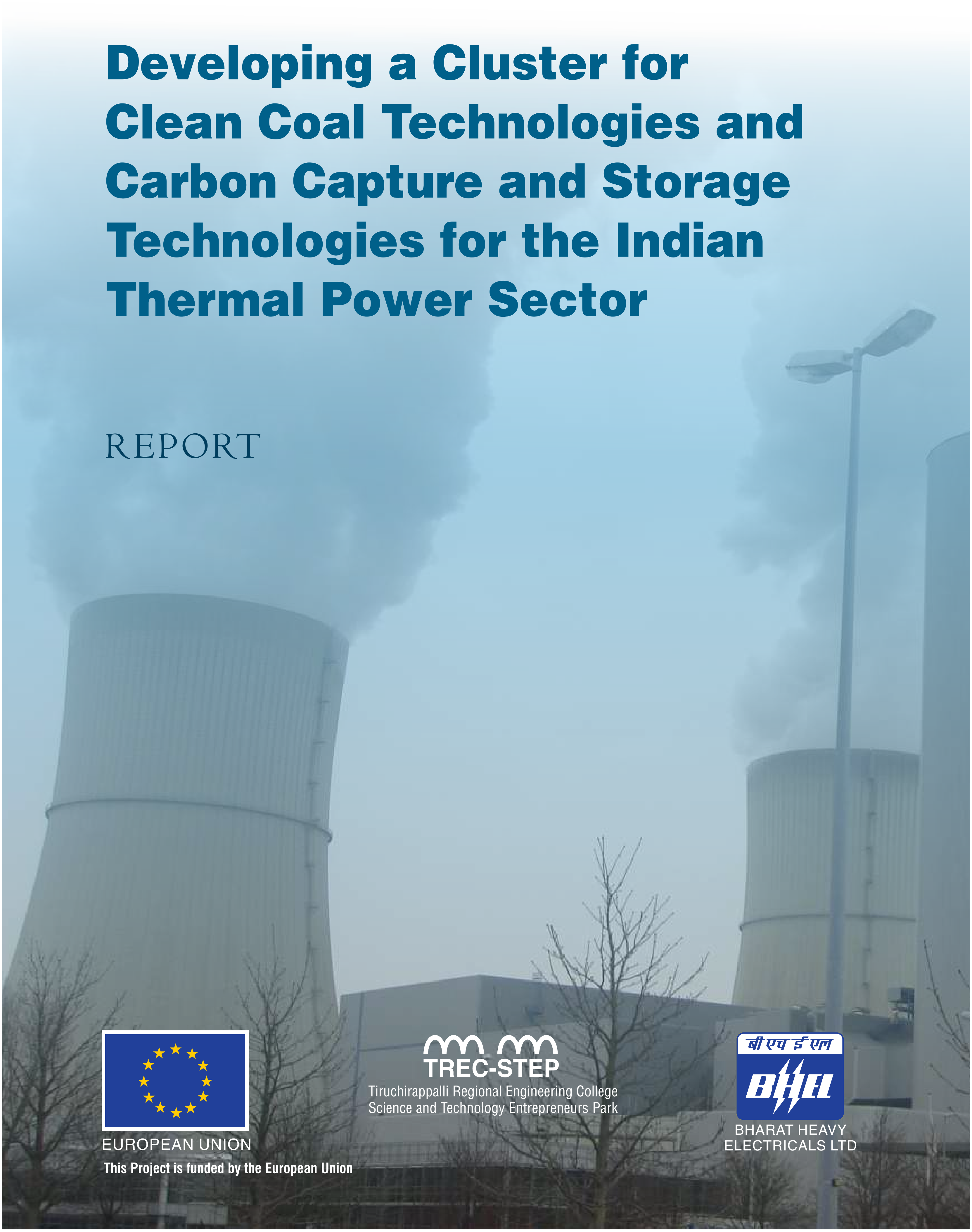
Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector

REPORT



EUROPEAN UNION

This Project is funded by the European Union

TREC-STEP

Tiruchirappalli Regional Engineering College Science and Technology Entrepreneurs Park

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BHEL

BHARAT HEAVY ELECTRICALS LTD

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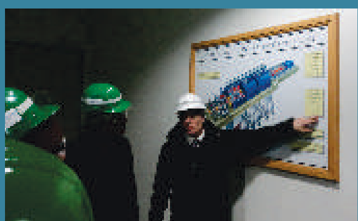

Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector

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REPORT, 2014

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I
BACKGROUND

"By the year 2000, the increase in atmospheric CO_2 may be sufficient to produce measurable and perhaps marked changes in climate."

The U.S. President's Science Advisory Committee, 1965.

BACKGROUND

March, 2011 represented a milestone for the climate change programme in India. That's when TREC-STEP, a premier Science and Technology Entrepreneurs Park in India and Bharat Heavy Electricals Ltd, India's largest power plant equipment manufacturer, formally launched their collaborative programme, 'Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector'. Funded by the European Commission's EuropeAid Cooperation Office, this EU TREC-STEP BHEL initiative was the first of its kind in India to disseminate state-of-the-art knowledge related to climate change, clean coal technologies and carbon capture and storage technologies and also explore two clean coal technologies to reduce carbon dioxide emissions.

AN ISLAND GOES DOWN

In the mid- 80s, Lohachara, a small island in the eastern part of India got swallowed up by the rising rivers in the Gangetic delta. Anticipating the catastrophe, the proactive local government had started the process of evacuating the islanders. Around 10,000 people were settled in islands close by. The older ones can still recall vividly what life was like on the island (box 1.1).

BOX 1.1
MEMORIES OF LIFE IN LOHACHARA

The island dwellers reared domestic animals and fowls. They did a lot of fishing, both for sale and for consumption.

There was a school in the village. There were playgrounds. Children played football and 'kabaddi'. There was a temple where religious ceremonies were held. We were happy living on the island.

Then, the sandy boundary areas of the island started caving in. This collapsing used to be intermittent, sudden and massive. During such events, large areas would get swallowed up.

The water sources started disappearing. We started getting drinking water from the adjoining villages. It became impossible living there.

BASANTA JENA, a former resident of Lohachara

Curiously, this event went unnoticed in the world till 2006. That's when an article in the Independent[1] reported: "Rising seas, caused by global warming, have for the first time washed an inhabited island off the face of Earth. The obliteration of Lohachara island, in India's part of the Sundarbans where the Ganges and the Brahmaputra rivers empty themselves into the Bay of Bengal, marks the moment when one of the most apocalyptic predictions of environmentalists and climate scientists has started coming true."

The newspaper report was based on studies conducted by researchers at Kolkata's Jadavpur University. Indeed, satellite imagery shows that the sea level in this area is rising at the rate of 3.14 mm a year as compared to the global average of 2 mm per year[2]. Climate change, believe many scientists, is the cause.

CLIMATE CHANGE STUDIES

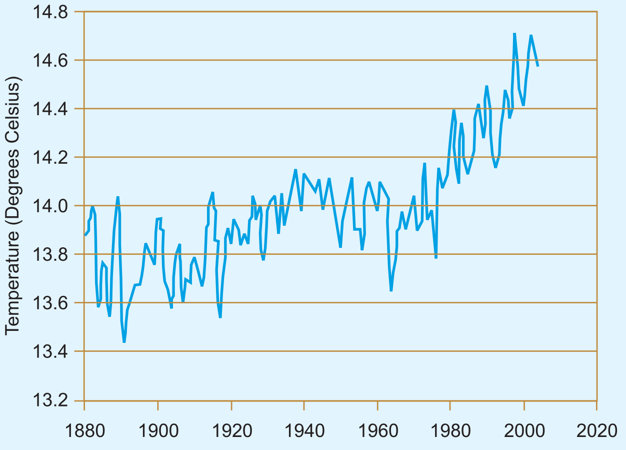
Average global temperatures have been rising in the last 100 years (box 1.2). According to the US Environment Protection Agency, average global temperatures are expected to

[1] "Disappearing World: Global Warming Claims Tropical Island", The Independent, Sunday, 24 December 2006.

[2] Hazra, S., Ghosh, T., Das Gupta, R. and Sen, G. (2002). Sea Level and Associated Changes in the Sundarbans, Science and Culture, 68(9-12) pp. 309-321.

increase between 1°C and 6.5°C by 2100 depending on the level of greenhouse gas emissions and the outcomes from different climate models. By 2100, global average temperature is expected to warm at least twice as much as it has during the last 100 years.

BOX 1.2
AVERAGE GLOBAL TEMPERATURES, 1880-2011



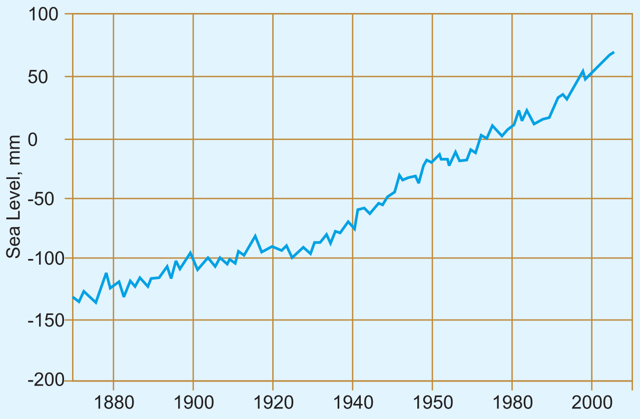
Source: GISS

Studies also show that mean sea levels have increased by 20 cms since 1870[3]. This is partly because ocean waters, which absorb as much as 90 percent of the excess heat due to warming, have expanded. Melting mountain glaciers and ice caps have also contributed to the rise in sea levels.

[3] IPCC (2012), Summary for Policymakers in: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, A Special Report of Working Groups I and II of The Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

It must be added though that local factors also influence sea level rise for coastlines around the world. Such relative changes in sea level depend upon geological forces which can lead to land elevation changes[4]. Nevertheless, it is beyond doubt that on an average, global warming has accelerated the rate of sea-level rise (box 1.3) and increased flooding risks to low-lying communities.

BOX 1.3
AVERAGE ANNUAL GLOBAL MEAN SEA LEVELS: 1870-2006



Source: IPCC

It was in the 1960s that scientists started recognising serious long term problems associated with global warming. These new concerns were to catch the attention of the U.S. President's Science Advisory Committee[5]. In 1965 it reported: "By the year 2000, the increase in atmospheric CO_2 ... may be sufficient to produce measurable and perhaps marked changes in climate..." However, there were many sceptics. The following year, a

[4] http://www.epa.gov/climatechange/science/future.html
[5] Weart, Spencer, The Discovery of Global Warming, Harvard University Press, 2008

panel of the U.S. National Academy of Sciences warned against "dire predictions of drastic climatic changes."

Today, there is a strong consensus that apart from a rise in sea levels, global warming will have serious long term consequences for the planet.

