural Zeolites from Deccan Traps

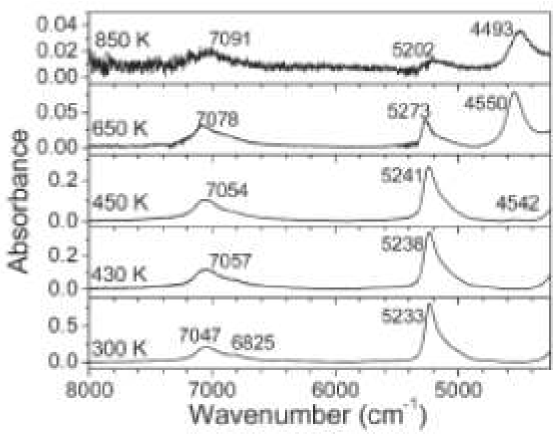
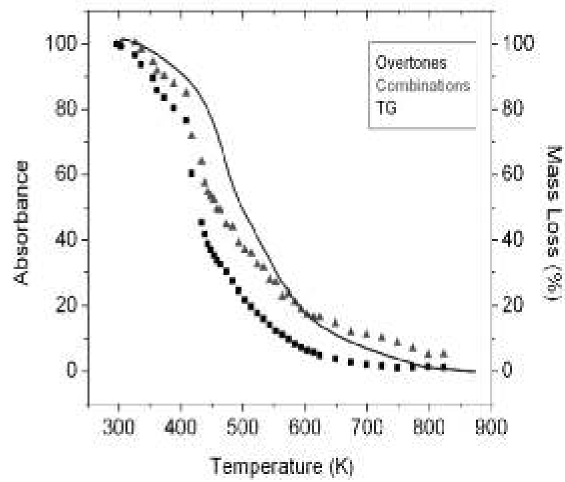
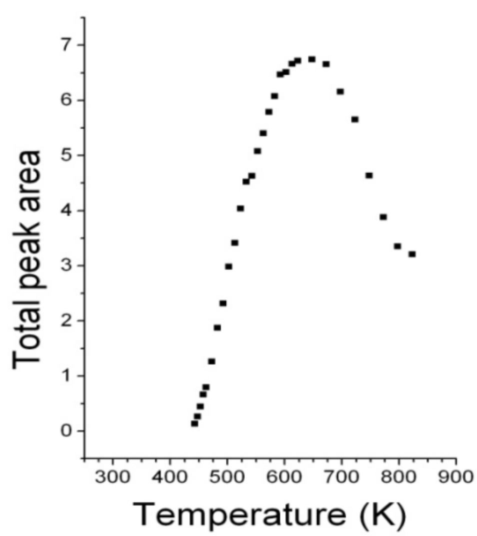


Figure 4: Background corrected spectra of stilbite collected at different temperatures of dehydration (300, 430, 450, 650, and 850 K) in the wavenumber region 4000-8000 cm_{-1}





Stilbite (STI): $Na_2Ca_8(Al_8Si_{54}O_{144})60H_2O$

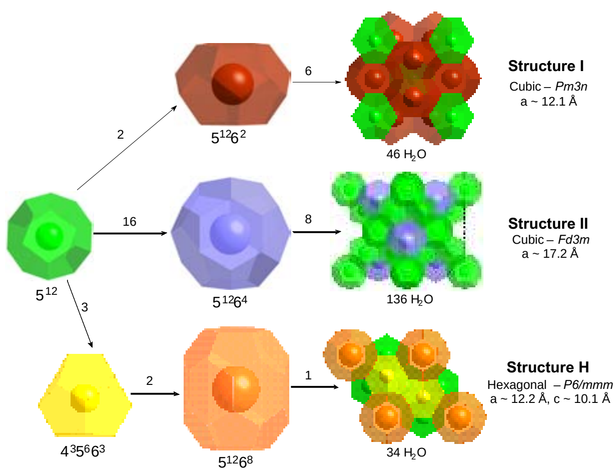
Conclusions

- Structural Modifications in natural zeolites are at second (high) stage dehydration
- Si is more prone for protonation than Al

Prasad *et. al.*, Am Mineral, 90, 1636-1640 (2005); Eur J Mineral, 18, 265 - 272 (2006); Micropor Mesopor Mater (2006)

Clathrate Hydrate Structures

Hydrate Type	Structure I		Structure II		Structure H		
Cavity	S	L	S	L	S	L	M
	5^{12}	$5^{12}6^{2}$	5^{12}	$5^{12}6^{4}$	5^{12}	$4^{3}5^{6}6^{3}$	$5^{12}6^{8}$
# Cavities / Unit Cell	2	6	16	8	3	2	1
Average Radius (A)	3.95	4.33	3.91	4.73	3.91	4.06	5.71



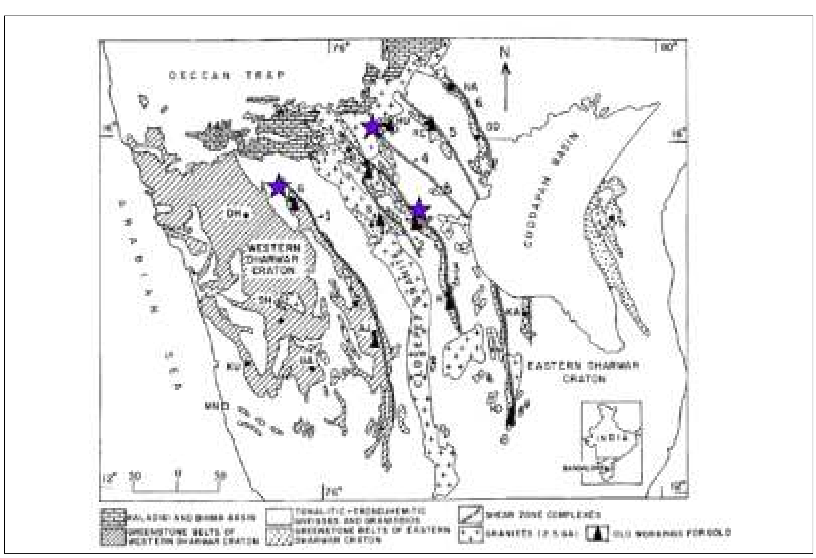
Optimum ratio – 0.76 to 1.00

Molecule	Dia (A)
CO^2	5.12
CH^4	4.36
C^2H^6	5.5
C^3H^8	6.28
N^2	4.10
Kr	4.0
Ar	3.8

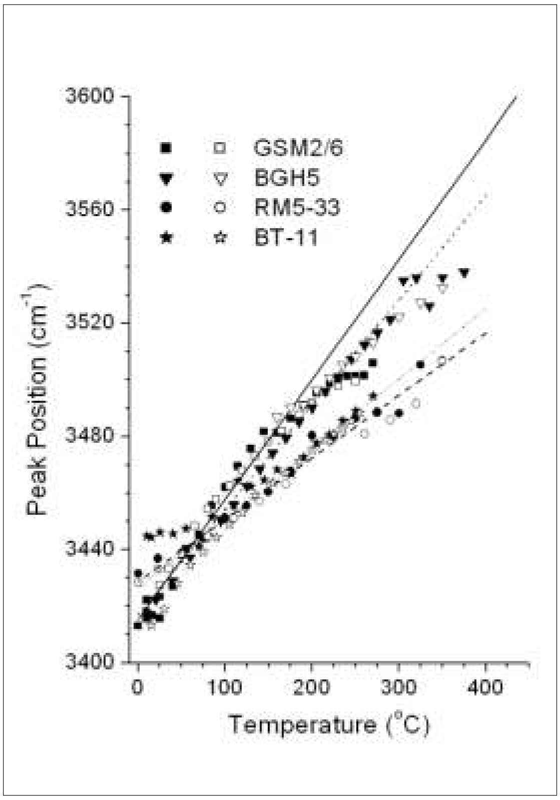
Structure I	
S	0.855
L	0.744
Structure II	
S	0.868
L	0.655

