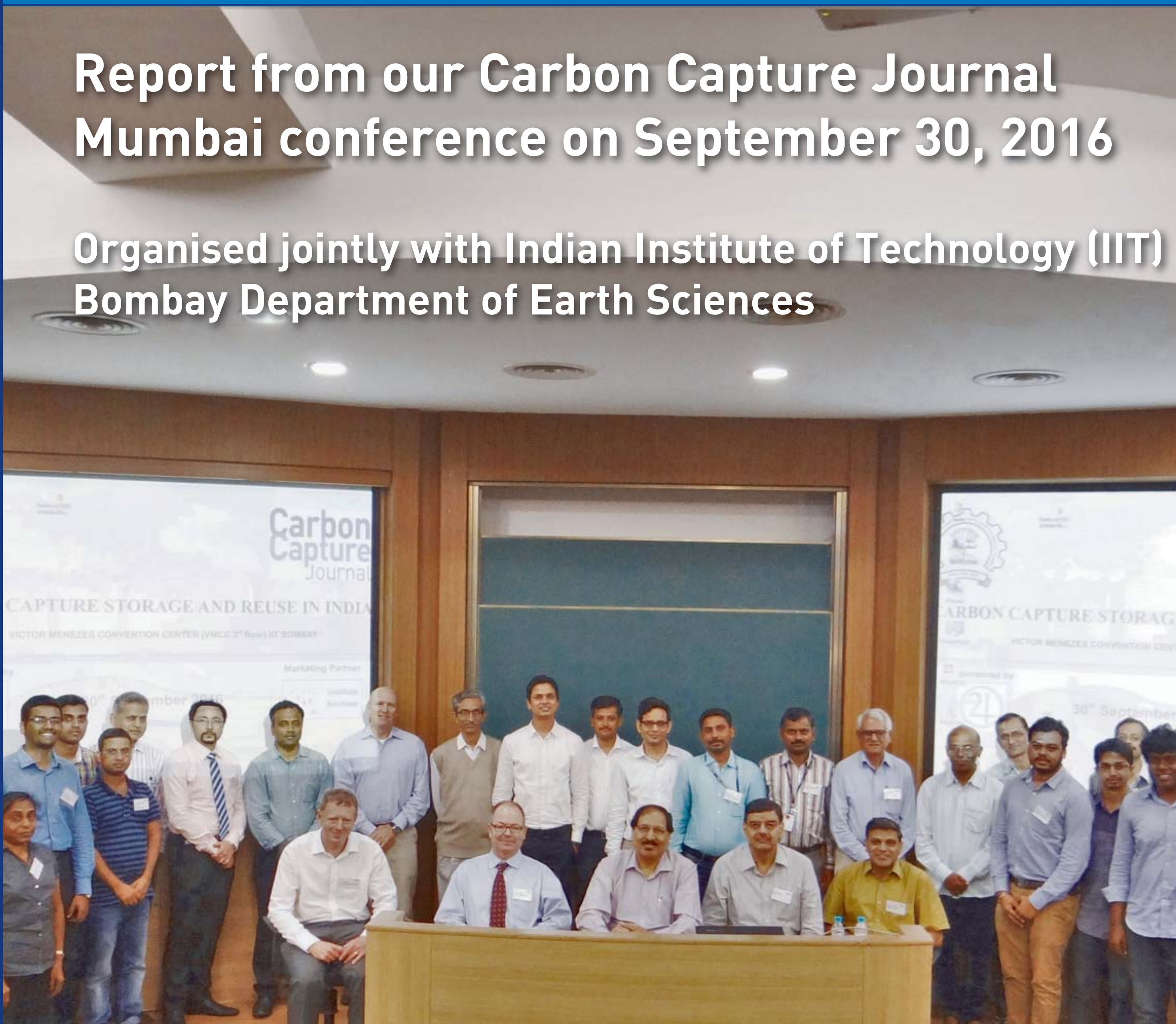
Carbon Capture Journal

Report from our Carbon Capture Journal Mumbai conference on September 30, 2016

Organised jointly with Indian Institute of Technology (IIT) Bombay Department of Earth Sciences



You can download many of the videos and presentations from the event online at conta.cc/2iD3Yh6

Carbon capture in India – potential for coal bed methane?

There could be a potential business in India with carbon capture together with enhanced coal bed methane recovery, we learned at our first Mumbai conference we organised together with Indian Institute of Technology Bombay.
By Karl Jeffery

There could be an exciting business opportunity in India doing carbon capture together with enhanced coal bed methane recovery, we learned at our first Carbon Capture India conference we organised in Mumbai on September 30, 2016.

The conference was organised jointly with Indian Institute of Technology (IIT) Bombay Department of Earth Sciences.

There is a region in the North and East of India (around Singrauli Coal Field in Madhya Pradesh and Uttar Pradesh) which many coal power plants (to generate the CO2) and many coal mines containing methane (where the CO2 could be injected). There is a great deal of coal seam which is too deep to mine (deeper than 600 metres), so there would not be any loss to future coal extraction if it was used for CO2 storage.