1. Dangerously hot weather is already occurring more frequently than it did 60 years ago. Scientists expect heat waves to become more frequent and severe as global warming intensifies. This increase in heat waves will create serious health risks and lead to heat exhaustion, heat stroke and aggravate existing medical conditions.
2. Rising temperatures will lead to increased air pollution, a longer and more intense allergy season, the spread of insect-borne diseases, and heavier rainstorms and flooding. All of these changes pose serious and costly risks to public health.
3. Strong scientific evidence shows that global warming is increasing certain types of extreme weather events, including heat waves, coastal flooding, powerful hurricanes and more severe droughts.
4. As temperatures increase, more rain falls during the heaviest downpours, increasing the risk of flooding events.
5. Global warming has the potential to seriously disrupt our food supply, drive costs upward, and affect everything from to cattle to staple food crops. This will lead to disruptions up and down the food chain. Developing countries may get hit the hardest.
6. The oceans will continue to become markedly more acidic, gravely endangering coral reefs, and probably harming fisheries and other marine life.

GLOBAL WARMING: CAUSES

In 1896, Svante Arrhenius, a Swedish scientist, presented a paper[6] which was the first to quantify the contribution of carbon dioxide to the greenhouse effect and to speculate

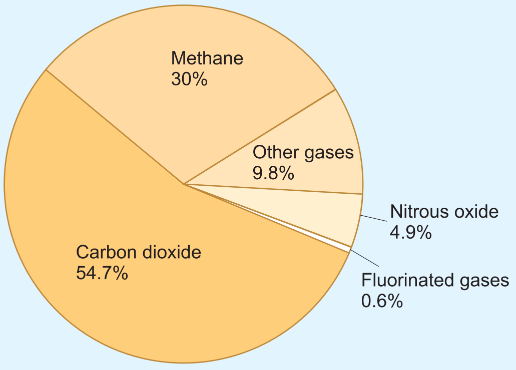
[6] "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground", Svante Arrhenius, Philosophical Magazine and Journal of Science Series 5, Volume 41, April 1896, pages 237-276.

about whether variations in the atmospheric concentration of carbon dioxide have contributed to long-term variations in climate.

Today, there is an overwhelming consensus in the scientific community that the concentration of greenhouse gases in the atmosphere will have far-reaching consequences for the climate. These greenhouse gases - carbon dioxide, methane, nitrous oxide and flourinated gases - accumulate in the atmosphere, trap heat and thus raise the planet's temperature. Of these, the contribution of carbon dioxide to this warming is the most significant (box 1.4).

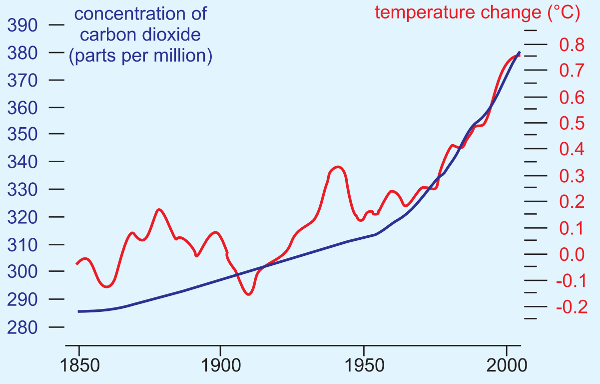
Data from the World Resources Institute show that humans have added 2.3 trillion tonnes of CO_2 to the atmosphere in the last 200 years. What is alarming is that half this amount was added in the last 30 years. Overall, the concentration of CO_2 in the atmosphere has increased 31 percent since the Industrial Revolution. CO_2 emissions are now 12 times higher than in 1900 as the world burns more and more coal, oil and gas for energy. Moreover, this increase in CO_2 emissions is tracked well by the rise in global temperatures (box 1.5).

BOX 1.4
MAJOR GREENHOUSE GASES FROM PEOPLE'S ACTIVITIES



Source: Intergovernmental Panel on Climate Change, Fourth Assessment Report (2007).

BOX 1.5
CO_2 EMISSIONS AND GLOBAL TEMPERATURES



CARBON DIOXIDE AND COAL

Coal is the most polluting of all fossil fuels and the largest single source of global warming pollution in the world. Globally, power generation emits nearly 10 billion tons of CO_2 per year. CARMA[7] provides a list of 12 top CO_2 emitters in the US and all are thermal power plants. This is not surprising. Coal generates more than half of the electricity in the US and about 22 percent of its energy. Burning coal is responsible for producing about 40% of the world's electricity.

Clearly, global efforts to tackle greenhouse gases will go nowhere if the world continues to burn coal as it does today. Indeed, some scientists feel that the world should do away with coal-fired power plants (box 1.6).

[7] Carbon Monitoring for Action (CARMA) is a database containing information about the carbon emissions of over 60,000 power plants and 20,000 power companies worldwide.

BOX 1.6
A NASA SCIENTIST APPEALS

A year ago, I wrote to Gordon Brown asking him to place a moratorium on new coal-fired power plants in Britain. I have asked the same of Angela Merkel, Barack Obama, Kevin Rudd and other leaders. The reason is this - coal is the single greatest threat to civilisation and all life on our planet.

The climate is nearing tipping points. Changes are beginning to appear and there is a potential for explosive changes, effects that would be irreversible, if we do not rapidly slow fossil-fuel emissions over the next few decades.

The amount of carbon dioxide in the air has already risen to a dangerous level. The preindustrial carbon dioxide amount was 280 parts per million (ppm). Humans, by burning coal, oil and gas, have increased this to 385 ppm; it continues to grow by about 2 ppm per year.

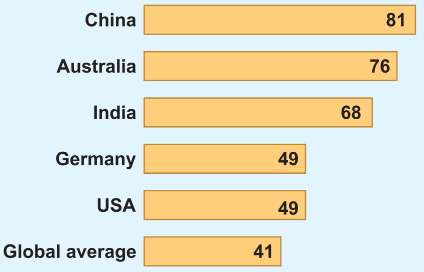
Clearly, if we burn all fossil fuels, we will destroy the planet we know. Carbon dioxide would increase to 500 ppm or more. We would set the planet on a course to the ice-free state, with sea level 75 metres higher. Climatic disasters would occur continually.

Excerpted from "Coal-fired power stations are death factories. Close them" by James Hansen, director of NASA's Goddard Institute for Space Studies. The article appeared in The Observer, Sunday, 15 February 2009.

Despite the threats posed by coal-fired plants and global warming, countries are not likely to stop using coal. After all, coal is one of the cheapest ways of generating power. In America, Australia, China, Germany and India, it provides half or more of the power supply (box 1.7). Indeed, governments prize such a secure domestic source of energy particularly because oil and gas prices are unpredictable and forever rising.

BOX 1.7

PERCENTAGE OF ELECTRICITY GENERATED FROM COAL



Source: IEA

The cheap energy that coal provides is particularly important for the growth of emerging economies like China and India. India for instance, has still to lift millions out of poverty and can ill-afford to pay more for secure energy. Clearly, these countries have no option but to invest heavily in thermal power plants. In the process, they will, as they already have, become significant emitters of carbon dioxide. China for instance, emits 27 percent of the global carbon dioxide. This is 9 percent more than what the US emits.

THE TREC-STEP PROGRAMME

Can emerging economies like India start exploring the possibilities of using 'clean coal technologies' like the developed countries already have? Can the power sector start discussing and debating issues related to this vital subject? Can professionals in the sector be empowered with knowledge and the intellectual capacity to have a level of preparedness to initiate these technologies?

Addressing these very questions was the programme 'Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector'. This programme, initiated by TREC-STEP, a premier Science and

Technology Entrepreneurs Park in India (box 1.8) was funded by the European Commission's EuropeAid Cooperation Office, and implemented in partnership with the Bharat Heavy Electricals Ltd between 1st March, 2011 and 31st August, 2014.

BOX 1.8
TREC-STEP, TIRUCHIRAPALLI

Located close to the sprawling campus of the National Institute of Technology is TREC-STEP, a premier entrepreneur's park. TREC-STEP was established in 1986 and was a part of national initiative to set up knowledge-based ventures in the country. The institution has been promoting entrepreneurs, incubating them and helping them start their own enterprises. It has also been taking initiatives to foster technology-based growth in the country.

In order to fulfill its mandate, TREC-STEP has 25 'nursery sheds' that incubatees can use to kick-start their enterprises. They can also access the common facilities for machining, designing and information support. The Software Technology Parks of India has established an earth station in the TREC-STEP Campus. As a result, entrepreneurs can reach global business networks.

As of today, TREC-STEP has promoted around 200 enterprises in engineering as well as information technology. Apart from promoting entrepreneurs, TREC-STEP trains over 2,500 men and women in technology and business skills every year.

In 2001, The Ministry of Science and Technology, Government of India declared TREC-STEP as the 'Best Performing STEP'. Further recognition came by way of TREC-STEP's incubatees winning six awards from the Indian STEP and Business Incubator Association (*ISBA*), two each in 2008, 2009 and 2010. In 2006, a TREC-STEP European Union initiative won the institution a prestigious award from the EurOffice Project for being the "Best Success Story in Business Boosting Services and Soft-landing of Small Innovative Firms". Then, in 2008, TREC-STEP won the prestigious World Bank Development Marketplace Award for its project on Mini Cold Storage Ventures. The project developed a specialised mini cold storage unit for farm produce that could be run by trained youth as a business venture.

2
REDUCING INDIA'S CARBON FOOTPRINT

This would be the first time in India that two clean coal technologies would be tried and tested, albeit on a very small scale. What is also significant is that the actual design, fabrication and the elaborate testing would be carried out by the programme partner, Bharat Heavy Electricals Ltd, BHEL for short.

REDUCING INDIA'S CARBON FOOTPRINT

In 2011, TREC-STEP began implementing a programme exploring the possibilities of clean coal technology (CCT) in India. The institution was aware that as an emerging economy, the country faces daunting challenges when it comes reducing greenhouse gas emissions (GHG). After all, around 280 million of its people, more than four times than population of France, are still without access to electricity. Moreover, the country is engaged with the monumental task of lifting millions out of poverty and all possible resources have to be leveraged for this endevour. Can the country really place the vital issue of climate change higher up in its agenda?

INDIA'S RESPONSE TO CLIMATE CHANGE

India is aware of the threats posed by climate change and has made a commitment that it will reduce its emissions per unit of GDP in 2020 by 20 to 25 percent below 2005 levels.

The country has taken a number of policy measures to address the issue of climate change. Its strategy has been multi-pronged. The main approach has been to channel its limited resources towards interventions which can deliver climatic benefits without sacrificing energy availability. This has led to policies which foster energy efficiency, encourage the use of renewables, and promote afforestation. In 2008, India released a National Climate Change Action Plan (NAPCC) which led to eight national missions: the National Solar Mission, the National Mission for Enhanced Energy Efficiency, the National Mission on Sustainable Habitat, the National Water Mission, the National Mission for Sustaining the Himalayan Ecosystem, the National Mission for a "Green India", the National Mission for Sustainable Agriculture and the National Mission on Strategic Knowledge for Climate Change.