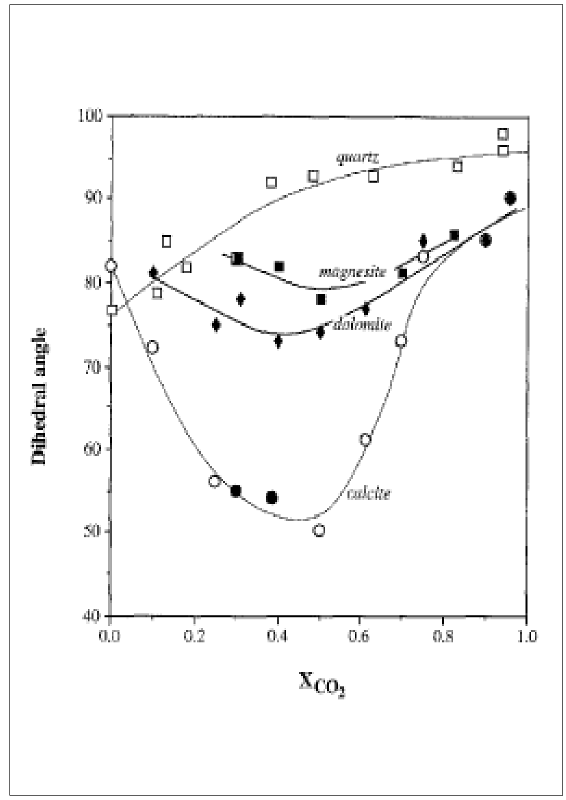
CH_4

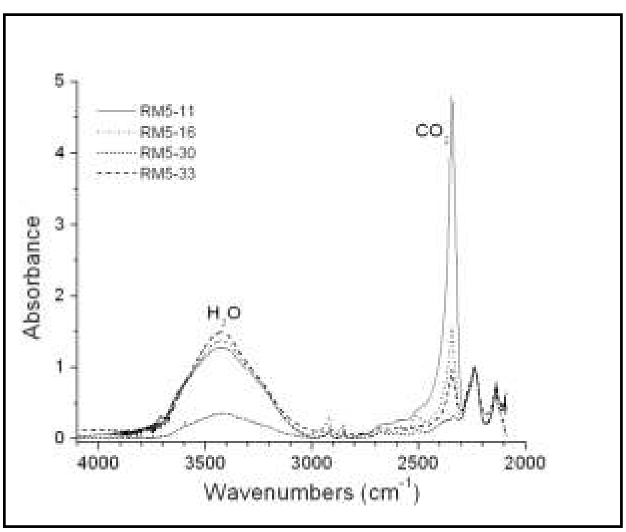
FTIR Studies on CO_2 – H_2O in Quartz veins



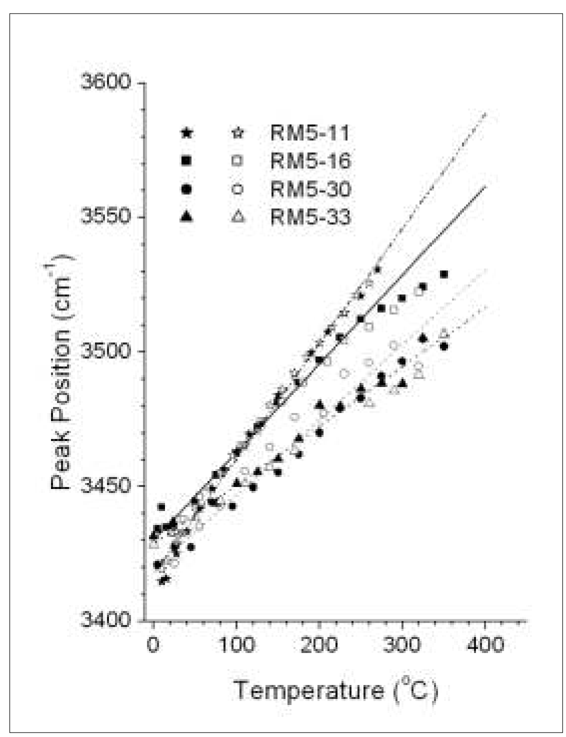
WDC – 0.37 to 0.46 cm^{1} °C^{-1}
EDC – 0.22 to 0.25 cm^{1} °C^{-1}

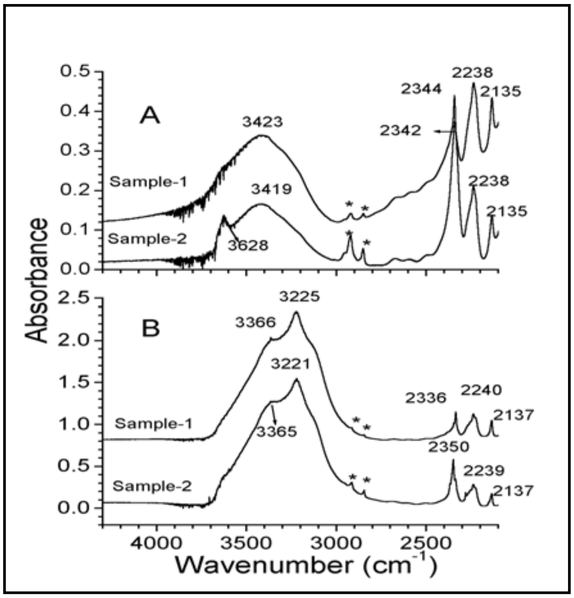


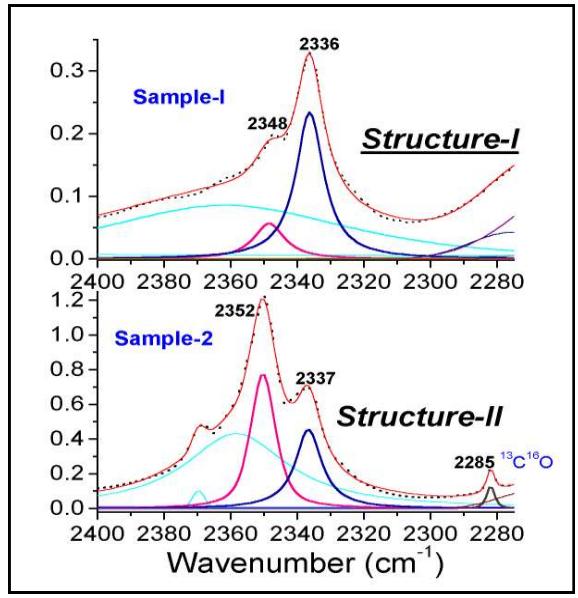




CO_2 – 0.22 to 0.43 cm^{1} °C^{-1}



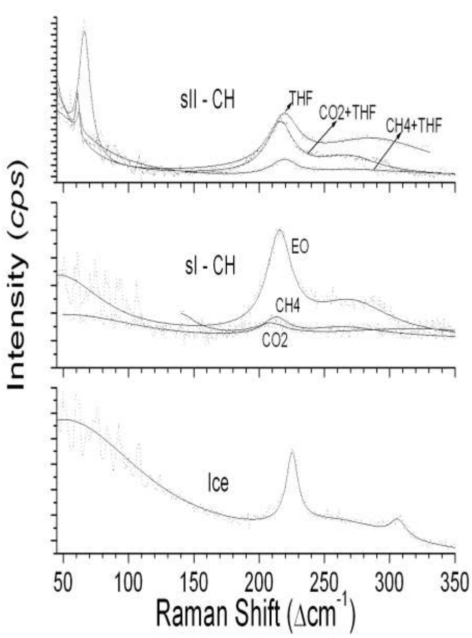




Acrylic Cell @ 1 MPa

Propane Hydrate

Can one distinguish sI & sII from Raman Shift ?