The deeper coalfields have not yet been extensively explored, so the amount of coal is unknown.

Delegates at the inaugural Carbon Capture Journal India conference in Mumbai

Studies have shown that there could be 2.63 trillion cubic feet of coal bed methane which could be produced in India, and that would use up to 800m tonnes of CO2. (As an illustration, annual UK gas consumption is 2.73 trillion cubic feet of gas).

Researchers at IITB are trying to understand how the mechanism works injecting CO2 into coal seams, and how much methane might actually be produced.

The coal seam contains both free methane and methane adsorbed onto the coal surface. The free methane can be released by drilling into the coal seam, and the methane adsorbed onto the coal can be released by flooding the coal seam with CO2.

The mechanics of what actually happens is not yet very well understood, but research has shown that it is possible to inject three volumes more CO2 into the reservoir than methane which is recovered. This is good if storing large volumes of CO2 is one of the main objectives. Further, the injected CO2 enhances the recovery of coalbed methane during secondary recovery.

There may also be a business opportunity with CO2 + Enhanced Oil Recovery – although we learned that ONGC explored a CO2 EOR project in 2003, in Gujarat, Western India, and did not decide it was feasible. One reason is that fields are thought to need to be depleted by a certain amount for CO2 EOR to be viable, and not many fields are this depleted.

Standalone carbon capture and storage seems unlikely to work in India. The government's position could be generally summarised as "we won't finance carbon capture, but we won't obstruct it either," and unless there is a real cost to CO2 emission, standalone carbon capture and storage needs government funding.

Very possibly, there could be funding arranged through the UN from developed countries to developing countries such as India, to cover the cost of climate change mitigation, as agreed through the climate discussions, which could pay for carbon capture. Most people in India take a 'believe it when I see it' approach to this.

India is the third largest producer of coal in world, after China and the US, with 677m tons of coal produced in 2015. It also imports coal.

The conference was jointly organised by Vikram Vishal, Assistant Professor at the Department of Earth Sciences, at Indian Institute of Technology who has a PhD on carbon storage and enhanced coal bed methane recovery, to try to understand the mechanics of what happens in the subsurface.

Professor Garg - living with coal

One of the key arguments about why India should have carbon capture and storage is that the country is so dependent on coal, and the dependence is likely to increase as electricity demand increases, said Professor Amit Garg, from the Indian Institute of Management in Ahmedabad, India, in his opening address.

Professor Garg was a member of the UN body Intergovernmental Panel on Climate Change that was awarded the Nobel Peace Prize in 2007.

By using carbon capture and storage, India can continue with its domestic coal as the mainstay of India's energy system, he said.

Coal employs about two million people in India, and adding their families, means that 7 to 8 million people are dependent on the coal industry.

Meanwhile Indian CO2 emissions are growing at 5 to 6 per cent a year, and power generation is the biggest source of those, also industrial.

Some people in India think that it can wait for other countries to do carbon capture first. "But if emissions are going down around the world, the pressure will be on India," he said.

India should not close options down. "Everything is on the table, there is no silver bullet," he said.

“We say to the government, 'please don't shy away from saying India is dependent on coal. Coal has to continue.'"

Carbon capture will strengthen India as a nation, and give the country the ability to counter arguments that it is not doing anything about emissions.

“We can’t say, 'very primitive country, we are not ready'”, he said.

“We are leaders in many places in the world. We should take our place.

We should not shy away.”

"Everything is on the table, there is no silver bullet" - Professor Amit Garg, from the Indian Institute of Management in Ahmedabad, India

Also India has some advantages over other countries, including being able to innovate at low cost.

And if India doesn’t invest in carbon capture, with its enormous coal power production, perhaps no-one else will, he said.

As far as a regulatory regime to force or encourage carbon capture, in India "we have not even thought about these things. We are very primitive. But "I think the perspective is changing."

In terms of the current attitude of the Indian government and industry, Professor Garg said, “Different ministries are responding in different forms. I was in a [carbon capture] forum where Oil India, NTPC was there.

The government’s attitude to enhanced oil recovery and ECBM does not include “anything negative,” he said. So if the business case works, companies should ‘please go ahead’. “I don't think there's anything stopping you,” he said.

Oil and gas production in India is declining, so there might be interest in using CO2 to try to get it on the increase again.

And if industry gets more engaged in carbon capture, the scenario could change very quickly.

“When we proposed that one of these big corporations should go for big demonstration projects, they were sort of neutral to this. “But the corporates are not saying ‘don't do it’”.

But whether or not there is a high carbon price, the cost of emitting CO2 will continue. And India “may start a carbon market very soon,” he said. The Indian market could also connect with some of the other carbon markets around the world, creating an enormous business opportunity, if it can store CO2 cheaper than anywhere else in the world.

But not enough is known about the CO2 storage potential in India so far, Professor Garg said.

Professor Garg’s team has been working on a major project to connect sources and sinks across the whole of the country.

