Indian National Academy of Engineering

Department of Science and Technology
Government of India

INAE - DST Round Table on

CLEAN COAL TECHNOLOGIES IN INDIA: CURRENT STATUS, DEMANDS AND ASPIRATIONS – PATHWAYS TO ACHIEVEMENTS

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Foreword

Secretary, DST requested INAE to organise a review on the current status of Clean Coal technologies in the country, the gaps if any and identify the thrust areas of research which could be considered for funding. In response, INAE and DST jointly organised two Round Table meetings on "**Clean Coal Technologies in India: Current Status, Demands and Aspirations – Pathways to Achievements"** on June 10, 2016 and Oct 26, 2016 at Delhi. The objective of the first-round table was to examine the current status of clean coal technologies in the Country, to identify the technology gaps, to suggest thrust areas for future R&D efforts and to define the way forward. Dr Baldev Raj, Past -President, INAE and Director, National Institute of Advanced Studies (NIAS), Bangalore, a domain expert in the field was requested to prepare a base paper and also to Chair the INAE-DST Joint Initiative on Clean Coal technologies. The domain experts who have specific experience in the area of clean coal technologies from R&D centres, industry from all over India, Government and INAE Fellows were invited for the first meet and detailed presentations and discussions were held.

Based on the suggestion from Dr R Chidambaram, Principal Scientific Adviser to the Govt. of India, who inaugurated the Round Table meet, INAE undertook the task of preparing a comprehensive report highlighting the specific areas, gaps, and further actions needed to bridge the gaps, including the identification of research areas where further funding can be considered. Accordingly INAE requested the experts to prepare a detailed write ups on the topics identified during the Round Table. INAE is very happy to receive the overwhelming response from all specialists and a final comprehensive report was prepared. This final report was discussed in the second round table meet and a total of about 11 proposals were accepted for submission to DST. Details of the proposals covering the background, timeframe, cost aspect and participating agencies were sought by all the identified specialists for onward submission to DST. The proposals so received were reviewed again with Dr. Baldev Raj in the Chair to prioritise the proposals and it was recommended that all the 11 proposals merit the funding.

Accordingly, all 11 final proposals were submitted to DST for further consideration and funding through their appropriate mechanisms.

On behalf of Indian National Academy of Engineering (INAE), I have great pleasure to present the comprehensive report "**Clean Coal Technologies in India: Current Status, Demands and Aspirations – Pathways to Achievements".** I express my sincere thanks to all the experts who have devoted their valuable time and efforts in contributing to this report. I also express our sincere gratitude to all the experts who participated in the Round Table meetings and made significant contributions for the fruitful outcome. Words cannot express my gratitude to Dr Baldev Raj, Immediate Past -President, INAE for his untiring efforts and meaningful contributions in leading this initiative and steering all activities at every stage of planning and execution.

I am extremely happy that the joint efforts of INAE and DST has given the positive results and look forward to have such joint initiatives in future for the benefit of the Nation. I am confident that this report would provide very valuable inputs to all the concerned experts in the area of Clean Coal technologies and look forward to extend the necessary assistance to take this INAE-DST initiative on Clean Coal technologies further.

Dr BN Suresh
President
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Preface

It has indeed been a pleasure, privilege and valued duty for me to Chair the INAE-DST Initiative on Clean Coal Technologies, on the invitation, of Dr BN Suresh, President, Indian National Academy of Engineering (INAE). I would like to give a brief background about the genesis of this designed activity. Department of Science and Technology (DST) desired to invite research proposals to be undertaken in the area of Clean Coal Technologies; the current thrust area of the Government. DST requested INAE to convene a meeting of experts from INAE, R&D, industry and Academia and enable identification of the thrust areas of research, institutes, individuals, organizations, etc in Clean Coal technologies for funding of projects. While looking at the mandate given by Secretary, DST, efforts were made to assemble credible experts from R&D, Academia and industry related to the field of clean coal technologies which can have dialogue and have a mindset to contribute in a significant manner. Accordingly, INAE identified suitable experts and conducted two meetings on Clean Coal technologies on the topic "**Clean Coal Technologies in India: Current Status, Demands and Aspirations – Pathways to Achievements**" on June 10, 2016 and Oct 26, 2016 at New Delhi. Prior to the first Round Table, an approach paper was prepared which was circulated to the select participants of the Round Table and their views were sought to enrich deliberations during the planned Round Tables. The first-Round Table meeting was attended by about 35 domain experts from Industry, Academia and R&D centres. The proceedings validated our conviction that we had identified a right combination of delegates who represent all facets of coal from mining, beneficiation, combustion technologies, flue gas capture and other promising technologies. All of us were convinced that their contributions would be valuable in reaching the desired objectives.