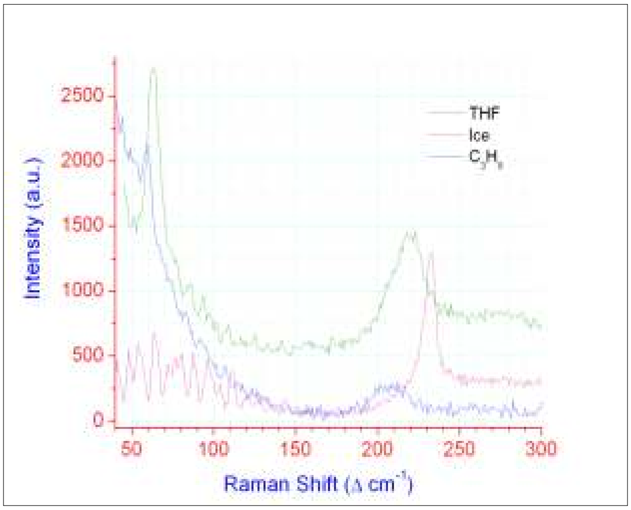


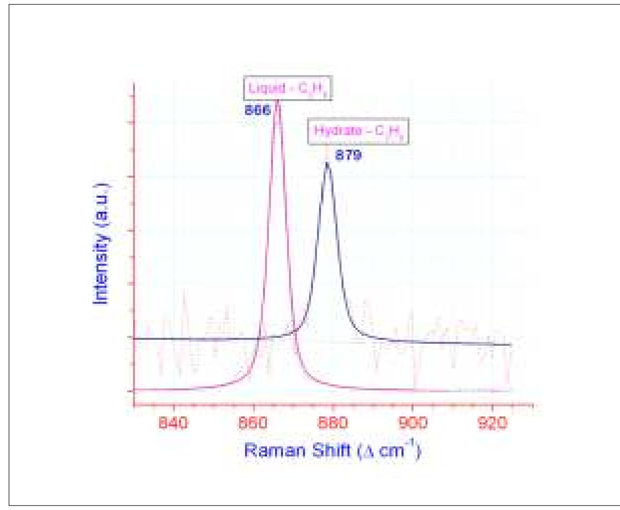
Guest Molecule	Observed Raman Peak (cm^{-1})		CH Struct
	Position (width)	Position (width)	
THF	219 (27)	66 (10)	sII
Propane	209 (29)	60 (6)	sII
CH_4 + THF	219 (20)	62 (4)	sII
CO_2 + THF	216 (27)	61 (3)	sII
EO	214 (28)	--	sI
CH_4	213 (24)	--	sI
CO_2	208 (28)	--	sI
Ice	225 (10)	--	--

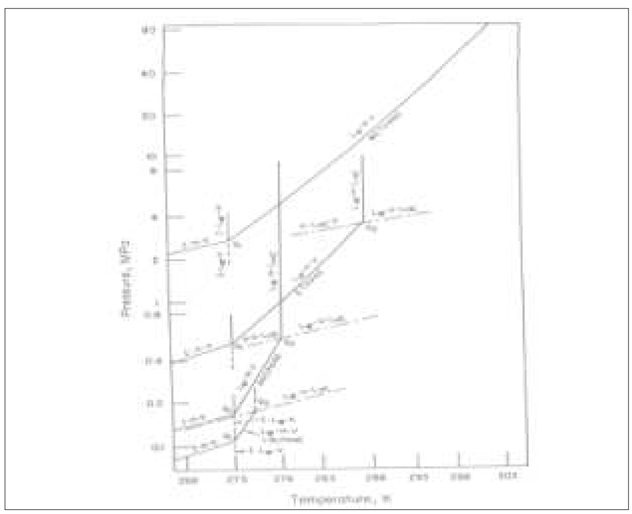
YES - Raman mode around ~ 60 cm^{-1} is the unique feature for sII hydrates

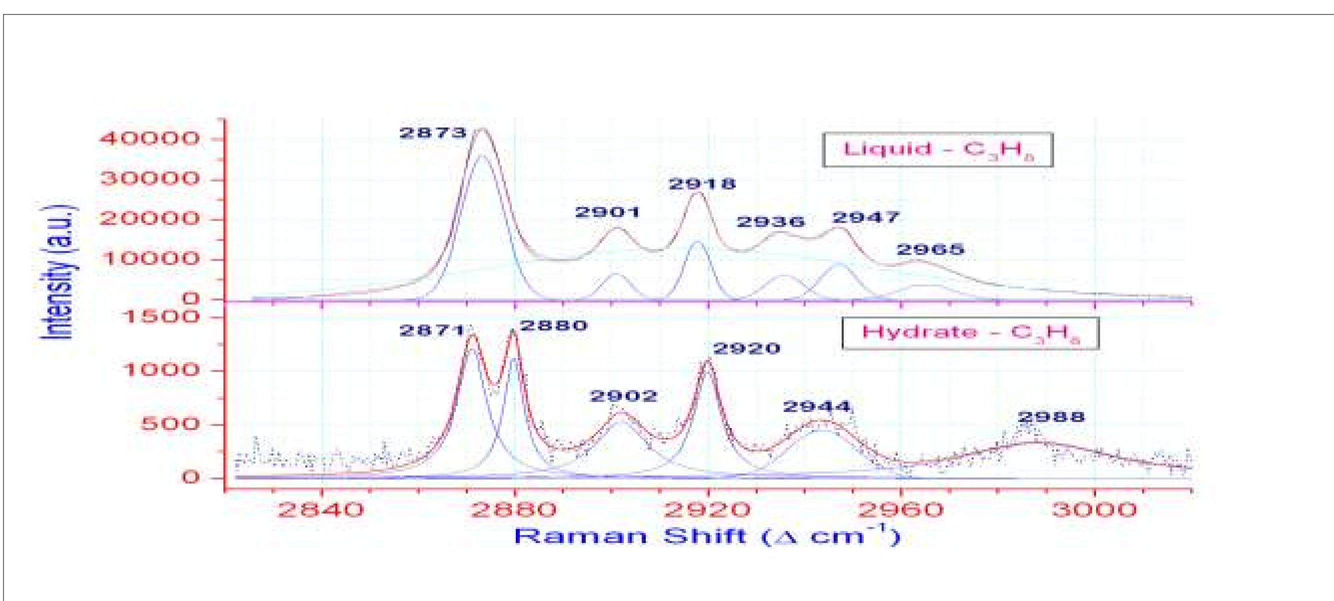
Prasad et al., Current Science, 94 (2008) 1495