One audience member noted that there is 3.14km2 of land in India, of which 1km2 has not been explored at all, and there is no knowledge about whether there might be oil and gas. As the government opens up its policy to oil and gas licensing, it may help encourage more exploration.

More information

Video presentations from the conference are online at:

conta.cc/2iD3Yh6

Dr Ajay K Singh – how to store carbon

Coal bed methane specialist Dr Ajay Kumar Singh explained the different ways CO2 can be stored in India – including in oil fields, unmineable coal seams, saline aquifers and basalt formations – and also how the enhanced coal bed methane recovery works.

Dr Ajay Kumar Singh, a specialist in coal bed methane, explained the various options for storing CO2 in India, including in oil fields, unmineable coal seams, saline aquifers and basalt.

Dr Singh is a specialist in coal bed methane. He is a senior scientist with The Central Institute of Mine and Fuel Research (CIMFR), which is part of the Council of Scientific & Industrial Research (CSIR), based in Dhanbad, a city in Jharkhand State in eastern India.

CSIR is an autonomous body under the Government of India Ministry of Science and Technology.

Dhanbad is known as the coal mining capital of India, according to its Wikipedia page.

Dr Singh was also one of the lead authors of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC was awarded Nobel Peace Prize in 2007.

Dr Ajay Kumar Singh, senior scientist with The Central Institute of Mine and Fuel Research

Oil reservoirs

For oil reservoirs, sometimes the CO2 mixes with the oil, sometimes it doesn't, depending on the gas injection pressure, he said.

If it mixes, it is known as miscible CO2-EOR (enhanced oil recovery). The CO2 mixes with crude oil, causing oil to swell, reducing the viscosity of oil, while also maintaining reservoir pressure. Alternatively, CO2 may not mix with crude oil, resulting in immiscible CO2-EOR.

Looking at oilfields in India, the key ones are Assam in North East India; Cauvery Basin in South East India; and Rajasthan and offshore Mumbai in North West India.

There is a need for enhanced oil recovery in India, because currently recovery rates from reservoirs are only about 27 per cent, he said.

And Indian oil production has declined from 38.2 million metric tons in 2011 to 37.5m metric tons in 2014.

Gas production is also declining much faster, with 53 BCM produced in 2010 and 34 BCM in 2014.

There are no examples of CO2 being used for EOR or EGR (enhanced gas recovery) in India. There have been projects with thermal recovery of oil, where oil is combusted in the subsurface, heating the oil around it and reducing the viscosity, so it flows more easily. "This is a similar phenomenon," he said. It is being done in the Balol heavy-oil field in the North Cambay Basin, North West India.

Indian state owned oil company ONGC did propose a CO2-EOR project in the city of Ankleshwar, in the state of Gujarat, North West India, with CO2 to be injected from a gas processing complex in Hazira, Gujarat, planning 600,000 m3/d.

The project has the potential to sequester 5-10m tonnes of CO2 in one location, and lead to an increase in oil recovery of around 5 per cent, he said.

Cairn Energy also has plans for a C02-EOR project, supplying CO2 to one of the company's oilfields in Rajasthan, he said.

Coal fields

Another option is storing the CO2 in coal fields – where the CO2 can be used to enhance recovery of coalbed methane, providing a revenue stream. This is known as CO2-Enhanced Coal Bed Methane recovery of CO2-ECBM.

Possible sites for doing this include the Eastern part of Raniganj, Jharia and North Karanpura Coalfields in eastern India, and the Western part of Ib Valley Coalfield and Talcher Coalfield, in Odisha state, North East India. Cambay Basin and Barmer-Sanchor Basin in western India can also be prospective sites for CO2 sequestration.

Indian coal reserves are estimated at 307 billion tons, up to a depth of 1200m, and there are huge reserves of coal deeper than this, perhaps a further 200bn tons, he said. It is not practical to mine deep coal, but it might be possible to produce the gas from the coal seams.

The deepest coal mine in India is currently 630m, in West Bengal, he said. It is very difficult to mine deeper than this, because it gets very hard to manage the rock stresses and ensure mine safety.

Technology may advance but it seems probable that mining beyond 1000m will always be "next to impossible," he said.

Most of the coal reserves are concentrated in the Eastern of India, although there is some in the North West.

Coal has a very large surface area within its structure – scientists have calculated that every gram of coal has 200m2 of surface. Either methane or CO_2 can attach to this surface.

Dr Singh has been involved in research to try to better understand what happens when CO_2 is injected into a coal seam through a vertical well.

First of all, there is usually water production from the coal seam. After the water has flowed to the well, the pressure in the coal seam is lower, and then gas gets released from the coal and it flows to the well. "This is the primary method of coal bed methane recovery process," he said. About 40 to 50 per cent of methane can be recovered via primary recovery (not using CO_2). Then CO_2 can be injected, to enable more gas to be produced. If the coal seam is flooded with CO_2, the CO_2 will fill the pores on the coal.