India is taking steps to increase its forest cover with the aim of sequestering 10 percent of its annual emissions. The country will also be increasing the fraction of electricity derived from wind, solar, and small hydel projects from the current 8 percent to 20 percent by 2020. On July 1, 2010 India introduced a nationwide carbon tax of Rs. 50 per metric ton of coal both produced and imported into India. The country is also making sure that the new coal-fired plants are more efficient. S Sundararajan, a general manager with Bharat Heavy Electricals Ltd (BHEL), an integrated power plant manufacturing company says, *"The government itself is driving BHEL and the power sector towards ultra super-critical power technologies which can increase efficiencies by 4 to 5 percent. This means lesser* CO_2 *produced."*

Meanwhile, the Department of Science and Technology (DST), Government of India, set up a National Programme on Carbon Sequestration (NPCS). As a part of this initiative, DST is supporting around 30 research projects in various universities and research organisations.

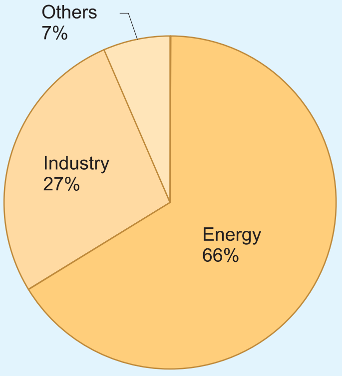
Another initiative involves a partnership between the government-owned National Thermal Power Corporation, the National Geophysical Research Laboratory, and the Battelle Pacific North-West National Laboratory, USA. This collaboration has resulted in an evaluation of the Deccan basalt formation in India as a potential long-term CO_2 storage option[1].

The Government has also indicated that it will soon set up a National Mission on Clean Coal Technologies. This will be an important step. After all, around 66 percent of India's gross CO_2 emissions came from the energy sector in 2007 with electricity generation accounting almost 48 percent of the gross emissions (boxes 2.1 and 2.2).

[1] India CCS Scoping Study: Final Report, TERI, January 2013

BOX 2.1

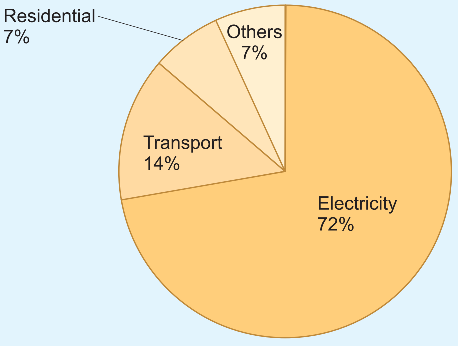
SECTORAL BREAK-UP OF INDIA'S CO_2 EMISSIONS



Source: TERI

BOX 2.2

BREAK-UP OF EMISSIONS FROM THE ENERGY SECTOR



Source: TERI

Looking ahead, India's energy needs are going to be very coal dependent. The 12th Five Year Plan has set itself a target of adding 100 GW of coal-based power. It is in this context that clean coal technology becomes even more relevant.

CLEAN COAL TECHNOLOGY

Coal is the dirtiest of fossil fuels. Burning coal produces deadly emissions: carbon dioxide, sulphur dioxide, mercury and nitrogen oxides. Broadly speaking, clean coal technology (CCT) refers to technologies that improve the environmental performance of coal-based electricity plants. These technologies include equipment that increases the operational efficiency of power plants, as well as those that reduce emissions.

The US Congress first coined the term 'clean coal technology' in the mid-1980s in reference to technologies that reduce sulphur dioxide (SO_2) and nitrogen oxide (NO_X) emissions. CCT is now evolving to reduce emissions of carbon dioxide.

All in all, some of the common CCTs include:

1. Coal cleaning by 'washing' reduces emissions of ash and sulphur dioxide when the coal is burned and has been the standard practice in developed economies.
2. Electrostatic precipitators and fabric filters, also in widespread use, remove 99 percent of the fly ash from the flue gases which are emitted by coal-fired plants.
3. Flue gas desulphurisation reduces the amount of sulphur dioxide released into the atmosphere by 97 percent.
4. Low- NO_X burners allow coal-fired plants to reduce nitrogen oxide emissions by upto 40 percent. Today, there are plants which use technologies like catalytic reductions which can clean up 90 percent of the NO_X emissions.
5. Increasing the efficiency of plants means that there will be less emissions per unit of electricity produced. The newer plants now operate at thermal efficiencies of 46 percent. This is expected to rise to 50 percent in the future.
6. Co-firing biomass with coal can lead to efficiency improvement as well as reduction of CO_2.

7. Carbon capture and storage (CCS), the most promising CCT, entails isolating CO_2 wherever it is produced in large quantities, compressing it and pumping it underground. The International Energy Agency (IEA) estimates that the world will need over 200 power plants equipped with CCS by 2030 to limit the rise in average global temperature to about 3°C. However, economics is a big hurdle. As a result, there are no big power plants using CCS but there are many demonstration projects in the developed economies. Technologies for isolating CO_2 include amine scrubbing, oxyfuel combustion and precombustion capture.

Of the various CCTs listed above, two have a special importance in the context of the TREC-STEP CCT programme: biomass co-firing and oxyfuel combustion.

THE EU TREC-STEP BHEL CCT PROGRAMME

The EU TREC-STEP BHEL programme, 'Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector', was going to culminate with the deployment and demonstration of two technologies: biomass co-firing and oxyfuel combustion. This would be the first time in India that two clean coal technologies would be tried and tested, albeit on a very small scale. What is also significant is that the actual design, fabrication and the elaborate testing would be carried out by the programme partner, Bharat Heavy Electricals Ltd, BHEL for short. BHEL is an integrated power plant equipment manufacturer and one of the largest engineering companies in India (box 2.3).

BOX 2.3
BHARAT HEAVY ELECTRICALS LTD (BHEL)

BHEL is a leading Indian player in the design, engineering, manufacture, construction, testing, commissioning and servicing of a wide range of products and services for the core sectors of the economy like power, transmission, industry, transportation, renewable energy, oil and gas and defence. The company has the capacity to manufacture plants up to 1,000 MW. It is one of the few companies worldwide to be involved with the development of Integrated Gassification Combined Cycle (IGCC) technology, vital for reducing greenhouse gas emissions.

BHEL has a share of 57 percent in India's total installed generating capacity which contributes 69 percent of the total power generated from utility sets (excluding non-conventional capacity) as of March 31, 2013. In 2012-13, BHEL registered a turnover of US$9.23 billion.

BHEL has been exporting its power and industry segment products and services for over 40 years. It has a presence in over 75 countries; the cumulative overseas installed capacity of BHEL manufactured power plants exceeds 9,000 MW across 21 countries. They include Malaysia, Oman, Iraq, the UAE, Bhutan, Egypt and New Zealand. The corporation's physical exports range from turnkey projects to after-sales services.

But this CCT programme was much more than conducting trials with two clean coal technologies. It sought to bring together a large number of stakeholders like policy planners, power equipment manufacturers, thermal power plants, power distribution companies, investors, entrepreneurs, academicians, international experts and leading global institutions which have taken CCT initiatives. By creating such a network, the programme hoped to link major players in the thermal power sector and create a platform which could generate state-of-the-art knowledge in the area of CCT, conduct learning tours, build the capacity of thermal power professionals, disseminate knowledge and information, as well as incubate innovative clean technology ventures.

BOX 2.4
THE PARTNERS' PERSPECTIVES

We felt it would be a win-win situation since BHEL had already embarked on this journey and here was the EU giving us exposure through TREC-STEP for us to learn something more. We felt it was an important step for BHEL and we joined hands with TREC-STEP so that we could learn about what is happening in other countries.

AV KRISHNAN, Executive Director, BHEL, Tiruchirapalli

This project seeks to introduce the whole subject of climate change to thermal power sector engineers, prepare them with skills and with an understanding of the new technologies to fight climate change through carbon emission reductions. In this sense, this project represents a unique opportunity for both the Indian power sector as well as the global community to fight climate change.

RMP JAWAHAR, Executive Director, TREC-STEP

Since independence, we have created a capacity of over 200,000 MW. Another 200,000 MW is planned for the next ten years and mostly, it will be through thermal power generation. That's why we have to be very concerned about CO_2 emissions. So it is a very good opportunity for us to have a project on CO_2 emissions, its effect on global warming, and how we can reduce it.

S ARUMUGAM, Additional General Manager, Coal Research
BHEL, Tiruchirapalli

3
LAUNCHING THE CLUSTER

The first cluster meeting was organised in November 2011 and the ideas that emerged out of this interaction were very useful in identifying knowledge gaps and laying the foundation for the important phase of generating awareness and building capacities.

LAUNCHING THE CLUSTER

The EU TREC-STEP BHEL CCT programme was aware that there were a number of CCS-related research projects ongoing in Indian research institutions. However, it was also true that a vast number of professionals in the power sector had only a limited understanding of facts and concepts related to climate change and CCTs[1]. Clearly, what the programme needed to do at the outset was to create a platform for sharing knowledge and creating the critical mass of intellectual energy for taking the programme forward.

TREC-STEP was also aware that the platform should bring together not only thermal power sector professionals but also those who are indirectly related to it. These other 'cluster' players include power buyers, power distributers, investors, financiers, and those who provide support services. As RMP Jawahar, Executive Director, TREC-STEP put it, *"We need to develop a cluster of different players in the power sector and make them concentrate on climate change problems while acquainting them with Clean Coal Technology and Carbon Capture and Storage."*

LAUNCHING THE CLUSTER

The 'cluster' was officially launched on 10 September, 2011 and a memorandum of understanding was signed between TREC-STEP and BHEL, thus making the partnership formal. The launch brought together over 100 participants from the power sector, academic institutions and research organisations.

[1] In September 2011, NTPC did organise a national workshop on CCS in collaboration with the Ministry of Power.

The first cluster meeting was organised in November 2011 and the ideas that emerged out of this interaction were very useful in identifying knowledge gaps and laying the foundation for the important phase of generating awareness and building capacities.

As a part of this important endeavour, the programme conducted a number of cluster meetings in which policy planners as well as senior professionals from the power sector participated. The programme reached out to over 180 thermal power sector players and power sector related institutions[2] across India. This resulted in a vibrant network for generating and diffusing ideas and concepts related to CCT.

TREC-STEP also contacted 34 institutions working in the area of CCT in Europe, US and Canada. Interactions with these power sector players and research centres helped the programme design and develop project actions that could meaningfully empower the power sector with access to knowledge in this new field. Some of these key institutions included the Imperial College, London; the UK CCS Research Centre; Edinburgh University; the Pilot Scale Advanced Capture Technology PACT project, Sheffield; the ELCOGAS IGCC power plant in Spain; the Enel Ultra Super Critical Plant in Italy; and the RWE Westfalia Ultra Super Critical Plant in Germany.

Particularly useful were the interactions with Dr, John Topper, CEO, IEA Environmental Projects Ltd, UK and Dr. Keith Burnard, Energy Technology Policy Division, IEA, France. Apart from providing invaluable inputs on the state of CCT in developed economies, IEA experts reviewed each component of the capacity building programme and helped fine-tune it. They also provided vital suggestions about key institutions and enterprises in Europe that could provide important learning opportunities for professionals from their Indian counterparts.