Laser Raman Signatures of Propane Hydrate









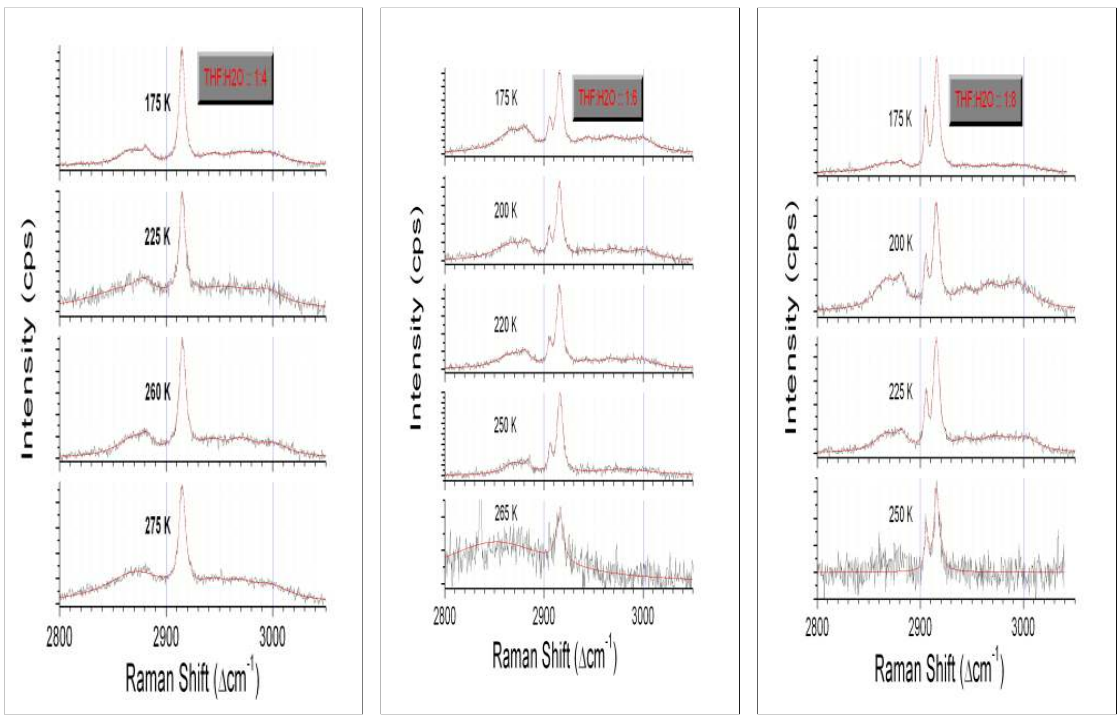
Can methane occupy vacant cages in mixed hydrates ??

- ❖ Conflicting opinion – mixed (sI + sII) phases
- ❖ Two hydrocarbons (THF & t-BuNH$_2$)

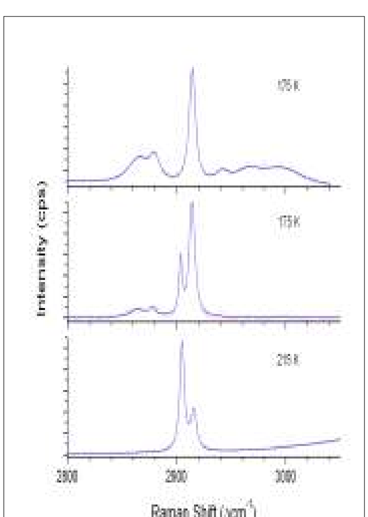
Prasad *et. al.*, Vibrational Spectroscopy 50 (2009) 319 -323

Prasad et al, J Phys Chem A 113 (2009) 11311 - 11315

Mixed Hydrates with THF (sII)



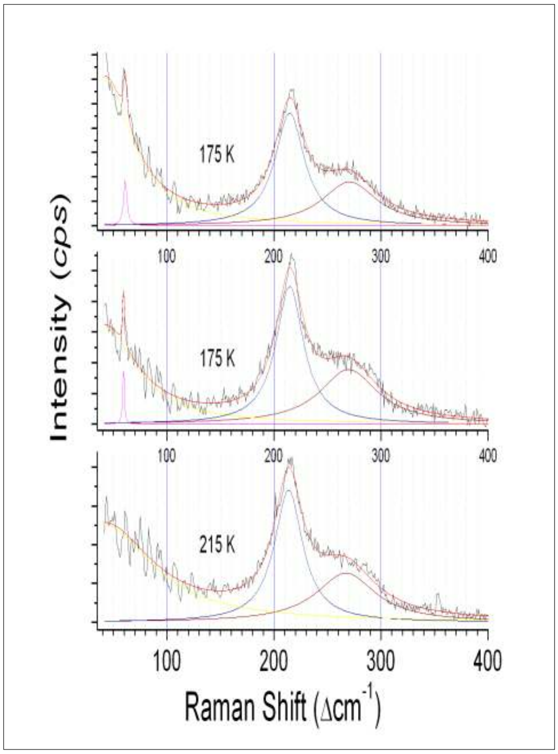
Mixed Hydrates with THF (sII)

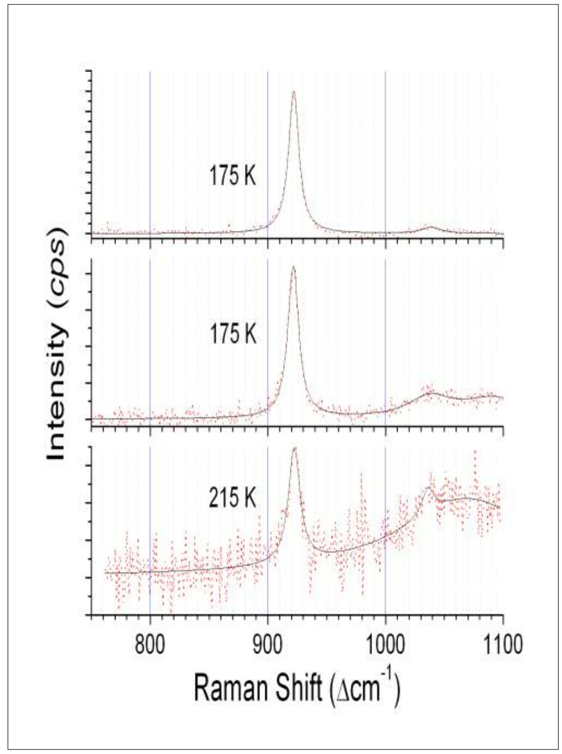


- ❖ THF + CH_4 hydrate (sII) & methane occupies vacant 5^{12} cages. Hydrates are stable ~290 K, 0.1 MPa
- ❖ Vacant $5^{12}6^4$ cages are also occupied by methane
- ❖ A unique structural transformation sII to sI has been observed THF (1.0 mol%) + CH_4

Prasad *et. al.*, Vib Spectrosc, 50 (2009) 319

Mixed Hydrates with THF (sII)