Saline aquifers and basalt formations

Another possibility is storing CO_2 in saline aquifers. The CO_2 is stored in water permeable rocks which are saturated by salt water, called brine.

Government funded studies have looked at the Ganga basin (North East India) where there are aquifers 300m below ground level, Vindhyan basin (central North India) and Rajasthan basin (North West India), he said.

A further option is basalt storage. There is an area in West Central India called the Deccan Plateau, covering 500,000 km2. The basalt varies in thickness from a few hundred metres to 1.5km. The basalt provides a solid caprock (above the CO_2 storage).

The basalt can slowly react with the CO_2 to convert into mineral carbonates, so the CO_2 is locked away forever.

Government attitude

Dr Ajay K Singh noted that "the government of India is always open to research and commercial scale projects on CCS.

India has been involved in the Carbon Sequestration Leadership Forum, and the government is supporting about 30 research projects.

But there is a big need for more detailed knowledge about Indian geology and suitable CO_2 storage sites, he said.

Jupiter Oxygen oxy-combustion capture + enhanced coal bed methane recovery

The cost of carbon capture can be reduced if the fuel is burned in oxygen with a high flame temperature rather than air firing, according to the Jupiter Oxygen Corporation.

Jupiter Oxygen Corporation (JOC, Chicago, IL, USA) believes that the cost of carbon capture can be substantially reduced if coal is burned in oxygen with a high flame temperature rather than air firing.

In India, the costs of carbon capture can be recouped by using the CO_2 for enhanced coal bed methane (ECBM) recovery from un-minable coal seams, the company believes.

India has a mature industrial structure for coal bed methane recovery, and a high potential to apply ECBM technology and significantly increase coal bed methane recovery.

India therefore provides an attractive business opportunity for the development of carbon capture, utilization, and storage technology.

This process enabling cost effective carbon capture is known as "high flame temperature oxy-combustion", resulting in high concentration CO_2 in the flue gas and a fuel savings.

Thomas Weber, president of JOC presented this carbon capture, CO_2 utilization and storage (CCUS) strategy at the Carbon Capture Journal Mumbai conference.

JOC has been applying oxy-combustion in the US since 1997 at an aluminium re-melting and coil-producing facility.

As a result of introducing high flame temperature oxy-combustion, the aluminium manufacturer reduced net energy consumption significantly, based on JOC's patented process.

Since 2001, Jupiter Oxygen has been developing high flame temperature oxy-combustion applications for coal and natural gas fired boilers. The technology is now ready for commercial-scale demonstration in coal-fired power plants, as well as natural gas fired units.

JOC intends to showcase the economic advantages of high flame temperature oxy-combustion for coal power plants with carbon capture at commercial-scale demonstrations in both China and India in the near term.

Between 2006 and 2012, the Jupiter Oxygen Corporation operated a test facility for high flame-temperature oxy-combustion as part of an extensive joint research and development program established with the US Department of Energy's National Energy Technology Laboratory (NETL).

JOC and NETL developed an application of the JOC's high flame temperature oxy-combustion technology at this test facility that was integrated with air pollutant removal and carbon capture.

"The test facility has produced a lot of good data coming out of this unique oxy-combustion process in combination with integrated air pollutant control, carbon capture and water recovery," he said.

JOC is now in the process of setting up a demonstration project in India that will include use of the produced CO2 for enhanced coalbed methane recovery.

For non-chemist readers, air is made up of about 20 per cent oxygen and 80 per cent nitrogen.

When coal (mainly carbon) is burned in air, the flue gas that results is mainly composed of nitrogen oxides (NOx). Separating out the carbon dioxide from the nitrogen post-combustion is an energy-intensive and expensive process.

By contrast, if the coal is burned with high flame temperature oxy-combustion, then the flue gas is mainly carbon dioxide and water vapour. Separation of the carbon dioxide is more cost-effective.

The oxygen needed for combustion is provided through a cryogenic air separation unit, which separates the incoming ambient air into oxygen, nitrogen and argon. This is a well-established process in the industry.

A principal advantage of using high flame-temperature oxy-combustion is that coal burns more efficiently. Fuel efficiency gains in the boiler close to 5% or greater have been demonstrated using JOC's unique approach.

Another advantage of oxy-combustion technology is that it results in ultra-low concentration of NOx in the flue gas, largely because the nitrogen has been removed from incoming air before sending pure oxygen to the burner.

Overall the upfront air separation process combined with carbon capture at the back end of system creates a net energy penalty of about 20 per cent.

In the JOC patented technologies, carbon dioxide is effectively separated from the much-reduced flue gas volume through steps of compression and condensation.

The final products are highly concentrated, pipeline quality CO2 and process water collected for treatment and re-use. Key local air pollutants (NOx, SOx, particulate matter, and mercury) are substantially reduced.

To convert an existing coal power plant to high flame temperature oxy-combustion with carbon capture using the JOC technology requires only moderate changes to the coal-fired boiler. Thus, it can be put to work more quickly than a new-build carbon capture plant, Mr Weber said.