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[2] Some key ones include ALSTOM; the Central Power Research Institute; the National Thermal Power Corporation; the Neyveli Lignite Corporation; the NTPC Energy Technology Research Alliance, the Tamilnadu Electricity Board; the Mettur Thermal Power Station; the Andhra Pradesh Power Genration Corporation Ltd; the Karnataka Power Corporation and the Panipat Thermal Power Station

The programme also facilitated important interactions between some senior faculty members of the National Institute of Technology (NIT), Tiruchirapalli, the BHEL Coal Research Division and Dr Shen-En Chen, Professor, Department of Civil and Environmental Engineering, North Carolina University. Professor Chen is currently working on a research project with the Chinese coal mining industry which is looking at ways of using fly ash for carbon capture.

KNOWLEDGE EXCHANGE WEB PLATFORM

The programme created a knowledge exchange web platform "www.carboncap-cleantech.com" which provides the latest updates on developments in the field of CCT. This vehicle allows users to access more than 100 reports and articles. There are over 40 videos which include animations of CCT demonstrations, and interviews with experts. Moreover, the website hosts over 20 hours of capacity leveraging programme implemented by the TREC-STEP CCT programme.

TREC-STEP is also developing a 'link library' which will provide the details of all coal-based power plants in the country, the key players in the Indian thermal power sector, and their main suppliers. Such a library will provide a knowledge link to all the cluster members, academicians, researchers and policy planners so that they can reach out to each other and strengthen the network further.

Interestingly, the portal received 438 hits within two months of its launching. 85% of these hits represented new visitors. This was an indication of the interest being taken in the programme and the subject matter. During the course of the programme implementation, TREC-STEP kept a continuous track of the geographic coverage of the user community and analysed the usage of different segments of the portal. This helped the institution to fine-tune the portal for better dissemination of the programme outputs.

4
DIFFUSING KNOWLEDGE

"I didn't want to miss even a few minutes of any of the sessions. I have been working in a power station for more than ten years in the field of environmental monitoring and since I have been searching for a lot of latest technologies, this conference has been an eye-opener."

M Renumathy, Assistant Executive Engineer, Environment,
North Chennai Thermal Power Station, India

DIFFUSING KNOWLEDGE

The TREC-STEP CCT initiative had kick-started the programme by launching a cluster, a process that went on to create a productive network between power plant equipment manufacturers, power plants, distributors, investors, research organisations and academic institutions, both in India and in the developed economies. It was a platform that allowed various stakeholders to interact with one another, seek conceptual clarity and explore new ideas. It also laid the foundation for an important component: diffusing knowledge related to CCT.

BUILDING AWARENESS

Training for raising awareness about climate issues and CCTs was going to be an important component of the TREC-STEP CCT initiative. The programme now had to identify quality institutions that could provide inputs for training Indian professionals and empower them with CCT-related knowledge and insights.

TREC-STEP got in touch with various organisations[1] in India and abroad and, based on its perceptions of training needs, selected Ernst and Young as one knowledge partner.

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[1] National Centre for CCS, University of Nottingham; Centre for Innovation in Carbon Capture and Storage (CICCS) in UK; British Geological Survey; Advanced Energy Technology Initiative, University of Illinois; powerEdge Asia, Singapore; IEA, France; the Energy Institute, UK; Ernst and Young, Singapore; and Indian Carbon Outlook, India.

The two training programmes were: “Introduction to CCS and CCT” conducted in December 2011, and “Climate Change, Clean Coal and Carbon Capture” in August 2012. The second event, the first of its kind in India, focussed on academic institutions and research centres and was able to reach out to 117 participants.

During these two events, trainees got a chance to understand the complexities of climate change, the various technologies that were available to the coal-power sector, concrete developments that were taking place worldwide, regulatory issues as well as future scenarios (refer annexure 1).

LEVERAGING SKILLS

The Capacity Leveraging component of the CCT programme took participants to a higher level of training. Feedback from the Awareness Building training sessions helped the programme grasp what the next level of inputs could possibly be. Based on this analysis, TREC-STEP went on to design and conduct two Skill Leveraging programmes.

The first one, “Technologies for Carbon Capture, Transport and Storage and Cleaner Coal” was conducted in January 2012. The panel of resource persons included the former Chairman and Managing Director of Central Coalfields Ltd, the former CEO of Reliance Energy, International experts from Alstom and IEA, apart from those from Ernst and Young. 45 professionals from BHEL and other Thermal Power plants participated in this programme (refer annexure 1 for themes covered).

The second Skill Leverage initiative, “International Training Programme on Clean Coal Technologies and Carbon Capture and Storage” was conducted in October, 2012. This training programme was designed to provide participants with a comprehensive understanding and knowledge of new technological developments and proven CCTs implemented across Europe (refer annexure 1). TREC-STEP planned and designed this programme with the help of experts from the IEA Clean Coal Centre, UK. The programme was meant for power sector professionals as well as policymakers,

entrepreneurs, innovators, academics and researchers (see box 4.1 for responses). Experienced professionals from advocacy organisations and power sector corporations[2] conducted the training programme.

BOX 4.1
TRAINEES' RESPONSES

After attending this training programme, one can easily conclude that urgent steps are required to be taken in the area of clean coal and carbon capture and storage. Prior to attending this programme, I had very little information about the subject. But this training programme has inspired me. I would like to be closely associated with any project in this area that my organisation may undertake.

RAJESH KUMAR GULATI, Senior Manager, Haryana Power Generation Corporation

TREC-STEP has taken the right step to create awareness in these topics of which we were aware of only very distantly. Now, we have got a close look at this subject and become much more aware. I feel that India should do more in the area of CO_2 capture and storage. India needs to execute more research projects so that we can gear up for the future when it becomes real.

SHIV PRASAD, Chief Manager, Neyveli Lignite Corporation Ltd.

The resource persons were from all over the world. There were experts like John Topper from IEA, Keith Bernard, and also some of our competitors who are experts in areas like oxyfuel combustion – companies like Doosan and Foster Wheeler. The resource people were wonderfully chosen for this programme. In fact, there was a lot of sharing of experiences by people from various fields. And because the technology is so new, people were very open about sharing information.

S ARUMUGAM, Additional General Manager, Coal Research, BHEL, Tiruchirapalli

[2] These included John Topper, CEO, IEA Environmental Projects Ltd, UK; Keith Burnard, Senior Coal Analyst, Energy Technology Policy Division, IEA, France; Ralph Joh, Head of the Laboratory for Carbon Capture Technologies, Siemens AG Energy Sector, Germany; Fransisco Garcia Pena, Engineering R&D Director, Elcogas, Spain; Ceri Vincent, Geophysicist, British Geological Survey; and Sarvananan Swaminathan, Senior Engineer, Doosan Power Systems, UK.

The training programmes were conducted by international faculty members. We got exposed to a lot of state-of-the-art technology developments that are taking place especially in Carbon Capture and Storage. We also made contact with international experts. This will be very useful for BHEL when it executes projects in this area.

R DHANUSHKODI, Deputy General Manager, R&D, BHEL, Tiruchirapalli

A CONFERENCE

By the end of the programme period, the EU TREC-STEP BHEL CCT initiative had disseminated a wide range of ideas, concepts and concrete case studies related to CCT. A spectrum of power sector professionals from all layers, academicians, entrepreneurs and policy planners had understood and absorbed these new developments taking place in some of the developed economies. Moreover, Indian professionals had the unique opportunity to exchange ideas and share their experiences with their European and American peers.

On 2 and 3 December, 2013, TREC-STEP organised a conference on "Clean Coal and Carbon Capture and Storage Technologies"

This two day convergence conference provided the participants with valuable inputs on a spectrum of latest CCT and CCS technologies successfully implemented in countries like UK, Germany, Italy and US.

Present at the conference were over 300 participants. These included senior power sector professionals from BHEL; the Central Power Research Institute or CPRI; the Neyveli Lignite Corporation; the Tamilnadu Generation and Distribution Corporation Limited; the Mettur Thermal Power Station; the Tuticorin Thermal Power Station; the North Chennai Thermal Power Station, the Dr. Narla Tata Rao Thermal Power Station; the Maharashtra State Power Generation Company Ltd; and the Nashik Thermal Power Station. In addition, climate technology enthusiasts, engineering students and academicians also participated in the conference.

The resource persons and speakers in the conference included experts from the European Commission, Belgium; IEA Coal Research Ltd, UK; IEA Green House Gas R & D Programme; Foster Wheeler, Italy; ThyssenKrupp Uhde GmbH, Germany; Doosan Power Systems India; British Geological Survey, UK, University of Stuttgart, Germany; University of Darmstardt, Germany; and University of North Carolina at Charlotte, USA.

During the conference, some of these speakers found the time to give interviews and share their perspectives and observations (box 4.2)

BOX 4.2
CONFERENCE: SOME EXPERTS' PERSPECTIVES

Well, I can understand the concerns about coal. There's no denying the fact that it is the most carbon-intensive fuel. And if climate change is happening, and I'm certain that it is, then the CO_2 that is emitted from coal is the most important contributor to the warming that we are seeing.

However, much as people may fulminate against coal, it is not going to go away anytime soon. There are 1.3 billion people in the world today not connected to power. Many of them are sitting close to significant coal reserves. It's puerile to pretend that they are not going to find a way of using it if it is available and it is cheap.

The problem that we face at the moment is that adding a CCS system to an existing plant is likely to add 60% to 80% to the capital costs. That's a huge sum!

What I think should be done is that it will be good if governments adopted policies of phasing out as rapidly as possible old inefficient power plants and replacing them with new state-of-the-art ones with provisions for fitting in Carbon Capture and Storage even if it does not fit in with their policies right now.

All experience shows that over time, second, third and fourth generations get cheaper. The more plants you build, the cheaper it gets. So the cost curve for Carbon Capture and Storage should diminish over time. That's been the experience of all other technologies and there's no reason why this should be any different.

JOHN TOPPER, CEO, IEA Environmental Projects Ltd, UK ►

Biomass co-utilisation in combustion or gasification was introduced as a result of the Kyoto Protocol. That's why the European Commission decided to support research on using biomass for power and energy generation. Research started in conjunction with industry. I know from my own experience that around 1992, we had the first biomass tests done on a large scale with about 2 to 3% biomass added to the coal.

We now have over 20 years of experience with biomass co-utilisation. And it is certainly worthwhile to disseminate this experience in order to help other colleagues. I think 20 years is a long time and in India you can do it in a shorter period if you take advantage of the experience elsewhere.

KLAUS R.G. HEIN, Professor Emeritus, University of Stuttgart, Germany

Carbon Capture and storage is a very expensive venture. It takes millions of Dollars. So in order for it to work, we have to be able to create a business model. And that requires some advanced technologies and also new ways of thinking so that people will be willing to be motivated to capture carbon and store it. So that's what my research is about.

I think that one important message that has been conveyed through this conference is that developing countries should not follow the footsteps of the developed countries. We have made a lot of mistakes and others should not repeat those mistakes. I think there is a huge opportunity for India and China to create their own solutions to problems.

SHEN-EN CHEN, Professor, Department of Civil and Environmental Engineering, North Carolina University

The conference is very well-represented. There are more than 200 delegates. There are many people coming from local industries, BHEL and also professionals from all over India. So I can see that there is a lot of interest in Carbon Capture and Storage.