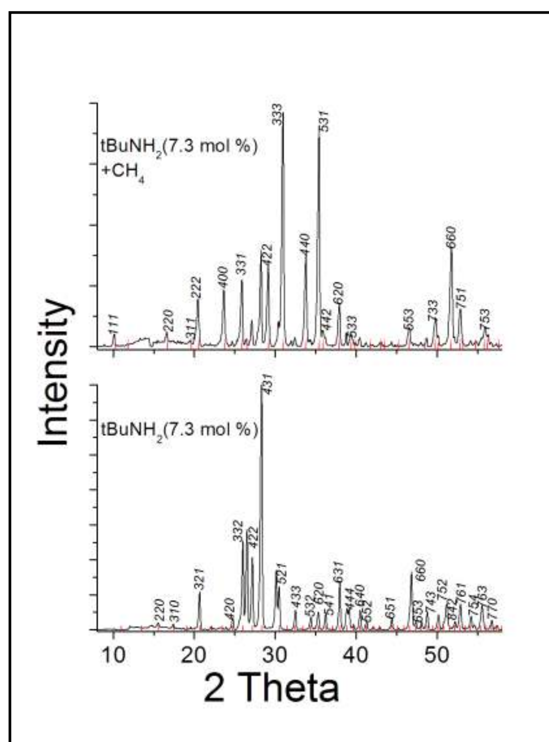




Mixed hydrates with t-BuNH2 + CH4

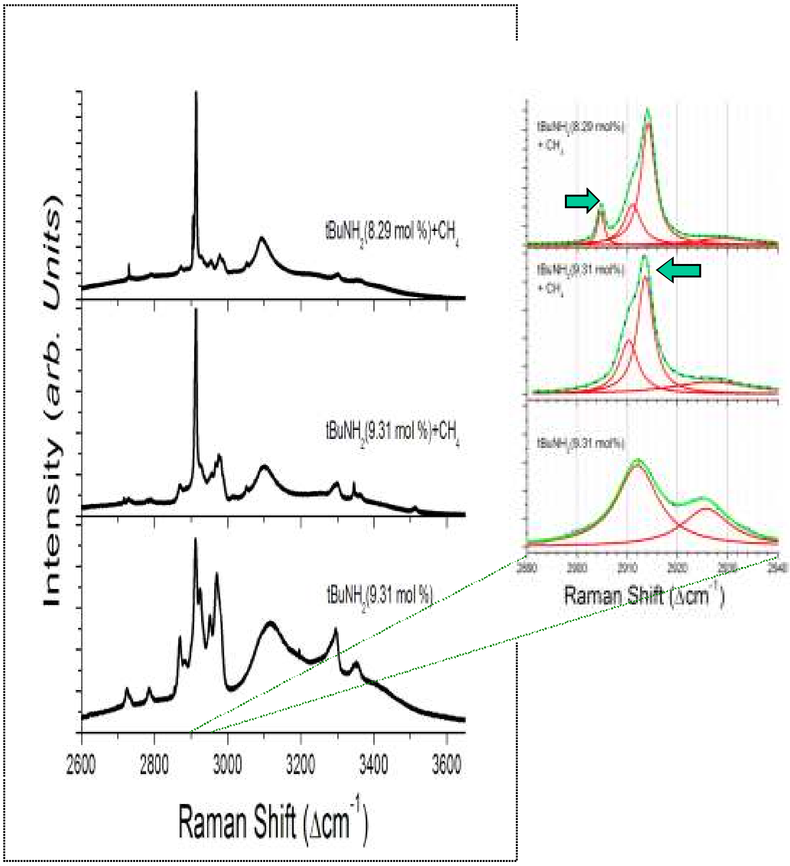
- Upon pressurizing with CH_4 (□ → $4^4 5^4$)
- sII – (Fd3*m*) a = 17.3984 ± 0.0177 Å
- Clathrate Hydrates with
  12□ 16tBuNH2.156.H2O
  sVI – (I-*43d*) a = 18.6341 ± 0.0046 Å

XRD measurements – 0.1 MPa & 120 K



Prasad *et. al.*, J Phys Chem A, in press (2009)

Raman results on (t-$BuNH_2$ + CH_4)



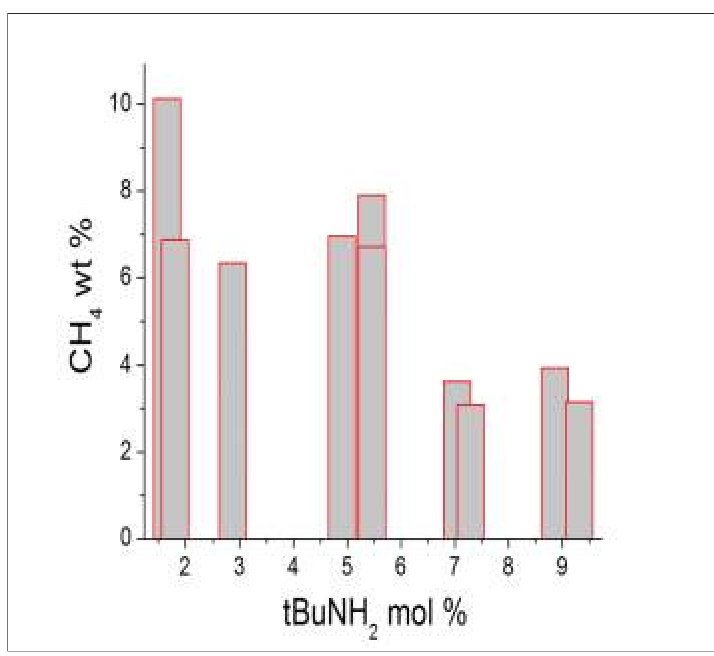
Conclusions

- t-$BuNH_2$ + CH_4 system always stabilize in sII structure. CH_4 is too large for 4_45_4 cage of sVI
- CH_4 can occupy all the vacant cages of sII.

Prasad et al., J Phys Chem A, 113 (2009) 11311

Gas Storage in Double Hydrates

- The storage capacity (~ 8.0 wt%) is consistent with reported cage occupancy
- Useful for shifting (P,T) conditions
- Could be useful in NGH storage and transportation

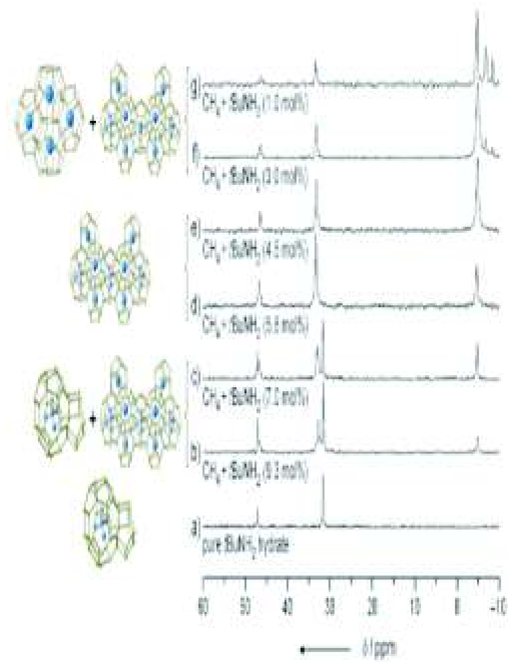


What is known
Tert-Butylamine + H_2O + CH_4

- Tert-butylamine – forms type VI clathrates 16(CH3)3CNH2.156(H2O) cubic (I -4 3d) a = 18.81 Å # cages – 16 (43596273) & 12 (4454)
- Tert-butylamine + CH4 – forms type II clathrates 16S.8L.136H2O cubic (F d 3m) a = 17.306 Å tBuNH2 in 5.6 - 4.5 mol %

The storage capacity of CH_4 gas in the hydrate phase increases drastically as the initial concentration of $tBuNH_2$ decreases.