Nitrogen and enhanced coal bed methane recovery

The nitrogen from the air separation unit provides an additional synergy in applications of the JOC technology. Nitrogen can be injected together with the CO2 into coal bed methane seams, enhancing CBM production, according to Mr Weber.

How much production is increased depends on the coal rank of the affected seams and the specific ratio of CO2 to N2 that is injected. Whether applied to low-, medium-, or high-rank coal seams, the additional injection volumes made up from adding nitrogen improves the level of coal bed methane recovery and the resulting economic feasibility of the application.

According to the experts from Advanced Resources International (ARI), a further advantage of injecting nitrogen with CO2 is the resulting reduction in swelling of the coal seam, which otherwise would lower permeability in the seam and reduce methane production.

Making CO2 utilization via ECBM work

To get a CO2 capture – ECBM project running requires an alliance of carbon capture technology providers, coal bed methane experts and local energy companies, according to Weber. Mr The oil and gas industry also needs to be involved in providing infrastructure that can take the methane to market.

Mr Weber suggested that CCS trust funds (including those held by the World Bank and the Asian Development Bank) could be useful in financing a feasibility study that would explore the technical and economic viability of a project in India, ultimately demonstrating whether the increased methane production would give the investors an adequate financial return.

"If investors see this as an attractive project, they will engage in a second step which would be a more detailed engineering study," he said.

JOC has already started a similar project in Western China. In China, the main driver pursuing this CCUS – ECBM project is to increase profitability of CBM operations from extracting more coal bed methane.

Welcome co-benefits of such a project are carbon capture, air pollutant control and water recovery from coal fired power plants, as well as permanent and safe storage of large amounts of CO2 underground via ECBM.

"Right now we're doing a feasibility study. Hopefully, in a couple of months we'll have interesting results to share. It is quite an interesting parallel to what we'd like to do in India," he said.

In India, Jupiter is preparing a consortium of US based and Indian companies, to establish a carbon capture, utilization and storage demonstration project, in the near future. The commercial scale demonstration will include retrofit of a local coal-fired boiler with JOC oxy-combustion technology, and CO2 utilization with enhanced coal bed methane recovery.

Mr Weber is confident that the costs of the carbon capture plant will be "more than offset" by revenues from CO2 / N2 sales for enhanced coal bed methane recovery. But a carbon tax or other incentives for unconventional domestic gas production would also help.

Jupiter Oxygen Corporation is a leading innovator in oxy-combustion technology applications, providing consultancy and know-how, based on patents in many countries of the world, and can be a critical part of strategic alliances for the financing and management of successful carbon capture and utilization projects, he said.

More information

Video presentations from the conference are online at:

conta.cc/2iD3Yh6

Status of carbon capture in India

India has had many carbon capture in the past – although perhaps the peak of its enthusiasm was in 2011, as Amit Verma explained

India has been involved in many carbon capture projects over the past 10 years, with interest perhaps peaking in 2011.

Amit Verma, assistant professor at the Indian School of Mines, Dhanbad, presented some of the findings of a study he had done as part of previous employment with TERI (The Indian Energy and Resources Institute).

The Department of Science and Technology (DST) of the Indian Ministry of Science and Technology would be responsible for research and development in CCS in India. It has floated a lot of research projects, he said.

It set up a "National Program on Carbon Sequestration Research" in 2007.

There was an "Agreement of Co-operation in Science and Technology" agreed with the government of India and the government of Norway, whereby DST and the Research Council of Norway started a program for joint funding of Indian-Norwegian joint research projects in climate research, including CCS.

ONGC has talked about plans (2003) to set up a pilot experimental EOR project in Gujarat, with CO2 from a gas processing plant in Hazira to be supplied to a depleted onshore reservoir in Ankleshwar, where it would be recompressed and injected for enhanced recovery of crude oil. "Somehow it has become not feasible," he said.

The National Aluminium Company (NALCO) announced (March 2011) plans to set up a carbon capture unit at its coal fired plant at Angul, Orissa state for bio sequestration.

NTPC, as part of the Carbon Sequestration Leadership Forum (CSLF), has partnered with the National Geophysical Research Laboratory, India (NGRI)

And the Battelle Pacific North West National Laboratory, USA, to evaluate the Deccan basalt formation in India as a potential long term CO2 storage option.

NTPC also organized a national workshop on CCS in collaboration with the Ministry of Power in September 2011.

Bharat Heavy Electrical Ltd. (BHEL) and APGENCO, the power generating company of Andhra Pradesh, are talking (April 2013) about setting up a 125 MW demonstration IGCC plant in Andhra Pradesh, India's first IGCC plant. BHEL is also coordinating with Indira Gandhi Centre for Atomic Research (IGCAR) and NTPC to design, develop and build ultra-super critical boilers.

BHEL has also collaborated with TREC STEP (Tiruchi Regional Engineering College Science and Technology Entrepreneurs Park) to implement a set of initiatives in CCT and CCS, as part of a three year EU funded project.