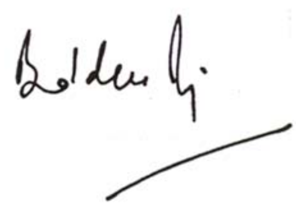
The objective of the Round Table was to examine various aspects of clean coal technologies and identify the technology gaps with respect to national context and suggest thrust areas for R&D efforts. Also, to suggest a way forward for R&D for clean coal technologies. During this meeting, the experts deliberated on the current status of the technologies available in India vis a vis the current international status of Clean Coal technologies; so as to arrive at the gaps which need to be addressed, on priority. Based on the deliberations in the first Round Table, the areas requiring chosen R&D and the experts to undertake the studies were identified. During the final session of the workshop, it was also decided to prepare a comprehensive document highlighting the specific domains of high interest, gaps and further actions needed to bridge the gaps, including the identification of research proposals where further funding can be considered. The specialists were also identified to prepare status reports. The reports have since been obtained from the authors on the topics identified during the first Round Table.

During the second Round Table meeting held on Oct 26, 2016 at New Delhi, the papers prepared by the authors were discussed and suggestions were invited for suitable research proposals emanating from the inputs; for giving inputs to DST for consideration to fund the projects. The meeting was attended by 25 invited experts in the area of Clean Coal technologies. During this meeting, a total of 11 proposals were discussed. Further the research proposals incorporating suggestions of the second round table were examined at length and approved for submitting to DST for consideration during a meeting on November 19, 2016, at NIAS, Bengaluru, The research proposals were recommended to DST by an Expert Committee appointed by President, INAE.

I am delighted to present a comprehensive report based on the papers prepared by the speakers. I thank authors with gratitude for their valuable contributions and immense efforts. The success of this initiative is attributed to synergistic efforts of all the concerned specialists and experts from Academia, Industry and R&D and also Fellows of INAE working in the field of Clean Coal technologies. The participants have worked as a team with enthusiasm, and have enabled INAE in carrying this initiative to its fruition. Such joint efforts at a national scale are indeed laudable and this exercise serves as a model that needs to be emulated and replicated in other areas of engineering and technology to the country.

We have demonstrated that INAE can create and work with national teams of high merit to deliver tangible outcomes with mandated objectives. I earnestly believe that this comprehensive report covers important facets of Clean Coal technologies and shall be value the experts and policy makers. We look forward to the sustained participation and contributions of all the experts involved in the two Round Tables and Expert Committee in the next phase of activities to realise national goals and priorities in clean coal technologies.

My gratitude and thanks to President, INAE, Dr BN Suresh and Secretary, DST, Prof. Ashutosh Sharma for giving me an opportunity to serve the country**.**



Dr Baldev Raj,
Chairman, INAE-DST Round Table on
"Clean Coal Technologies in India: Current Status,
Demands and Aspirations – Pathways to Achievements"

INAE-DST Meeting on Clean Coal Technologies

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Clean Coal Technology: Current Status, Priorities and Implementation Strategies in Mining

Prof DC Panigrahi and Prof RM Bhattacharjee

India is endowed with huge coal resource of over 301 billion tonnes and is the third largest producer. Currently about 69 % of power generation in India is coal based. Most of India's coal production
(+ 90 %) comes from public sector undertakings such as Coal India Limited (CIL) and Singareni Collieries Company Limited (SCCL). In order to achieve sustainable development, our per capita energy consumption must increase 5 to 8 times over medium to long term. India does not have option to choose energy form for its development and need to harness all forms of energy such as hydro, renewable, coal etc.