DOBRIN TOPOROV, Deputy Head, Gasification, ThyssenKrupp Uhde GmbH, GERMANY

I am really surprised at the number of people attending the conference.

LUCA MANCUSO, Process Director, Power Division, Foster Wheeler, Italy

STUDIES FOR KNOWLEDGE GENERATION

In order to strengthen the dissemination of information component of the programme, TREC-STEP commissioned experts to put together three studies related to emissions from coal fired plants. The objective was to provide thermal power plant professionals with a rigourous understanding of the three subject areas and provide India-specific information.

The first study[3], *'Existing Gaps and Potential for CCS and CCT Areas in the Thermal Power Industry in India',* provides an overview of the existing power scenario in India, power shortages that the country faces, the energy mix that exists in the country, aspects of coal usage, the future plans for expansion of capacity, and GHG emissions. It spells out in detail the spectrum of governmental initiatives to combat climate change and what the thermal power sector has already achieved by way of developing and introducing technologies to increase the efficiencies of a new generation of coal-fired plants. The report also presents the wide array of clean coal technologies worldwide with a particular emphasis on carbon capture and storage, the accompanying storage risks, and the potential for CO_2 storage in India. Finally, the study outlines the various research and development initiatives underway in India as also other technology options for India for reducing CO_2 emissions through energy efficiency, bio-fuel utilisation, hydel and wind power.

The second study[4], *'Mercury Emissions and Health Hazards',* examines the various mercury emission sources, particularly the thermal power sector. It lists a growing number of modern industrial products that use mercury in its various forms: notebook computers, modern telephones, new lighting technologies and anti-lock brakes in cars. It goes on to outline how mercury emissions, once transported through the air, contaminates land and water and can enter the food chain. The study examines the impact of mercury on the health of humans and what is being done worldwide to tackle this very important issue.

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[3] Author: M Soundara Raj, retired Assistant General Manager, BHEL, Tiruchirapalli
[4] Author: SR Kannan, retired Deputy General Manager, BHEL, Tiruchirapalli

The third study[5], *'Developments in Chemical Looping Technology Worldwide',* provides a comprehensive overview of the main developments of this technology. Chemical looping is an innovative strategy of excluding gases like nitrogen found in air and delivering only oxygen to the coal combustion process. This enables an almost pure CO_2 gas to be produced, which can then be relatively easily stored without any further major processing. This technology is increasingly being viewed as a competitive technology in carbon capture and storage, with the successful completion of pilot plant trials in the US and EU. The study examines the potential of chemical looping combustion and the possibility of its integration into power plants, especially for countries like India which have large coal reserves. The report goes on to point out that an important positive aspect of this technology is that it can be retrofitted into existing power plants.

[5] Author: PV Suresh, Assistant Professor, Department of Chemical Engineering, National Institute of Technology, Warangal

5
THE LEARNING TOURS

Importantly, the BHEL professionals had started work on the biomass co-firing demonstration project and were grappling with concrete issues related to this technology. All these developments meant that the visitors had evolved. This made the trip particularly enriching for them.

THE LEARNING TOURS

By launching a CCT cluster, TREC-STEP had created a bridge between the Indian stakeholders in the thermal power sector and their peers in the developed economies. This had enabled the programme to create a network and set into motion a range of activities aimed at diffusing knowledge related to CCT. What the programme now facilitated was a number of learning tours to some key facilities and research institutions in Europe in order to provide comprehensive field level knowledge.

THE FIRST BENCHMARKING LEARNING TOUR

The first learning tour took place between 6 February and 17 February, 2012. Three researchers from the BHEL Coal Research Centre and three project management team members visited ten institutions in the UK and Germany[1].

During these visits, the team got an opportunity to see for themselves what they had been reading and hearing about: the latest developments in CCT. They got a chance to interact with professionals in these organisations, raise questions and get their doubts clarified. They were able to strengthen their linkages with important CCT institutions in the UK and Germany and lay the foundation for the internship programme which was to follow. Importantly, researchers from the BHEL Coal Research Centre were able to obtain a great deal of conceptual clarity on the two technologies that they would be exploring during the BHEL demonstration projects: biomass cofiring and oxyfuel combustion.

[1] Schwarze Pumpe Power Station and the Oxyfuel pilot plant, Spremberg; CO_2 Storage Facility, Ketzin; Staudiner Post Combustion Pilot Plant, Offenbach; RWE Coal Innovation Centre, Niederaussem Power Plant, Niederaussem; IEA Clean Coal Centre, London; British Geological Survey, Nottingham; National Centre for Carbon Capture and Storage, Nottingham; Post-combustion Carbon Capture Pilot Plant, Ferry Bridge Power Station, Yorkshire; Renfrew Test Facility, Doosan Power Systems, Glasgow (see annexure 2 for details)

THE SECOND BENCHMARKING LEARNING TOUR

The second learning tour took place between 6 and 13 October, 2013. The team of eight included BHEL professionals and project management team members.

The team visited modern coal-fired plants in Germany and the Netherlands[2]. They also had intensive discussions at the International Energy Agency (IEA) offices in Paris. These interactions helped them get a detailed understanding of the current state of CCT as well as the policies which need to be put in place for these technologies to be implemented on a meaningful scale. The trip enriched the members' understanding of biomass co-firing, CCS, and wood gasification technology. They got a good exposure to a new generation of power plants that had improved their efficiencies and had thus cut their CO_2 emissions significantly. Also of interest were the various safety practices in the plants and the possibility of adapting them for Indian conditions.

This trip had a context. The EU TREC-STEP BHEL CCT programme had helped the members engage with CCT-related issues for around two years. They had already been through extensive networking and training programmes. Importantly, the BHEL professionals had started work on the biomass co-firing demonstration project and were grappling with concrete issues related to this technology. All these developments meant that the visitors had evolved. This made the trip particularly enriching for them.

All in all, the two trips helped BHEL professionals to gain insights into the latest developments in CCT. It gave them exposure to the varied technical hurdles that the engineers and researchers had been through and it strengthened their knowledge networks (box 5.1).

[2] Amer Power Plant and Maasvlakte Power Station in the Netherlands; Lünen Power Plant and Datteln Power Plant in Germany (see annexure 3 for details)

BOX 5.1
LEARNING TOURS: GAINS

Seeing is believing. That is the first step. Our people were very fortunate in seeing actual plants in operation and also understand what are the critical carbon storage issues, safety measures, control logics, and so on. All this cannot be understood by going through information on the net.

S ARUMUGAM, Additional General Manager, Coal Research
BHEL, Tiruchirapalli

I visited the Amer power plant in the Netherlands. They were firing wood along with coal. They first co-milled wood along with coal but they had a lot of problems of preferential grinding. They made a lot of modifications in the mill but they still could not overcome the problem. Then they designed separate mills for the two fuels. This also led to some problems in the furnace. Our interactions with engineers gave us some important insights into the kind of ups and downs you will face when you co-fire with wood. It was a great experience for us.

R DHANUSKODI, Deputy General Manager, R&D, BHEL, Tiruchirapalli

We visited many power plants and demonstration plants in the area of Clean Coal Technologies and Carbon Capture and Storage Technologies in Germany and UK. What we understood is that they are ready with the technology. Once their government policies are in place, they can readily switch over to CCS and CCT. I felt that we too should be ready with these technologies.

K GANESH PALAPPAN, Senior Engineer, Coal Research, BHEL, Tiruchirapalli

Here at BHEL, we are experimenting with oxyfuel combustion. The European Union trip helped us understand the various hurdles our European counterparts faced. We spoke to eminent experts in this field and understood a lot of concepts related to this new technology. Based on these insights, we will be able to design the subsystems required for retrofitting in our facility.

K. SIVARAMAKRISHNAN, Deputy General Manager, Coal Research, BHEL, Tiruchirapalli

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During the visit, we saw one plant which was using T-24, a high alloy steel which can withstand high temperatures. They are adopting these high-level steel parameters so that they can achieve higher efficiencies. This impressed us very much and we hope to adopt this material in our boilers in the future.

M MUTHUKRISHNAN, General Manager, R&D and Coal Research BHEL, Tiruchirapalli

The learning tours have opened up a new world of emerging technologies in the area of clean coal technology and carbon capture and storage technologies for the thermal power sector professionals in India. Moreover, the learning tours have helped the Indian professionals build networks and linkages with experts who have hands-on experience with these technologies. I'm sure these linkages will be helpful to the power sector professionals in the long run.

BINDU BALAKRISHNAN, Deputy Manager, TREC-STEP .

INTERNSHIPS

Development and demonstration of biomass co-firing and oxyfuel combustion was an important leg of the programme. These trials, the first of their kinds in India, needed specialists who had an in-depth understanding of these technologies. This was precisely what the internship component of the programme aimed to do.

The internship team consisted of three young professionals from the Coal Research Centre of BHEL, Tiruchirapalli. After doing all the groundwork in India, these interns took a trip to the UK. Here they got a chance to visit seven important institutions[3] where they attended workshops, interacted with experienced professionals and researchers, widened their understanding of CCTs and got a deeper understanding of the operational problems of these technologies. It also boosted their confidence in their own abilities (box 5.2)

[3] Imperial College, London; Edinburgh University; The Scottish Government Office, Glasgow; Howden Global, Renfrew; University of Newcastle; University of Leeds and the Pilot Scale Advanced Capture Technology (PACT) facilities; and the University of Nottingham (see Annexure-4 for details)

BOX 5.2
INTERNS' VIEWS

One of the important lessons that I learnt was that we have the same instrumentation facilities as the European companies but the interpretation of the data can come only with interaction with the specialists and with experience. I am now confident that if we have the resources, we too can demonstrate CCT and CCS technologies in India.

One important point that struck me during the internship tour is that we really need to do intensive research in the area of CO_2 transportation. There are many important research areas like CO_2 specifications, purity, the pressure during transport, the materials required to prevent corrosion, and so on. Sooner or later, India will move on to carbon capture and storage technologies. This internship tour has given us the confidence for demonstration and successful implementation of such projects.

P HEMA LATHA, Development Engineer, Coal Research, BHEL, Tiruchirapalli

We visited the Howden facility in Glasgow. One thing that impressed me was that they had coated adsorbents to air preheaters so that when flue gas enters the preheater, CO_2 is adsorbed. In India, we do manufacture preheaters but they are not coated. We should try to develop adsorbents for such coating purposes.

When we visited the Imperial College in London, a professor explained their work on carbonate chemical looping combustion. At BHEL, we have also started our research on chemical looping combustion. This internship will help us with research in this area.

This internship programme has boosted our confidence of working in the area of clean coal technology and carbon capture and storage. We have established a very good network with researchers and specialists. This has helped us to understand what to do and what not to do and prioritise our work. Importantly, we now know what pitfalls we may face once we get into clean coal technology aggressively.

THULASI E, Development Engineer, Coal Research, BHEL, Tiruchirapalli

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During our internship visits, we met with professionals who have over 20 years of experience with clean coal technologies. Our interactions really helped us to clarify our simple but important doubts. The professionals have gone through the ups and downs of this technology and have seen its rise. This really helped us understand the fundamental aspects of clean coal technology.