$[n(CH_4)/n(tBuNH_2)]$? upon $n(tBuNH_2)$ ~5.6 ? 1.0 mol%

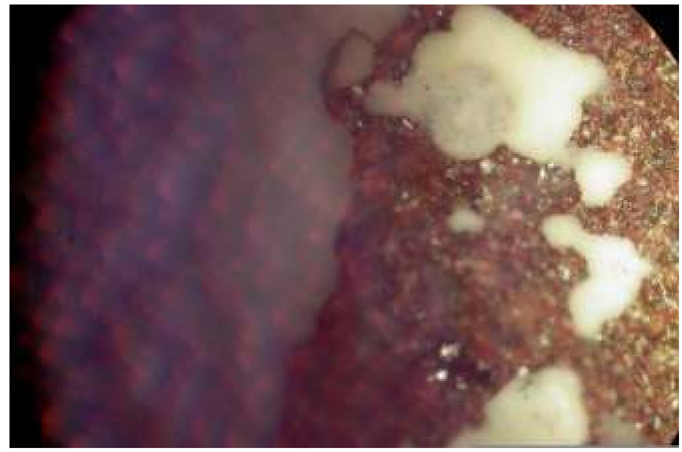


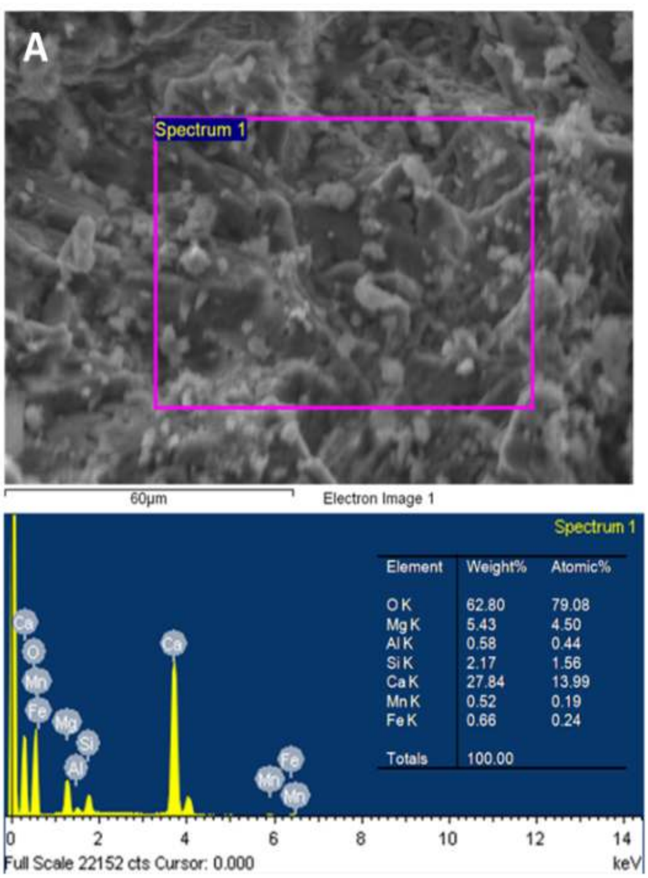
Dia molecular / (Dia of the cage – 2.8)

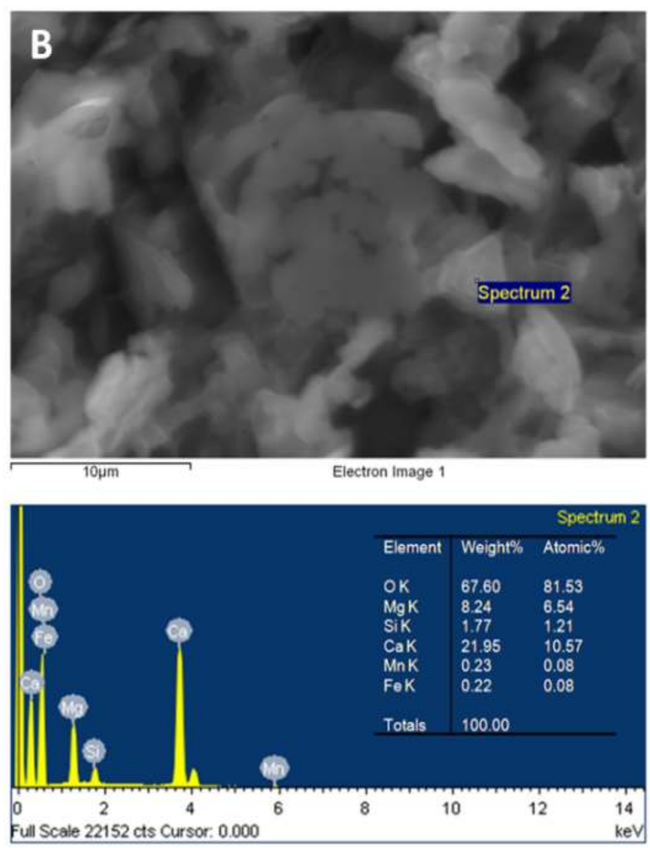
	Structure - II		Structure - VI	
	5^{12} (7.82 Å)	$5^{12}6^{4}$ (9.46 Å)	$4^{4}5^{4}$ (5.80 Å)	$4^{3}5^{9}6^{2}7^{3}$ (10.2 Å)
Hydrogen (2.72 Å)	0.542	0.408	**0.907**	0.368
Methane (4.36 Å)	0.868	0.655	**1.453**	0.589
$tBuNH_2$ (6.72 Å)	**1.339**	1.009	**2.24**	**0.908**