Owing to its origin, Indian coal, by and large, is considered of poor quality in terms of impurities such as high ash content leading to poor heat value per kg. Calorific values of Indian coal range from 3000 kcal to over 5000 kcal per kg and ash % ranges from 25 – 55 %. Because of nature of non-homogenous mix, Indian coal is also difficult to wash beyond a certain limit which is causing huge amount of generation of ash after burning. The ash in Indian coals is mostly high in silica and hence, abrasive. This requires careful adoption of appropriate technology while doing mining as ash percentage further increases due to inefficient mining practices.

Clean Coal Technology (CCT) is defined as technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use. International Energy Agency (IEA) has identified the following groups of CCTs during various stages of coal life cycle;

- Coal upgrading (Mining)
- Efficiency improvements of existing power plants
- Application of Advanced Technologies
- Near-zero emission with potential to dramatically reduce GHG emission.

The first step towards utilization of coal is "Mining". The country needs to upgrade its mining practices to produce coal efficiently and in a sustainable manner. India must not only produce the required quantity of coal efficiently, but also ensure the that the impact of mining is minimal on the environment and at the same time, quality of coal produced is suitable for achieving desired efficiency and effectiveness of downstream processes such as Coal Beneficiation, Coal Combustion, Coal Gasification etc. to address our targets of achieving Clean Coal Technologies. Therefore, the efficiency of mining needs to be measured not only with reference to the mine productivity and utilization but also from the perspectives of environment management, energy efficiency and supply of clean and consistent quality coal to the downstream activities.

Depending on the Geology and Scale of operation, mining of coal in India is primarily carried out either by Open Cut or Underground methods. Despite severe environmental challenges associated with Open Cut Coal Mining, geo-mining conditions of Indian coal favours Open Cut Mining for production of Coal at economic cost. Approximately 93 % of India's coal is currently produced by Open Cast Mines. However, from the sustainability point of view, thrust must be given for underground mining as its environmental impact is much less compared to opencast mining. This is also important to accept the fact that the reserves amenable for opencast mining is limited and we have significant reserves of good quality coal in the deeper horizons, which can only be mined by underground method. Until and unless suitable technology is developed or introduced for extracting these deep seated good quality coal in bulk by underground mass production technology in coal mines, the sustainability of coal as a source of energy will be doubtful.

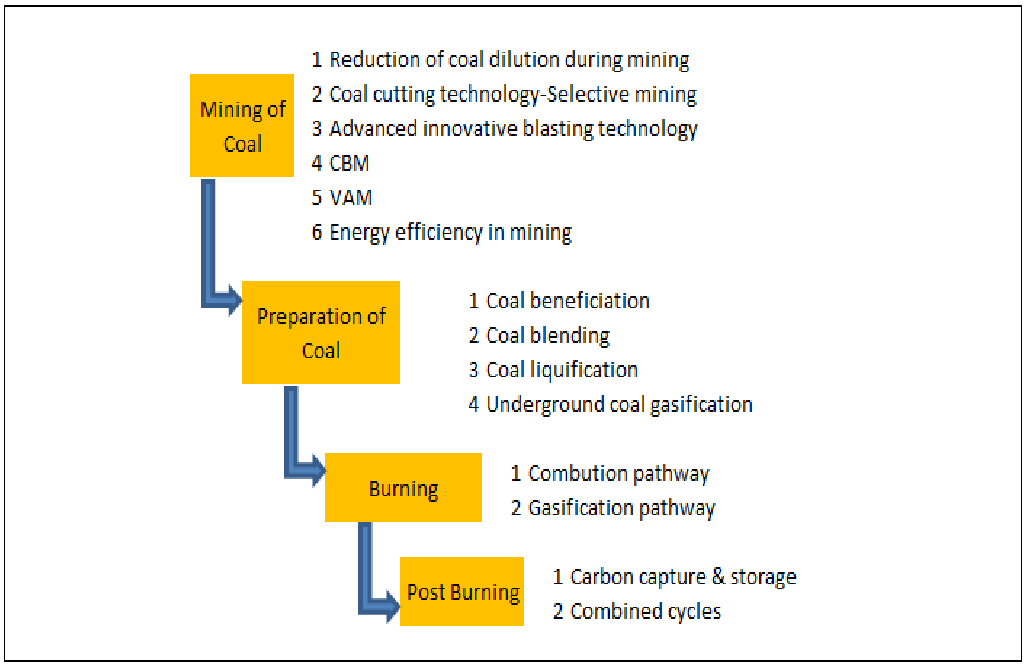

Fig. 1 : CCTs during various stages of coal life cycle

Coal mining has severe impacts on the environment that goes beyond the emission of CO_2, Sulphur dioxide (SO_2), oxides of nitrogen, CO and other gases on burning. This includes the following:

- Mining process generates methane trapped in the coal bed which is having 22 times stronger greenhouse effect than CO_2 and the probable solution can be methane drainage prior to mining which includes CBM, CMM, VAM, underground drainage etc.

- Mine fires in many coalfields of India is another serious issue which needs to be tackled on top priority as it is not only causing the environmental pollution but also makes mining of clean coal unsafe and difficult.
- Dilution of coal quality during mining process –
    - Application of modern mine planning technologies and integration of mine planning with operation.
    - Reduction in dilution of coal quality using selective mining methods such as application of Surface Miner technology for production of coal.
    - Improved drilling and blasting practices to prevent dilution of coal quality due to blasting.
- Energy efficiency in mining operations: At every step of mining operation, from exploration to despatch, energy is used in different forms like electricity, diesel or petroleum products, hydraulic or pneumatic. If the mining operations can reduce the energy consumption per tonne of coal production, it will have a significant impact in the reduction of GHG emission.
    - Energy audit in mining operations
    - Improving efficiency in use of energy for production of every tonne of coal.
- CO_2 Sequestration and Carbon capture and storage (CCS)
- Underground Coal Gasification
- Application of modern technologies for effective environment management
- Integrated Mine Planning and Operation to achieve optimum product quality

Therefore, there is an urgent need to reduce the environmental footprint of coal by increasing Efficiency, Innovation and Control across the entire mining value chain from exploration through to mining, beneficiation and conversion into energy form (combustion, liquefaction, gasification, fuel cells etc.). Needless to say that it requires participation of all stakeholders. If we can deal with these issues, coal will certainly go a long way as primary source of energy in the economic development of the country.

Keeping into considerations the above impact of mining operations towards accomplishing the goal of clean coal technologies, scientific study into the following thrust areas may be undertaken:

1. METHANE DRAINAGE PRIOR TO MINING AND VENTILATION AIR METHANE

In order to extract the deep seated coal deposits, the coal mining industry in India is aiming for increasing the share of underground coal Production to 30% by 2030. Coal mining activities causes the emission of methane gas. Methane is emitted either from the coal seam itself or from other gassy formations underground. The amount of methane generated during the coal mining operations depends on the production of the mine, gassiness of the coal seam and any underlying and overlying formations, operational variables, and geological conditions. The methane gas produced during and after coal mining operations is termed as coal mine methane (CMM). However, methane captured prior to mining is more appropriately termed as coalbed methane (CBM). Emission of methane from coal mines has increased significantly over the past few decades because of higher production, greater comminution of the coal and the trend towards recovery from deep seated coal seams. It is envisaged that in near future, with increasing coal production at greater depths, the quantum of methane emission from coal mines will be more than the present emission.

Methane emitted from the coal mines across the world represents approximately 8% of the world's anthropogenic methane emissions contributing 17% to the total anthropogenic greenhouse gas emissions. It is estimated that by 2020, CMM emissions will increase to a level as high as 793 Mt CO_2e (×1000 tons CO_2 equivalent). Out of all the emission sources, it has been identified that underground coal mining is the most important source of fugitive methane emissions, and nearly 70% of this methane is emitted through mine ventilation air at low concentrations.

Methane is a greenhouse gas (GHG). The millions of cubic meters of methane vented to the atmosphere causes a long term threat to the environment. In addition, the release of methane into mine atmosphere raises concern about the mine safety due to the explosion hazards associated with methane gas. The coal seams before mining may contain 60-95% methane and the gas drained from fractured formations above mined seams and accumulated in gobs may contain 30-95% methane. Keeping the aforementioned challenges in view, efforts should be made to develop, design and implement appropriate methods of mining for more productivity and safety.