SIVAJI SEEPANA, Senior Engineer, Coal Research, BHEL, Tiruchirapalli

6
THE DEMONSTRATION PROJECTS

"When we started off with this programme, we were designing concepts and technologies on paper. We never had a demonstration project. But because of this EU programme, we were able to install two pilot projects, one for biomass co-firing and the other for oxyfuel combustion."

S SUNDARARAJAN, General Manager, Engineering (FB), BHEL, Tiruchirapalli

THE DEMONSTRATION PROJECTS

The programme, by way of training programmes as well as learning trips, had built the capacity of some BHEL professionals. This initiative was strengthened further by creating a team of interns who went on to visit key institutions engaged with clean coal technologies. The programme was now ready for a vital initiative: demonstration and deployment of two clean coal technologies - biomass co-firing and oxyfuel combustion.

BIOMASS CO-FIRING

Biomass includes any natural renewable fuels such as wood, agricultural residues, and energy crops which have been planted specifically for producing energy. Co-firing is the process of replacing part of the coal supplied to a power station or boiler with such 'carbon neutral', renewable biomass. Biomass is considered 'carbon-neutral' because it returns the CO_2 that was absorbed from the atmosphere as the plants grew.

Since biomass can replace between 20 percent and 50 percent of coal, this technology has an enormous potential for reducing CO_2 emissions. Moreover, there are other environmental benefits in the form of also lower ash, dust and SO_2 emissions. At present, some 230 power plants worldwide use biomass co-firing (box 6.1).

However, there are a number of significant challenges which prevent the more widespread use of biomass. Compared to coal, biomass is less dense and its use requires the plant's fuel feed systems to be able to handle much larger volumes of fuel. There are also milling issues which can affect flowability of the mixture. Moreover, there is the issue of feedstock availability. Drax, a leading player in this area, has started working

with local farmers to encourage them to promote biomass cultivation as a business opportunity. In this context, it may be emphasized that in India, there is an abundance of biomass and it is conceivable that farmers and young entrepreneurs in the countryside can be involved in the organised supply of this valuable fuel.

BOX 6.1
BIOMASS CO-FIRING: THE GLOBAL PICTURE

Several European countries and American states offer policy incentives or have mandatory regulations to increase the renewable share in the electricity sector. As a result, there has been an expansion in the number coal-fired plants with biomass co-firing these countries.

The EU is the world's leader in terms of both technology development and installation capacities. There is considerable experience in Finland, Germany, the UK, Sweden, Denmark, Italy and the Netherlands. Some of these power plants have ambitious plans: the UK's largest coal-fired power plant, Drax, plans to reduce its CO_2 emissions by 18 percent over the coming years by raising its biomass co-combustion rate and carrying out renovations of the plant's turbines.

With the second largest number of co-firing installations in the world, the US is projected to have strong growth in electricity generation using this technology. At least 20 utilities in North America are now using wood chips to replace 5-25 percent of the needed coal or natural gas. According to the U.S. Department of Energy, biomass plays a key role today with 7,000 megawatts of installed capacity. The agency believes that the co-firing of biomass and fossil fuels is the most immediate step that utilities can take to cut their carbon dioxide emissions.

DEMONSTRATION: BIOMASS CO-FIRING AT BHEL

The project procured three biomass sources: rice husk, wood waste and prosposis juliflora. These bio-fuels were analysed at the Coal Research Centre laboratory for their

elemental composition and calorific value. In addition, the laboratory used computer controlled scanning electron microscopy to determine mineral matter composition of the biomass. These basic findings were necessary to make an assessment of the critical parameters that would come into play once the trials began.

In order to execute the project, BHEL designed and made modifications and additions to the existing facility at the Coal Research Centre's Solid Fuel Burning Test Facility. A biomass silo was designed, fabricated and erected. A variable drive biomass screw feeder was procured and fitted on to the system. A ball mill was installed and trials carried out with rice husk. The programme also experimented with co-milling of different biomass products along with coal in order to ascertain what the best system for creating the right mix that would ensure that the system was giving the desired results.

There were a number of hurdles that had to be overcome before optimum results were obtained. Sivaji Seepana, Senior Engineer at BHEL's Coal Research Centre and one of the three interns was closely involved with the project. According to him, *"When we co-fire biomass with coal, we have to look at various parameters such as particle size of the biomass after pulverisation, the flowability of the biomass along with coal, the proportion of the biomass in the coal mixture, the flame stability, as well as ash-related issues. To optimise these parameters, we have had to carry out modifications and experimentation for over a year."*

The trials have been successful. The critical hurdle of co-milling wood pellets with coal has been overcome and the co-fired flame temperature (with 10-20 percent wood pellets) is close to that of pure coal firing. Fouling and slagging characteristics have been favourable and the deposits can be cleaned easily. Morever, as was expected, the co-firing flue gas emissions contain less NO_X and SO_2.

BHEL is now exploring taking these trials to the next level. S Arumugam, the Additional General Manager at Coal Research says: *"After the successful demonstration of biomass co-firing, we now have the confidence of demonstrating the technology in a larger power plant. The real benefit comes when it is done in a larger power plant. We have been talking to our customers. We are looking for a customer with a 210 megawatt capacity where we can feed the biomass along with the coal and generate power."*

OXYFUEL COMBUSTION

Air has a high (78 percent) content of nitrogen. During combustion with air, most of this nitrogen passes through the process unchanged, with only a small fraction being converted into oxides to form NO_x gases. A typical power plant exhaust gases contain about 75 percent nitrogen, which must be removed to create a CO_2 stream for storage. This separation is energy-intensive and expensive.

Oxyfuel combustion significantly changes how the combustion is conducted. It uses oxygen instead of air, thus eliminating nitrogen from the oxidant gas stream and producing a CO_2-enriched flue gas. This flue gas is ready for storage after the water has been condensed and other impurities have been separated out.

Oxyfuel technology has been developing steadily since the late 1990s. Pilot-scale oxyfuel demonstrations have so far confirmed that plant operations can be effectively switched from air-firing to oxyfuel firing and a highly enriched CO_2 flue gas produced for transportation and storage (box 6.2). Moreover, the process results in a significant reduction in NO_x emissions.

Another significant advantage of Oxyfuel combustion is that it offers possibilities of retrofitting the existing fleet of modern pulverised coal-fired power plants for CO_2 reduction.

DEMONSTRATION: OXYFUEL COMBUSTION AT BHEL

Once again, the tests have been carried out at the Coal Research Centre's Solid Fuel Burning Test Facility. One challenge was to design the burner. S Arumugam, Additional General Manager, Coal Research explained: *"Based on what we had learnt during the training programmes and our internship visits, we could make a good burner. A special burner is required for oxyfuel combustion and it has to be made with high quality materials. The burner has been made and retrofitted."*

BOX 6.2
OXYFUEL COMBUSTION: DEMONSTRATION PLANTS

In September 2008, Vattenfall commissioned a 30-megawatt pilot facility on the site of the Schwarze Pumpe lignite power plant in Brandenburg, Germany.

In December 2011, CIUDEN announced it had successfully tested oxyfuel combustion in a 30 MW boiler built at Cubillos de Sil in Spain. By October 2012, it had conducted the full CO_2 capture process and planned to upscale the technology to 323MW by the end of 2015.

In March 2012 CS Energy carried out successful oxyfuel firing trials as part of its Callide project in central Queensland, Australia. This project retrofitted a retired 30 MWe coal-fired power plant for the trials. The first stage of the project involves CO_2 capture while stage two will include the transport, injection and storage of captured and liquefied CO_2. Results from the project will be used to inform how the technology can be applied at new power stations.

In Germany, Vattenfall had planned for a 250 MW fully integrated oxyfuel combustion project at Jänschwalde. This project was cancelled during 2012 for reasons mainly associated with the lack of political support for the project's proposed geologic storage.

China Datang Corporation and Alstom have announced their intention to commence feasibility studies for a 350 MW oxyfuel combustion plant at Daqing. A final investment decision is planned for 2015.

In addition, a cyclone assembly has been fitted to remove ash particles from the exhaust flue gas. A heat exchanger was added to cool the flue gas and an induced draft fan installed to pump flue gas into the burner along with oxygen. The project has had to mount a probe system in order to measure the heat flux so that it could be compared with the one for conventional firing. An oxygen transportation line has been integrated as has been a cooling water line for supplying water to the heat exchanger and heat flux sensor. Dampers and orifice plates were fabricated and installed in order to control and monitor the exhaust flue gas.

Extensive tests using this trial apparatus have been carried and once again, the results have been encouraging. Successful recirculation of the flue gas from the chimney has been achieved as has been the transition from air-coal combustion to oxy-coal combustion. NO_X and SO_2 emission levels have been quantified for the purpose of comparisons and the optimum flue gas circulation for a favourable flame temperature determined.

What needs to be emphasised is that while a lot of design work was carried out based on academic reports and research papers, important insights that were obtained during the learning trips proved to be indispensable. Sivaji Seepana, one of the three interns actively involved with the projects, recalls: *"During the tour, we had met Robin Irons from E.ON, a major power plant player. He made two important suggestions for oxyfuel combustion. One was to circulate the air through the recycled flue gas ducting after completing the experimentation to prevent cold corrosion. The other suggestion was to remove the moisture in flue gas that was to carry the coal to the burner. We have implemented these two suggestions at our site and they have been very useful for our tests."*

7
INCUBATING CLEAN TECHNOLOGY VENTURES

After all, smaller companies are able to take big risks, challenge traditional thinking and innovate quickly without bureaucracy getting in the way.

INCUBATING CLEAN TECHNOLOGY VENTURES

The EU TREC-STEP BHEL CCT programme had, as a starting point, launched a cluster hub for the thermal power sector and allied industries. This had led to the creation of a robust international network for sharing knowledge related to climate change and CCTs. Participating in this intensive knowledge diffusion process were professionals, academics, researchers as well as entrepreneurs who had launched their own small and medium enterprises (SMEs) and start-ups. SME associations that had participated actively included the Tiruchirappalli District Tiny and Small Scale Industries Association and the BHEL Small and Medium Industries Association.

The programme had chosen to stress the importance of startups. After all, smaller companies are able to take big risks, challenge traditional thinking and innovate quickly without bureaucracy getting in the way. Indeed, there is growing evidence that start-ups are important agents for what has come to be known as disruptive innovations[1].

This is why the programme had a dedicated component for supporting and handholding a small number of start-ups that had their crosswires set on clean technologies.

LOCATING CLEAN TECHNOLOGY VENTURES

The programme organised a number of interactions with reputed universities and research organisations[2] in order to identify clean technologies that could be supported in their commercialisation. It also scanned the inventory of innovative ideas identified by the

[1] Disruptive innovation is the introduction of new technologies, products or services in an effort to promote change and gain advantage over the competition. The Harvard Business School professor Clayton Christensen is noted for popularising the term in his book The Innovator's Dilemma.

[2] The Centre for Climate Change and Adaptation Research and the Centre for Environmental studies at Anna University, Chennai; Centre for Nano Technology and Nano Science, Centre for Bio-organic Chemistry, Centre for High Pressure Research and Centre for Geographic Information Technology, Bharathidasan University; University of Madras; Alagappa University; Madurai Kamaraj University; and Periyar Maniammai University, among others.