Optimum ratio – 0.76 to 1.00

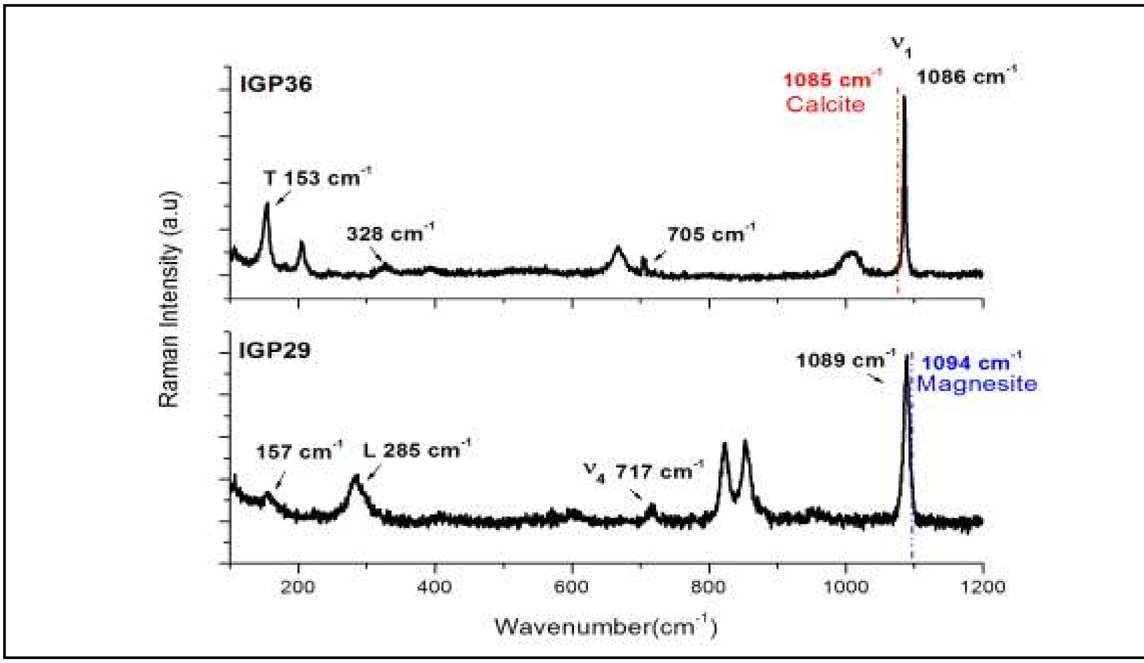
Mineral Carbonation Studies



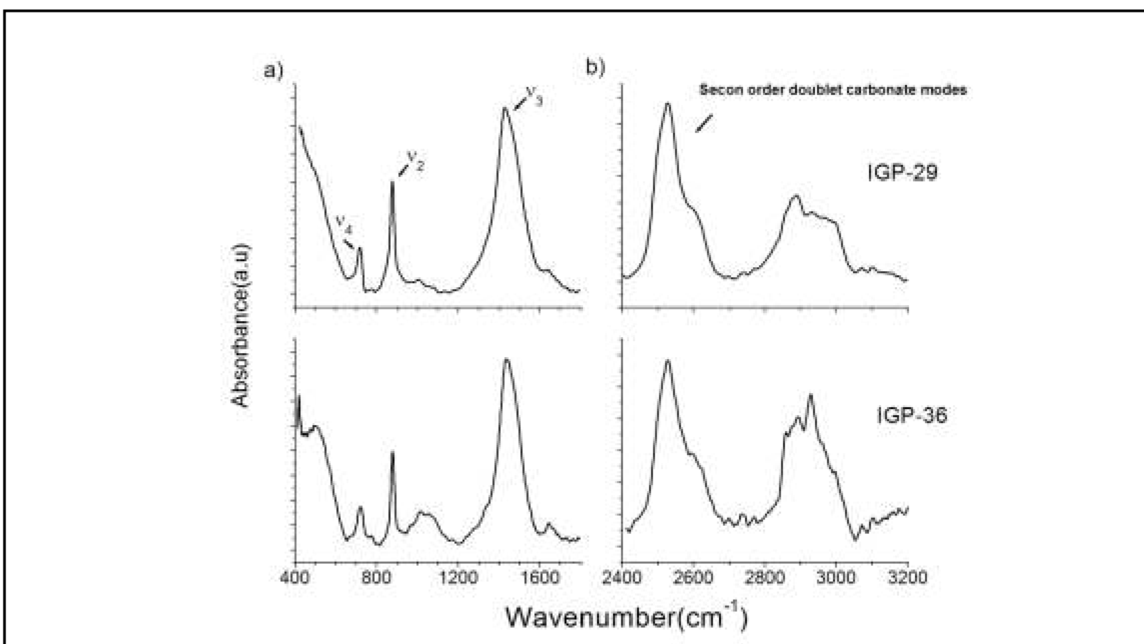




Micro-Raman Characterization



FTIR Characterization



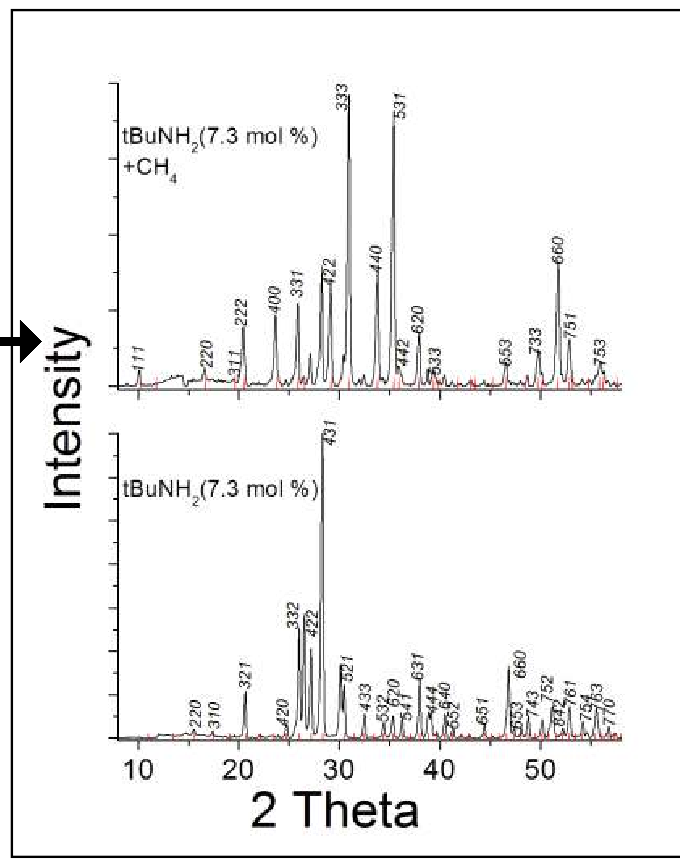
Pressurizing with CH_4

Experimental Conditions

Pressure: 7.0 MPa
Temperature: 250 K

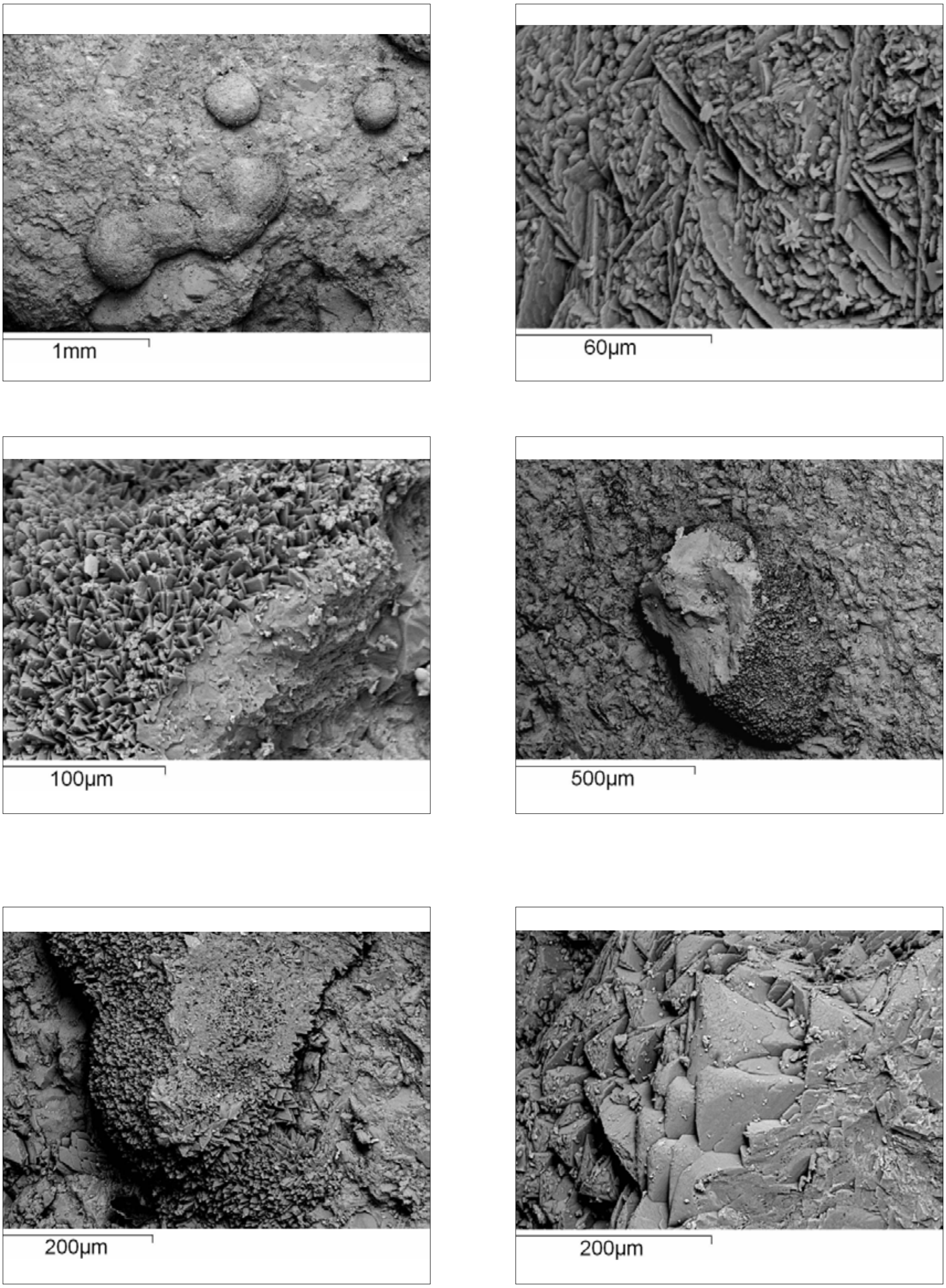
PXRD results (CH_4)

- Upon pressurizing with CH_4 (? ? $4^4 5^4$)
- sII – (*Fd3m*) a = 17.3984 ± 0.0177 Å
- Clathrate Hydrates with
  12? 16tBuNH$_2$.156.H$_2$O
  sVI – (*I-43d*) a = 18.6341 ± 0.0046 Å



XRD measurements – 0.1 MPa & 120 K

Secondary Carbonate Formation in Picritic Basalt from DVP



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ANNEXURE I

List of Speakers for the Awareness and Capacity Building in Sustainable Energy (ACBSE 2010), held on Dated: 6th August 2010 At India International Centre, New Delhi

1. **Prof. P. N. Desai**, JNU, Delhi
2. **Dr. (Mrs.) Malti Goel**, JNU, Delhi
3. **Dr. V. K. Garg**, JERC, Gurgaon
4. **Dr. P. Chaturvedi**, IAAS, Delhi
5. **Dr. C. Sharma**, NPL, Delhi
6. **Dr. T. Satyanarayana**, DU, South Campus, Delhi
7. **Dr. V. S. Verma**, CERC, Delhi
8. **Dr. D. M. Kale**, ONGC Energy Centre, Delhi
9. **Dr. A. K. Singh**, CIMFR, Dhanbad
10. **Dr. S. N. Charan**, NGRI, Hyderabad
11. **Dr. P. S. R. Prasad**, NGRI, Hyderabad

ANNEXURE II

AWARENESS AND CAPACITY BUILDING IN SUSTAINABLE ENERGY

(ACBSE – 2010)
Dated: 6th August 2010
At India International Centre (New Delhi) Conference Room - II

Sl. No.	Name	Organization
1.	Dr. P. C. Viswanathan	C/o NCAER"Pansila Bhawan"
2.	Dr. K. S. Rao	Fellow, Sustainable alternatives AP Gunter, FPRI
3.	Mr. G. B. Bagai	Retired Engineer
4.	Prof. T. Satyanarayana	Department of Microbiology, University of Delhi South Campus,
5.	Mr. Sid Misra,	Economist, Columbia University
6.	Dr. (Mrs.) Malti Goel	Programme Coordinator