Methane is a highly explosive and greenhouse gas. Emission of methane adversely affects both the safety and productivity of underground coal mines as well as surface environment. Limiting its emission to the environment and its gainful utilization are beneficial both in terms of environment protection and making coal mining safe. Methane is also a rich source of energy and coal bed methane is a major source of clean energy. Therefore, methane drainage from the coal seams prior to mining will not only bring down the methane emission in highly gassy mines and minimize explosion hazards therein but also provides an additional source of energy to be utilized in industrial and household purposes. Therefore, the broad objectives of methane drainage may be outlined as follows:

The capturing and utilizing CMM/CBM employing methane drainage technique is the best solution to the problems, which will not only decrease greenhouse gas emission and ensure mine safety but also will provide an additional source of energy which otherwise will be lost. Many mines across the globe are now using degasification system to extract as much coalbed methane as possible from their coal seams before or during mining to improve mine safety and decrease downtime as a result of methane in the mine openings. Degasification methods utilizing methane drainage technique include vertical wells, gob wells, horizontal boreholes and cross-measure boreholes. However, the success of methane drainage technique greatly depends on the geo-technical conditions of the coal seams such as gas content and permeability of the coal seams.

In methane drainage, horizontal boreholes drilled from underground entries or vertical boreholes from surface are drilled into the coal seams. In addition, boreholes are drilled from the surface to the goaf for venting the gob gas. The most important parameters dictating the economic viability of methane drainage are the volume of gas-in-place, porosity and permeability of the coal seams. The methane content of coal seams depends on depth and degree of coalification or rank of coal. High rank coals have higher methane sorption capacity than the low rank coals. Coal with sufficient permeability is the prerequisite controlling parameter for economic gas flow rate and methane production. The permeability of coal is influenced by cleat spacing, which in turn depends on the coal rank and reservoir pressure. Generally, cleat frequency increases with rank of coal. Therefore, it is necessary to collect core samples of coal and do analysis for feasibility of methane drainage technique.

Hence a study of these parameters for Indian coal mines is a pre-requisite for the success of methane drainage in India. However, it is equally important to evolve a suitable technology for Indian geo-mining condition. The study should aim at determining the parameters influencing the capturing of methane from the coal bed and associated strata and also from the goaf from where coal has been extracted and application of suitable methane drainage technique for successful capturing of methane.

The other issue of fugitive gas emission from mine is through Ventilation air methane. As mentioned earlier, nearly 70% of this methane is emitted through mine ventilation air at low concentrations. This emission is for 24x7 for all 365 days in a year. Though the concentration of methane in ventilation air is very low, the quantity of methane emitting into the environment is enormous from each underground mine. Methane of such low concentration is continuously emitted to the environment, increasing the GHG effect. If this low concentration high volume methane emitted from mine can be extracted from the ventilation air and the concentration is enriched through processes like chemical looping, large quantity of high concentration methane can be effectively utilised for power generation. Such study is essential to evolve suitable technology for capturing the methane in ventilation air and not allowing them to go into the atmosphere increasing the GHG effect.

2. CONTROLLING MINE FIRE

Mine fires in many coalfields of India is a serious issue of concern as the magnitude of the problem is enormous. The impact of the fire in Jharia and Raniganj coalfields is huge, which is continuing for a long period of time. In some cases, the history of such fires are century old. Million tonnes of coal are being burnt into ashes because of the long standing unabated fire, both in underground and surface. This phenomena of mine fire is associated with great impact on the environment, safety of the mine workers and local residents and loss of huge national property. Many serious accidents have taken place in the past due to mine fire. Situation is no different today. The risk of mining in and around an area affected by mine fire is not acceptable. The greatest difficulty is assessment of the extent of the fire as in most of the cases the fire is progressing below the surface cover, from one seam to another, from one mine to another. Because of the fire in the upper seams, exploitation of lower seams are dangerous or not possible on many occasions.

The available information about the environmental impact due to mine fire by release of such high volume of CO or CO_2 from the fire area over such a long period of time is also not enough as no proper assessment has been done so far on the release of such products of combustion into the atmosphere. Though, efforts have been made in the past for controlling the mine fire, the situation has not been improved and coals are still burning, releasing tonnes of noxious gases to the atmosphere. Comprehensive study shall be undertaken to assess the environmental impact due to such mine fires and also for finding effective methods for controlling such fires, both in underground as well as in surface to save million tonnes of coal from burning and causing environmental problem. Thus the ultimate objective of clean coal technology may be achieved by reduction of environmental pollution due to mine fire.