Department of Scientific and Industrial Research. Discussions with the Department of Science and Technology and the Indian Institute of Management's Centre for Incubation, Innovation and Entrepreneurship further helped the programme to access a database of 569 innovative venture ideas. TREC-STEP also placed advertisements in leading newspapers asking entrepreneurs with clean technology ideas to apply for support.

Entrepreneurs who applied had their proposals shortlisted and then evaluated by a selection committee which focused on attributes like the innovativeness, the cleanness of the technology, its commercial viability, the suitability of its incubation at TREC-STEP, and the entrepreneurs experience and profile. Finally, five enterprises were chosen for seed fund support and incubation.

AEYYES TUNGSTEN: RECLAMATION OF TUNGSTEN CARBIDE SCRAP

Tungsten carbide is a very hard compound used extensively for making cutting tools. The compound is very expensive and is in great demand. Consequently, a lot of tungsten carbide scrap is invariably recycled. The chemical process that is used normally is expensive and polluting: it releases effluents and a lot of CO_2 into the atmosphere.

A Jayakannan who started Aeyyes Tungsten, came up with the idea of reclaiming tungsten carbide using a new 'sequential thermo-mechanical process'. The process, as he conceived, would not only be cheaper but would also release less effluents and CO_2.

Jayakannan started large scale production with the help of some seed fund and incubation support from TREC-STEP. The process is indeed cheaper and cleaner, and the final product is as good as the one made by the chemical process. Aeyyes Tungsten has already supplied 800 mining tools for Neyveli Lignite Corporation and more orders are expected soon. Meanwhile, Jayakannan has patented the process in China, South Korea, USA, Russia and India.

BHARATH AGRO PRODUCTS: STRAW COMBINE THAT CAN PULVERISE BIOMASS

Prosopis Juliflora is a small tree that grows extensively in India where it is known as Vilayati Babul. Estimates are that nearly 62.4 million tonnes of Juliflora wastes are

discarded and burnt in the open in India every year. At present, there is no mechanism to collect and use this valuable biomass as a source of energy.

Based on the data available from a study by the Bangalore-based Centre for Interdisciplinary Studies in Environment and Development, Kannappan and Panneerselvam had estimated that Juliflora wastes had the potential to generate around 6000 MWe of power.

The duo came up with a design of a 'straw combine'. This machine is a tractor-mounted pulveriser capable of collecting and grinding Juliflora and other biomass wastes. The EU TREC-STEP BHEL CCT programme provided the support for them to design and fabricate their straw combine. Bharath Agro Products now sells this machine to farmers and young entrepreneurs in the state of Tamil Nadu.

GALAXY RESEARCH TECHNOLOGIES: HOLLOW FIBRE WATER PURIFICATION SYSTEMS

V Swaminathan of Galaxy Research Technologies has developed a new process for the production of hollow fibre membranes suitable for cost-effective water and gas purification. This technology has many advantages as it is more effective and reliable while being less expensive. Moreover, it has a lower environmental impact compared to its peers. This same process can also be used in water purification for many industrial applications in sectors like textiles, electronics, food processing, pharmaceuticals and power. The other important aspect of this membrane technology is that it could offer less energy-intensive CO_2 capture possibilities. The venture has already entered the market with its products for water purification. It is currently in the process of patenting this unique filtration process.

CONTURA SOLAR: INDIGENOUS SOLAR ENERGY SOLUTIONS

The Indian solar photovoltaic industry is witnessing a rapid growth, largely on account of the government's Jawaharlal Nehru National Solar Mission. India is targeting a generation of 67,000 MWe by way of solar power by 2022. The power policies of the various states like Tamil Nadu, Gujarat and Rajasthan are also expected to create significant demand for the solar power industry.

Contura Solar aims to provide cost effective solar energy solutions specialising in photovoltaic technology. The venture has developed innovative solar roof tops; solar mobile generators; solar charging stations for electric vehicles and battery charging; and lighting and deep freezer systems for fishing trawlers. Arun Rebero, the entrepreneur, feels the need to focus on water-resistant applications and to design for long life, less energy losses, and higher system efficiency. The enterprise has made presentations to the Neyveli Lignite Corporation for supplying solar products to their power plants.

RINUJA HI-TECH BIO-POWER: FUEL ADDITIVE

Abdul Aziz's venture has invented an additive for petrol or diesel. The formulation, made from various plant oils, improves fuel economy and engine performance while controlling pollution. It has been tested and analysed by research institutions like the Thyagaraja Engineering College, Madurai and the Agricultural University, Coimbatore.

A number of studies have now shown that the fuel additive reduces smoke emission by around 75 percent, engine sound by 35 percent, and carbon compounds in the emitted smoke by 70%.

The demand for the fuel additive has been growing and a network of over 30 agents now sells this product in different parts of Tamil Nadu.

8
IN RETROSPECT

The EU TREC-STEP BHEL CCT Programme was the first of its kind in India in that it successfully diffused CCT-related knowledge on a large scale.

IN RETROSPECT

Sea levels are rising and there is increased coastal flooding. Heat waves are becoming more common as are extreme storm events. And as more severe droughts occur worldwide, seasons are witnessing clear changes.

There is a broad consensus in the scientific community that global warming, which is already having a significant affect on our environment and our communities, is a reality. Further, it is convinced that this catastrophic process, a result of human activity, must be reversed by lowering greenhouse gases (GHG) emissions.

Coal is the most polluting of all fossil fuels and the largest single source of global warming pollution in the world. However, countries are not likely to stop using coal. After all, coal is one of the cheapest ways of generating power. In America, Australia, China, Germany and India, it provides half or more of the power supply. Moreover, governments prize such a secure domestic source of energy at a time when oil and gas prices are unpredictable and forever rising.

Countries like India need to grow fast and pull millions out of poverty. That is why the country is ramping up its thermal power generation. Yet, addressing climate change is an important agenda for the country. India has made a commitment that it will reduce its emissions per unit of GDP in 2020 by 20 to 25 percent below 2005 levels. In 2008, the country released a National Climate Change Action Plan (NAPCC) which led to eight national missions: the National Solar Mission, the National Mission for Enhanced Energy Efficiency, the National Mission on Sustainable Habitat, the National Water Mission, the National Mission for Sustaining the Himalayan Ecosystem, the National Mission for a "Green India", the National Mission for Sustainable Agriculture and the National Mission on Strategic Knowledge for Climate Change.

India has also accelerated its clean coal technology (CCT) programme. CCTs represent a range of technologies that improve the environmental performance of coal-based electricity plants. These technologies include equipment that increases the operational efficiency of power plants, as well as those that reduce emissions.

Carbon Capture and Storage (CCS) is the newest and the most promising CCT. It entails isolating CO_2 in plants and storing it so that it will have no impact on the environment. However, CCS is very expensive. As a result, emerging economies like India, will find it difficult to earmark its scant resources for this technology. Yet the country needs to have a level of preparedness.

This is the context in which TREC-STEP, a pioneering science and technology entrepreneurs park, initiated a programme, "Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector". This programme, funded by the European Union, was partnered by BHEL, India's largest power plant equipment manufacturer.

PROGRAMME OUTCOMES

The EU TREC-STEP BHEL CCT Programme was the first of its kind in India in that it successfully diffused CCT-related knowledge on a large scale (box). Moreover, for the first time, BHEL, a leading power plant equipment manufacturer was able to explore two vital CCTs concretely and gain critical insights. Then, by creating a team of young interns, the programme made sure that professional expertise would be readily available when Indian policy planners do move aggressively towards CCTs in the future. Finally, it demonstrated that start-ups could be invaluable agents for fostering innovations in the clean technology domain and commercialising them.

Summarised below are the important outcomes:

1. The programme launched the first Indian cluster of thermal power players and organised a number of cluster meetings. By doing so it brought together more than 250 professionals, academics, researchers and policy planners. The programme also got in touch with over 35 institutions in the developed countries and sought their cooperation for planning and executing the programme.

2. The programme created a knowledge exchange web platform which provides the latest updates on developments in the field of CCT. It is a vehicle which allows users to access more than 100 reports and articles, over 40 videos and animations of CCT demonstrations, and interviews with experts. Moreover, the website hosts over 20 hours of training programmes implemented by the TREC-STEP.

3. Three important studies were published in the programme period. These reports, all prepared by specialists in their respective fields, covered the potential for CCT and CCS in India, mercury emissions and health hazards, and chemical looping combustion technology.

4. Four training programmes and an international conference equipped a wide spectrum of thermal power professionals, academics, students, researchers and policy planners with the latest in CCT-related knowledge. Around 550 people participated in these programmes. The sessions were conducted by more than 25 professionals and researchers from leading power sector players and advocacy institutions. These events were also important opportunities for Indians to network with their peers from the developed economies.

5. Two learning tours and one internship visit to modern coal-fired plants, demonstration projects and universities in EU countries were organised. Participants in these learning tours included senior BHEL professionals and interns created specially for the programme. The tour gave the visitors a chance to see the latest technologies deployed and a number of demonstration projects which operate at the frontiers of CCT. Their meetings with a wide range of professionals, researchers and policy planners helped them grasp not only a wide range of technical issues but also larger policy-related ones.

6. As a part of the programme, BHEL executed two CCT demonstration projects. Successful trials with biomass co-firing and oxyfuel combustion provided the enterprise with an invaluable experience. The BHEL Coal Research Centre professionals, in the course of designing and rigging the pilot plant, got a thorough understanding of the technologies, confronted a range of challenges and learnt how to overcome them. These trials and the experience gained will be of direct benefit to the country when its policy planners do chose to pursue CCT more aggressively.

7. Recognising that start-ups have an inherent capacity for being dynamic and innovative, the programme provided support to five such enterprises which wanted to explore clean technologies. The seed capital and infrastructure support provided by the programme have helped these enterprises reach a level of maturity and profitability.

A SUCCESSFUL PROGRAMME

One thing we must understand that the first step in this project was to create awareness and take it forward through various methods. Secondly, we wanted to demonstrate oxyfuel combustion and biomass co-firing which we have been able to successfully do. With this, the basic objective of this project has been met and we are going to take it forward, both at the BHEL R&D division and also through any further programme that may get initiated by TREC-STEP and the European Union.

AV KRISHNAN, Executive Director, BHEL, Tiruchirapalli

This is the first initiative of its kind in India as far as CCT and CCS are concerned. It has prepared an army of young engineers and equipped them to fight climate change. Secondly, this project has created a unique partnership, a platform between Europe and India to fight climate change. Thirdly, it has generated a lot of interest and enthusiasm for launching new projects in CCT and CCS . Fourthly, we have developed the capacities of young engineers and have brought together research centres, universities and industries so that they can work together on climate change problems.

RMP JAWAHAR, Executive Director, TREC-STEP

Meanwhile, it may be helpful to take a pause and go back to Lohachara, the island that was swallowed up by the Indo-Gangetic deltaic waters over twenty five years ago. In same area is Ghoramara, another island which has now been witnessing frequent flooding. The local government has once again taken steps to protect the islanders by constructing an embankment all around the island.