TREC STEP, in collaboration with Ernst and Young, organized an EU funded 2 day training programme on 'Introduction to CCS and CCT' in December 2011, and a 3 day 'Skill Leverage Programme on CCT - CCS Technologies' in January 2012.

Indian Institute of Petroleum (IIP) has been working on developing new adsorbents for post combustion CO2 capture.

IIT Bombay is one of the players developing technologies for storage of CO2.

The Global Carbon Capture and Storage Institute has rated countries for their carbon capture interest and policy developments so far. It ranks India in the "lower mid-tier" for policy interest, but in the "upper tier" for inherent CCS interest, along with the USA, Canada, Germany, China, Indonesia and Russia.

GCCSI has also classified countries for their legal frameworks for carbon capture, where Band A is where the country has a full legal framework for CCS (either with special CCS laws or its existing laws cover CCS) – with just 5 countries – Australia, Canada, UK, US and Denmark, and band C with very few specific laws.

There are complicated laws related to regulatory approval and storage challenges, which is stopping private players coming into play, he said.

India's largest power company, NPTC (previously known as National Thermal Power Corporation Limited) does not have a particularly positive view on carbon capture implementation in India, he said.

"A degree of confidence will be gained in the technology only after the conversion of demonstration phase to commercial scale projects worldwide," he predicted.

More information about geological storage sites would be very helpful, he said.

The Indian Ministry of Science and Technology has expressed concerns that carbon capture would increase the cost of electricity in India, he said.

Concerns continue about CO2 leakage. "The ministry will shoot a question, if CO2 comes out in 100 years, what will you do. Nobody has an answer," he says.

There are complex legal issues including around acquiring land and possible CO2 leakage, which would need to be addressed before any large scale transport and storage of CO2 could be permitted, he said.

The Ministry is very positive about enhanced oil recovery, which could offset the costs.

But the business opportunities for EOR might not be so great. "Some people in ONGC found that very few reservoirs are suitable for EOR," he said.

Not many oil people are actually looking for enhanced oil recovery. "It has been stated by stakeholders in the petroleum sector that there are few oil fields which are sufficiently depleted for EOR to be required at present," he said.

If the CO2 is used for enhanced coal bed methane recovery, it makes the coal impossible to mine (because it is full of sequestered CO2). There is always a risk that future technology developments might mean that people want to mine the coal, he said.

"There is widespread belief that the IGCC and CCS technologies have not been extensively tested and customized for Indian conditions. Since

India has not been involved with any of the current projects, the understanding of the technology and its adaptation in India is low," he said.

Adding this all together, you could say that the government is at best dis-interested, and at worst, actually opposed to carbon capture, for all these reasons, and also a belief that the current accumulation of greenhouse gases is not India's responsibility, he said.

India is involved in the Carbon Sequestration Leadership Forum, a meeting of senior government officials with a role which might include carbon capture. But this does not lead to involvement of state governments and industry, he said.

Altogether, "CCS is not expected to be applied in India before 2030 in current global and regional modelling studies."

However India does have a range of legislation which could be adapted for carbon capture, including Indian Petroleum Act of 1934, which covers transportation of petroleum products (which could be used for transporting CO_2); the Oilfields Regulation and Development Act of 1948, which could cover EOR; the Petroleum Mineral Pipelines Act of 1962, covering acquisition of land for pipelines; the Oil Industry Development Act of 1974, which covers taxes on oil and gas production, which could be used to make a tax on crude oil and natural gas produced in EOR.

There will probably need to be a Liability Bill, perhaps based on the Nuclear Liability Bill, to show how the responsibility for any spill would be managed.

There may be regulation on power generating companies, telling them they have to reduce the CO_2 in their emissions, as well as carbon prices, he said.

There will probably need to be rules about cross border movement of CO_2.

Combining CCS and flue gas desulphurisation

CO_2 and SO_2 can both be removed from flue gases using the same materials - amines, ammonia and sodium hydroxide. Flue gas desulphurisation is going to be introduced in India soon. So would it make sense to introduce carbon capture at the same time?

The technologies to remove CO_2 from flue gas have some commonalities with technologies to remove SO_2. As flue gas desulphurisation (FGD) is going to be introduced in India, may be it would make sense to introduce both systems at once, said Professor Amitava Bandyopadhyay of Department of Chemical Engineering at the University of Calcutta.

India has newly promulgated emission standards for SO_2, NO_x and mercury in addition to existing standard for particulate matter (PM) for thermal power plants to clean up the flue gas, but not for CO_2, said Professor Bandyopadhyay.

Flue gas desulphurisation technology has been around for some time, with the first research in 1850, and the first full scale plant deployed at Battersea Park Power Station, London, in the 1930s, using water from the River Thames. The sulphur dioxide was removed with a lime based process.

The sulphur dioxide can also be removed with ammonia, reacting it to make aqueous ammonium sulphate. Ammonia as a solvent can also be used for CO_2 capture.

There is a demonstration project for a multi-pollutant capture system, operated by National Energy Technology Laboratory of Department of Energy in the US, where the flue gas is treated with ammonia to generate ammonium nitrate and ammonium sulphate along with compressed CO_2.