3. REDUCTION IN DILUTION OF COAL QUALITY USING SELECTIVE MINING METHODS SUCH AS APPLICATION OF SURFACE MINER FOR PRODUCTION OF COAL

Ever since the nationalization, opencast coal mining has become more popular in India than underground mining. This trend was spurred mainly by the rising demand for coal to meet the needs of thermal power generation, produced by coal firing. The entire focus of the nation is on availability of energy alternatives. Thermal energy being very predominant in India, the responsibility of coal sector increased manifold. The thrust at present is on increasing production from opencast mine.

The advent of Surface Miner equipment in mineral sector can be traced since early 90's. For producing coal and limestone in different mining projects application of surface miner is rapidly increasing due to the ease in application and also for producing sized product at a faster rate. Out of a current global population of nearly 300 surface miners in productive use around the world, some 105 operating machines are in India. In Coal India Limited, the total surface miners deployed at present are 71. In the year 2014-15 the total coal production by surface miner was 198 Million tons which is about 40% of total production. The total growth planned by Coal India Limited is around 84% till year 2020 i.e. almost 16% per annum. Thus a heavy dependence is being placed on surface miner production which will rise approximately to 70%. The production from surface miner in Coal India has increased significantly over the past years and so the percentage share of production. In 2014-15 the share was 40.14% as compared to 16.27% in 2007-08. Hence the surface miner technology assumes a strategic importance for the growth of Coal India Limited as well as for the energy mission of our country.

Table 1 : Surface Miner Production Share in CIL

Year	CIL Production (Mt)	SM Production (Mt)	SM share (%)
2010-11	431.320	106.111	24.60
2011-12	435.838	119.716	27.47
2012-13	452.211	155.801	34.45
2013-14	462.422	170.819	36.94
2014-15	494.240	198.388	40.14

Surface miners are deployed for eco-friendly mining and improved recovery of coal and minerals, especially in areas sensitive to blasting. Several surface miners are operating in the country in different subsidiaries of Coal India Limited although use of surface miner is different kind of rocks with variable hardness is still in is nascent stage. The other problem which attribute to the poor quality is the dilution of coal particularly deposits with interbedded coal seams. The same coal when used in the thermal plants produces huge waste apart from the ash which is also a major concern for Indian Coal. Surface miners can be useful in wining thin inter-bedded coal seams with less dilution of coal and increased ROM quality.