Such embankments, well-meaning as they are, can only offer temporary relief. They will not help protect the livelihoods of the 170 million people who live along India's 7,500 Km-long coastline. But by applying knowledge and technology, we may be able to check the rise in sea levels. That is why more initiatives like the EU TREC-STEP BHEL are so very critical for a safer world for all.

ANNEXURES


TREC-STEP
International Training Programme on
Clean Coal Technologies and Carbon Capture and Storage

ANNEXURE I
Sessions: Training Programmes

BUILDING AWARENESS: Sessions during the training programme, "Introduction to CCS and CCT" conducted on 21 and 21 December 2011

- **Climate Change and Context Setting**
  Climate Change
  Global Regulations and Initiatives
  Economic Impact of Global Change – Local and Global
  CCS and its Relevance for Global Impacts
  Future Implications and Road Map
- **CCS-Technology and Innovation**
  CCS-Summary of Technologies
  Key CCS Technologies
  Key Players and the Marketplace
  Future of the Technology
- **CCS Policies**
  Rules and Regulations around CCS
  Global CCS Policies – Status and Critical Synthesis
  CO_2 Pipeline and Regulations
  International Negotiations on CCS in UNFCCC
- **Clean Coal Technology and CCS**
  Clean Coal Technology
  Future CCS-Ready Power Plants
  Cost Economics of CCS in Relation with Power Plants
  Indian Perspective on CCS and the Power Sector

BUILDING AWARENESS: Sessions during the training programme, "Climate Change, Clean Coal and Carbon Capture" conducted on 27 and 28 August 2012

- Climate Change Challenges and the Thermal Power Industry
- Introduction to Thermal Power Sector and Systems
- Coal mining, Cleaning, and Usage
- Pulverised and Fluidised Bed Combustion Systems
- Super Critical / Ultra Super Critical / Advanced Super Critical Technologies
- IGCC Technology
- Oxyfuel Combustion, Carbon Capture and Storage-an Introduction

LEVERAGING SKILLS: Sessions during the training programme, "Technologies for Carbon Capture, Transport and Storage and Cleaner Coal" conducted from 23 to 25 January 2012

- CCS Overview
- CCS Value Chain
- CO_2 Capture
- Oxyfuel Combustion and Precombustion Capture Systems
- Gasification, Adsorbtion and Emerging Technologies
- Environmental Monitoring, Risk and Legal Aspects of Capture Systems
- Transporting CO_2
- Storage of CO_2
- Clean Coal Technologies
- Clean Coal Technology in Power Plants

LEVERAGING SKILLS: Sessions during the training programme, "International Training Programme on Clean Coal Technologies and Carbon Capture and Storage" conducted from 31 October to 3 November, 2012

- Clean Coal Technologies Worldwide
- Outlook for Coal-fired Power Generation – Policy and Technology Needs
- Clean Coal Technology Developments in India – BHEL Experience Sharing
- Clean Coal Technology Promotion In India – European Business and Technology Centre, India
- Ways of reducing accounted CO_2 emissions in coal fired power plant which can precede and facilitate the adoption of CCS
- IGCC Technology and CCS Demonstration - ELCOGAS Experience Sharing
- Oxyfuel combustion Technology Developments - Doosan Power Systems: Experience Sharing
- "Green Power" Carbon Capture Utilisation, Storage (CCUS) Technology – Siemens: Experience Sharing
- Carbonate and Chemical Looping in Power Plants
- Potential for Geological Storage of CO_2 in India

ANNEXURE 2
First learning tour: the institutions

Schwarze Pumpe Power Station, Spremberg, Germany

This power plant built by Vattenfall, has an important historical significance from the CCS point of view. For it is here that the first ‘carbon dioxide-free’ system started functioning from the middle of 2008. The purpose of the 30 MW pilot plant here is to learn and better understand the dynamics of oxyfuel combustion and to demonstrate the capture technology.

CO_2 Sink, Ketzin, Germany

Ketzin is located to the west of Berlin. It is here that the GFZ German Research Centre for Geosciences operates Europe’s longest- running on-shore CO_2 storage site. The main objective of the Ketzin project is to monitor the migration behavior of the injected CO_2 and gather data for simulation exercises. It is also demonstrate to governments and the public that storage options for CO_2 are safe.

Siemens Energy Sector, Fossil Power Generation Division, Germany

The team had the privilege to see their first post combustion facility here. The members were also able to grasp the various CCTs being explored and developed by Siemens.

RWE Coal Innovation Centre, Niederaussem Power Plant, Germany

The team was able to see several generations of technology development of coal-fired technologies at the Coal Innovation Centre here.

The British Geological Survey and the National Centre for Carbon Capture and Storage (NCCCS), Nottingham, UK

The team got a detailed summary of the research done on carbon capture including the static modeling of UK’s storage capacity and the surface gas and biological monitoring carried at the In Salah Gas project (Krechba, Algeria) where geological storage of CO_2 has been underway since mid-2004. The team was also able to learn about a technical study carried out on the potential for CO_2 storage in the Indian subcontinent.

The Ferrybridge Carbon Capture Plant, Yorkshire, UK

This plant is a result of a partnership between SSE (Scottish and Southern Energy), the owner and operator of the power plant, Vattenfall, and Doosan Babcock, the carbon capture technology supplier. In this pilot plant, 100 tons of CO_2 per day is captured from a flue gas slipstream corresponding to approximately 5 MW of electric power.

The Doosan Power Systems' Renfrew test facility, Glasgow, UK

In July 2009, Doosan Babcock began operating a 40MW oxyfuel burner test rig which had been designed to test its oxyfuel combustion capture technology on pulverised coal. The test programme was successfully completed in early 2011, after which it was concluded that the technology could be used at commercial scale.

ANNEXURE 3
Second learning tour: the institutions

Amer Power Plant, Geertruidenberg, the Netherlands

The Amer power plant in Geertruidenberg in the Netherlands was of particular interest to the team members because it uses biomass. The plant has been experimenting with different kinds of biomasses like wood pellets, citrus pellets, palm kernel chips, olive residue and coffee husk. Today, the plant uses a maximum of 35 percent by weight of biomass.

Maasvlakte Power Station near Rotterdam, the Netherlands

The team visited Maasvlakte where E.ON is building a state-of-the-art 1.1 GW coal-fired unit. Currently in the test phase and scheduled to enter service in 2013, the new unit will be 20 percent more fuel-efficient. Estimates are that it will emit 1.2 million metric tons less carbon dioxide annually than a typical coal-fired unit.

Lünen Power Plant, Germany

The Lünen coal-fired power plant has an installed electrical capacity of 750 megawatts. With an efficiency of almost 46 percent, Lünen saves up to a million ton of CO_2 every year.

Datteln Power Plant, Germany

The Datteln coal-fired plants have supplied electric power for the railway system and district heat for the municipality of Datteln since 1964. Datteln 4 will replace some very old power plants such as Datteln 1-3. Datteln 4 has been designed to operate at an efficiency of around 45%.

IEA, France

The visitors learnt about a range of High Efficiency Low Emission (HELE) technologies that are going to play a crucial role in reducing CO_2 emissions in the time to come. What the members also understood with great clarity was that while the individual component technologies of CCS are generally well-understood, there are strong hurdles that prevent the establishment of large CCS-equipped coal-fired plants. In order to overcome these challenges, governments need to put in place robust policies (box).

POLICIES NEEDED TO GET CCS GOING

Seven key actions required over the next seven years for enabling the wide deployment of CCS:

- Introduce financial support mechanisms for demonstration and early deployment
- Develop laws and regulations that effectively require new power plants to be CCS-ready
- Significantly increase efforts to improve understanding among the public and stakeholders of CCS technology
- Implement policies that encourage storage exploration, characterisation and development for CCS projects
- Reduce the cost of electricity from power plants equipped with capture through continued technology development
- Prove capture systems at pilot scale in industrial applications
- Encourage efficient development of CO_2 transport infrastructure

ANNEXURE 4
Details of the Internship visit

Imperial College, London

The interns interacted with a number of faculty members and learnt about their work in the area of CO_2 removal using chemical looping, biomass pyrolysis, oxyfuel combustion as well as techniques used in capturing CO_2 from the flue gas using solvent absorption. They visited the Centre for Process Systems Engineering's Chemical Engineering Laboratory to see the experimental test facility of post combustion CCS which captures 1.2 ton/day.

Edinburgh University

The interns were able to attend a workshop on CCS in industries. During this workshop, they interacted with experienced researchers and professionals from the Department of Energy and Climate Change, Government of UK, Johnson Matthey, Progressive Energy, Air Liquide, National Grid and the UK Carbon Capture and Storage Research Centre.

The Scottish Government Office, Glasgow

The team got the opportunity to interact with Collin Inrie from the Directorate of Energy and Climate Change who explained how the government has set up a roadmap to make CCS an important parameter in the country's future energy supply. In this endeavour, the department works with a wide range partners which includes the private sector, academia, and the EU institutions.

Howden Global, Renfrew

The interns were able to learn about the company's new technology for post combustion capture of CO_2. Called Veloxotherm, this process used an innovative separation process implemented in a rotary adsorption machine. Howden is collaborating with Doosan, InventyS, BP and Shell in putting up a 5 MW plant in Canada using this rotary adsorption technology.

University of Newcastle

The interns learnt about the university's work in the area of CO_2 transportation to storage sites. A project at this university has brought together a team of scientists and engineers from Newcastle University, Cranfield University, University of Edinburgh, Imperial College of London and the University of London. This team is working on specifications for fracture control, effect of impurities in pipeline manufacture, and parameters for preventing cracks and material degradation.

University of Leeds

The team was able to visit the Pilot Scale Advanced Capture Technology (PACT) facilities here. They were explained about 250 kW oxyfuel combustion experimental facilities and the post combustion CO_2 capture facility using amine scrubbing. They also understood the University's process modeling studies and a techno-economic assessment for different combustion technologies.

University of Nottingham

The interns understood the working of the university's post combustion CO_2 capture facility which uses adsorption technology. They visited the bubbling fluidised bed combustion test facility which uses biomass as fuel and where the syngas is cleaned using solid adsorption technology. Researchers at the university explained the results of their 20kW oxyfuel combustion investigation.

Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector

REPORT, 2014

TREC-STEP

TREC-STEP
Thuvakudi
Tiruchirappalli - 620 015
Tamil Nadu, India

Website: www.trecstep.com
Email: jawa_ts@yahoo.com

Research and design: Partha Sarkar
macro114@yahoo.com

Design execution: Jata Shanker Dubey

Developing a Cluster for Clean Coal Technologies and Carbon Capture and Storage Technologies for the Indian Thermal Power Sector

Project website: www.carboncap-cleantech.com

EUROPEAN UNION

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Delegation of the European Union to India,
65 Golf Links
New Delhi - 110 003
Tel : 011 - 24629237
Fax : 011 - 24629206

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A Project Implemented by

Tiruchirappalli Regional Engineering College - Science and Technology Entrepreneurs Park
Thuvakudy,
Tiruchirappalli - 620 015
Tel: 0431 - 2500697, 2500085
Fax: 0431 - 2501681, 2500175