Another multipollutant capture process is the one that is able to remove CO_2, SO_2, NO_x, mercury and other heavy metals, and acid gases (such as HCl, HF, H_2S) from the flue gas.

The process eliminates the limitations of lime/limestone and sodium based processes and is being commercialized in China by Airborne China Ltd. Such process could be the fourth generation FGD. There is a considerable potential for deployment of similar process under Indian perspective he added.

Amines, which are used in carbon capture plants, have also been used for removing H_2S from gas streams, he said.

Amine based systems can be dangerous considering possible emissions of amines into the ambient air leading to the formation of nitrosamines which are expected to be carcinogenic and have a safety limit of 0.1 parts per trillion (e.g., in Norway). Thus, ammonia may be relatively better than amines.

Cansolv Technologies Inc., a Canadian company, has a patented technology for removing both SO_2 and CO_2 from the flue gas, he said.

Another option for removing CO_2 is mineral carbonation, basically absorbing CO_2 into rock. Further, you can use sodium hydroxide, reacting with CO_2 to form sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$). Sodium hydroxide can also react with SO_2 (to make sodium sulphate: Na_2SO_4) and NO_2 (to make sodium nitrate: $NaNO_3$.

Is CCS relevant for India?

In order to cover all sides of the argument, Anand B. Rao, associate professor, with the Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology - Bombay (IITB), gave a talk on why carbon capture should not be a high priority for India.

As a developing country, perhaps India might be better off spending its limited resources on adapting to a high CO2 environment, rather than trying to stop the CO2 emissions, Mr Rao said.

India could argue that the responsibility for solving the CO2 problem should go to the countries that are responsible for putting most of the CO2 into the atmosphere, he said.

India is the third biggest CO2 emitter today after the US and China, but the US and Chinese emissions are much greater, he said.

"It is a tendency to address India and China together as though we are siblings and have the same realities, but we are in 2 different worlds. There is no comparison in terms of where India is, and where it is going in terms of energy production and consumption, compared to where China is," he said.

If the responsibility for managing emissions was linked to the country's level of development, and its emissions per person, then again India has an argument that it does not need to act, he said.

India is not short of other priorities. Much of India, particularly in rural areas, does not have basic minimal comforts, such as electricity.

Government data can be misleading. For example the government claims that 98 per cent of villages are now electrified, but counts a village as 'electrified' if only 10 per cent of households have a supply. The data also does not include distant hamlets. Mr Rao estimates that there are 50-60 million households in India with no electric connection.

If they were to use 1 unit (kWh) per day, that would need about 2.5 gigawatts of power generation, or about 4 or 5 typical coal power plants.

"Dealing with this is one of our biggest challenges," he said.

"I'm hopeful we don't have to use this [carbon capture] technology at all" - Anand B. Rao, associate professor with the Centre for Technology Alternatives for Rural Areas at the Indian Institute of Technology Bombay

Sometimes households have an electricity supply available, but it is unreliable, or the voltage is too low, or it is unaffordable, he said.

CCS will not contribute to improving any of these challenges, and could make it worse, if it pushes up the price of electricity.

There is still a lot of scepticism about big industrial projects in India, he said. "Bhopal is still fresh in the minds of people." The legal and regulatory issues regarding CCS need to be resolved.

Another question is the reliability of the technology – if a CCS plant has much higher downtime than a standard coal power plant, that will change the equation of electricity supply to the grid, he said.

There are questions of whether the public will accept it as an eco-friendly technology.

Perhaps it would be better for India to wait for the developed world to fully test and demonstrate the technology first, he said.

Meanwhile India can go a long way with improving efficiency or using renewables to reduce its emissions.

"I'm hopeful we don't have to use this [carbon capture] technology at all," he said. "I don't think CCS will come to India any time in the near future - or the next 2-3 decades at least.

I'm not denying that we should not have research on CCS, keeping it open as a future policy option. We should understand the potential of the technology. That does not mean we have to deploy it. We can keep CCS as an insurance policy."

However if the 'Green Climate Fund', where developed countries provide financing for developing countries to spend on climate change, should ever materialise, "CCS may get implemented," he said.

In the question session, one audience member commented that the talk had been mainly on conventional carbon capture and storage, but if there are other revenue models (such as with EOR) the discussion is different.

Mr Rao was asked what would happen if a big business opportunity was developed with CO2 utilisation, and India would miss out, by not having a CO2 supply.

"I understand this possibility, but this is a big 'IF,'" he replied. "There have been discussion about utilisation of CO2 – but it is maybe half a percent or 1 percent [of total CO2 volumes]. So to have all the CO2 we produce for power generation can be utilised, is going to take a lot of time."

Munish K. Chandel, assistant professor, Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay

Munish Chandel – analysing the options

Munish K. Chandel, assistant professor, Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay, talked about the work he has been doing to evaluate the different carbon capture options.