7.	Dr. V. K. Garg	Joint Electricity Regulatory Commission (For Goa and Union Territories)
8.	Mr. Abhijeet Kumar	
9.	Prof. P. N. Desai	CSSP, JNU
10.	Dr. P. Chaturvedi	Indian Association for Advancement of Science
11.	Mr. Harish Kapoor	Green Peace (self employed)
12.	Ms. Gurleen Kaur	Lady Irwin College
13.	Dr. A. G. Gaikward	National Chemical Laboratory, Pune
14.	Ms. Neha G. Tripathi	School of Planning & Architecture
15.	Mr. N. Sancha Prakesher	Delhi University
16.	Dr. P. S. R. Prasad	NGRI, Hyderabad
17.	Dr. S. N. Charan	NGRI, Hyderabad
18.	Dr. G. D. Renwal (Bansal)	The Indian Institute of Metals-Delhi Chapter
19.	Dr. Meenakhi Dhote	School of Planning and Architecture
20.	Ms. Sonam Batra	School of Planning and Architecture
21.	Mr. K. B. Ranjit Kumar	School of Planning and Architecture
22.	Ms. Madhura S. Khambate	School of Planning and Architecture
23.	Ms. Rakesh Sharma	JNU
24.	Dr. A. K. Singh	CIMFR, Dhanbad

Sl. No.	Name	Organization
25.	Dr. K. K. Singh	CIMFR, Dhanbad
26.	Prof. V. S. Verma	CERC, Delhi
27.	Ms. Harveen Kaur	Lady Irwin College
28.	Dr. D. M. Kale	ONGC Research Centre
29.	Dr. Chhemendra Sharma	Radio and Atmospheric Sciences Division National Physical Laboratory
30.	Ms. Meenal Jain	Lady Irwin College,
31.	Mr. Vikas Kumar	University of Delhi
32.	Ms. Puja Jolly	Lady Irwin College
33.	Ms. Mansi Sharma	Lady Irwin College
34.	Ms. Ishita Malhotra	Lady Irwin College
35.	Ms. Raghavi Jain	Lady Irwin College
36.	Ms. Shefali Chopra	Lady Irwin College
37.	Ms. R. Pooma	Lady Irwin College
38.	Ms. Sohina Singh	Lady Irwin College
39.	Er. Sharad Gupta	Working with UN project on Millennium Development Goals
40.	Mr. R. L. Mishra	
41.	Ms. Komal Aggrawal	SPA
42.	Ms. Reshmi M. Kunan	SPA
43	Ms. Praujya Gogoi	SPA
44.	Ms. Debotri Chatterjee	SPA
45.	Ms. Shilpi Madnawal	SPA
46.	Ms. Triyanka Kinikat	SPA
47.	Ms. Nazia Talat	CSSP, JNU
48.	Dr. Sarvjit Dudeja	