Dr Chandel's team used 'Integrated Environmental Control Model' developed by Carnegie Mellon University (CMU), a software tool which can simulate different coal power plants with carbon capture with different designs and cost factors, to see what the energy penalty would be.

It looks at a range of technologies, including membranes and oxy combustion, and amine / ammonia solvents.

The standard chemical absorption solvent processes have been used in the oil and gas industry for many years.

The capture cost is estimated at around $42 per ton for amine solvents and $75 per ton for ammonia, he said, and higher for membranes.

It probably makes more sense to retrofit carbon capture technology on a larger, newer, more efficient plant, he said. Since much of the cost of carbon capture is in the energy requirement, the more efficiently the energy can be generated the lower the cost of the carbon capture.

There are questions about whether it might be better to scrap all the old coal power plants and build new ones, perhaps with an IGCC design, or a new "ultra-supercritical" plant, which would generate less CO2 for each unit of electricity generated. But these are very expensive to build.

"One big issue which probably will come up with retrofitting is physical space availability," he said

Carbon Clean Solutions – reducing CCS costs by 50 per cent

UK-headquartered Carbon Clean Solutions Limited (CCSL) is finding ways to reduce the cost of carbon capture by 50 per cent with advances in solvents and process.

Carbon Clean Solutions (CCSL), a company headquartered in the UK, but with offices in India and the USA (Cumming, Georgia), has developed a solvent for carbon capture which promises to reduce the operating cost of carbon capture by 50 per cent and capital cost by 30 per cent.

The company was presented by Ramesh Kumar, team lead with CCSL.

The company was founded in 2009, with UK private equity funding. It has 20 employees and has demonstrated the technology at more than 10 sites around the world.

The solvent is the critical component of carbon capture technology. It is brought into contact with a flue gas containing CO2, it selectively absorbs only the CO2, taking the CO2 out of the flue gas stream. The solvent then exchanges heat with the solvent coming from regenerator and is further heated in the stripper, which causes the CO2 to strip off from the solvent. Then the solvent gives its heat to the solvent from absorber and is further cooled down before being fed to the absorber and goes through the cycle again.

The biggest problem with the earlier generation solvents is the very high levels of energy required to regenerate the solvent. If that energy can be reduced, there is a big cost saving. Instead of carbon capture needing perhaps a third of the total energy produced by the coal power plant, it can run on just 15 per cent of it, Mr Kumar said.

The solvent the company has developed solvent chemistry that aims to combine the strengths of amine liquids and salts. New molecule is quick to absorb CO2 due to high reaction kinetic properties of amines and requires less energy due to salt like properties

The research work, which involved testing 30 different solvents and 100 components, was done at the company's own laboratory in India, and Imperial College in London.

Solvents normally degrade over time with continuous heating and cooling, as well as reacting with oxygen. CCS solvent was found to have almost zero degradation rates and has a longer life expectancy than conventional solvents, lasting for 5-6 years, rather than a year for traditional solvents. This means lower solvent disposal costs.

A further advantage of CCSL's solvent is that it is much less hazardous than normal amine solvents. This means it is safe to use in much higher concentrations. Because of this, the same amount of CO2 can be captured in a smaller volume of solvent – and so the size of the plant can be smaller, reducing the capital costs and the amount of pumping which is required.

Compared to standard amine (MEA), the CCSL solvent also resulted in 15 times less corrosion to the piping, said Mr Kumar.

Typical loading capability, in mol CO2 per litre of solvent, is 1.2 for a typical solvent like MEA, and 2.5 for the CCSL solvent, Mr Kumar said.

Pilot testing

The solvent was pilot tested at a facility operated by research organisation TNO in the Netherlands, capturing 6 tons of CO2 a day, to get a better understanding of energy requirements and degradation rates. The pilot plant used flue gas from a real coal power plant, including the usual contaminants. It has also been tested in a 10 ton/ day scrubbing plant in the US.

In late 2015, it was tested at Technology Centre Mongstad, Norway, at a bigger scale, of 240 tons of CO2 a day. The test studied rates of degradation, corrosion, emissions and product CO2 concentration. Norway has much tougher emissions requirements, which CCSL's technology met and faired outstanding versus other competitors.

Ramesh Kumar, team lead with CCSL

The company proposed a modified process configuration with patented heat integration in order to best utilize the benefits of its solvent chemistry.

Commercial plant

The company has built a greenfield commercial plant in India, commissioned in October 2016 (the month after the conference), using CO2 from a coal fired boiler plant, and supplying it to a soda ash manufacturing facility.

The customer will be able to capture CO2 with 30 per cent less CAPEX, 50 per cent less energy and operating costs, and nearly zero solvent emissions, Mr Kumar said. It will capture 60,000 tonnes of CO2 a year.

The technology has also been used on biogas production (gas which is formed from the breakdown of organic waste). Biogas is typically 60 per cent methane and 40 per cent C02 and by removing more than 95% CO2 from the biogas, a more valuable/usable biomethane (>98% Methane) is produced.

More information

www.carboncleansolutions.com