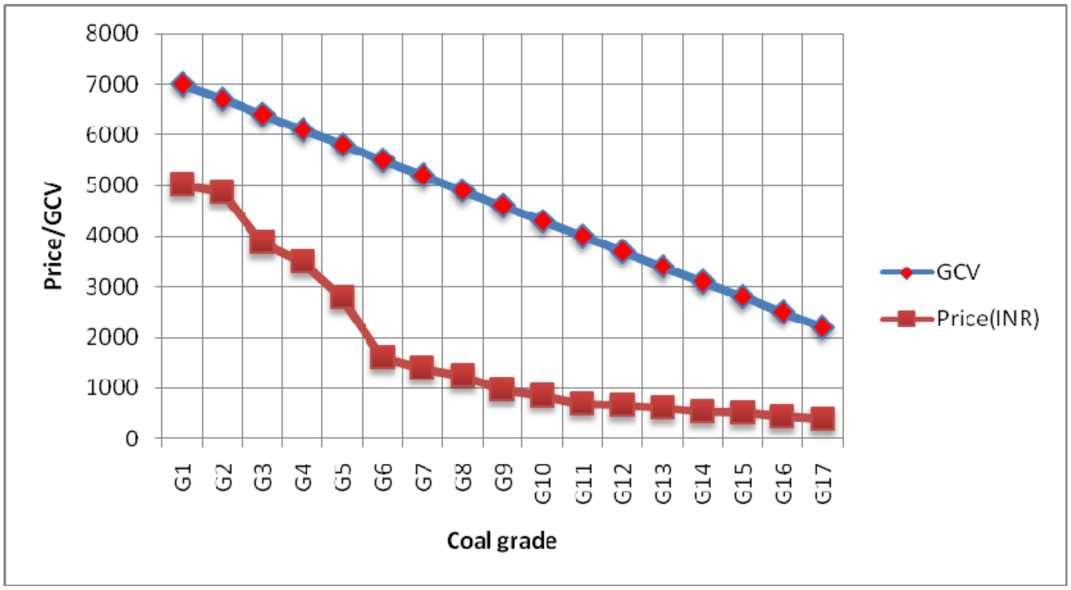

Fig. 2 : Effect change in coal grade on price variation

A comparison of Surface Miner with Conventional Mining as shown in Table 2 Method clearly brings out the advantages that can be reaped towards the clean and undiluted coal.

Table 2 : Advantages of surface miner application for clean coal production

Surface Miner	Conventional Mining
Cost of production is less.	Cos of production comparatively higher.
Single unit operation.	Multiple operation i.e. drilling, blasting & crushing.
Access to environmentally sensitive areas	Restricted in sensitive areas
Less chances of fire	Produces cracks which may lead to fire
Better stability of bench and highwall	Relatively poor due to induced stress by blasting
Environment friendly method	Adversely affect environment
Highly selective mining is possible	More dilution of coal
Thin seam mining possible	Thin seam not possible

Key Points in Surface Miner Technology

- Proven Technology: High peroformance @ 3,000 t/h with point-attack cutting tools for hard interburden material.

- Efficiency & Productivity: Significant reduction in operating costs.

- Desired Size: Compared to the mining method used to date, the SM produces a smaller percentage of fines (grain size < 2 mm) and a higher percentage of the end product fraction (grain size < 38 mm). Hence, improves the efficiency of the processing plant.

- Operating in the confined space of the mine & Rapid Manoeuvring

- Environmental Gain: Reduced noise and reduced dust and increased efficiency in selectively mining

Key Challenge

Selection of proper surface miner is crucial for project economics. The cutting performance can go down drastically as the rockmass changes. It is imperative, therefore, to understand the rock/rockmass to be excavated prior to selection of the machine and based on that a suitable excavating machine should be adopted.

Thrust Areas of Research

- Performance of surface miner relies on the physico-mechanical properties of intact rock and rock mass apart from design and operating parameters of the machine itself. To reap the full benefits and overall economic advantages, a detailed knowledge of the geological conditions, a correct interpretation of how these conditions influence the machine's design and performance is necessary.

- Performance prediction models, based on a few parameters related to machine specifications, intact and rock mass parameters individually in isolation, are found to have limited applicability. Thus, there is a need for further research in this area so that mine planners may be able to select suitable surface miner to achieve a required production target.

- Research is also imperative for suitable drum design, lacing pattern and pick spacing in relation to intact rock and rock mass parameters for enhancing production with minimum diesel and pick consumption apart from achieving desired chip size. The research methodology must focus on achieving the key performance parameters namely production, reduced diesel and pick consumption. An outline of the research methodology is provided in Fig.4.

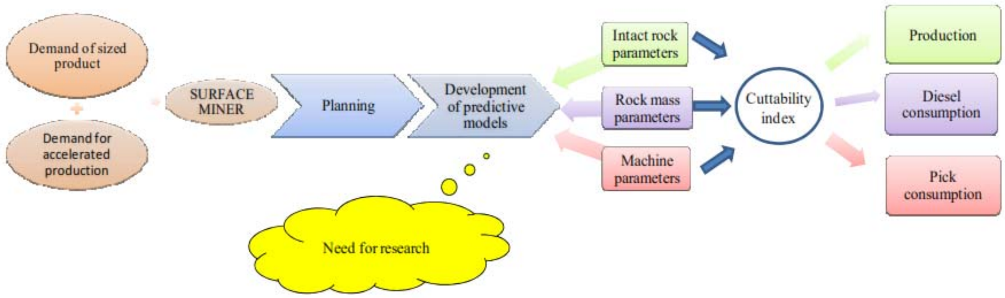

Fig. 3 : Planning of surface miner technology

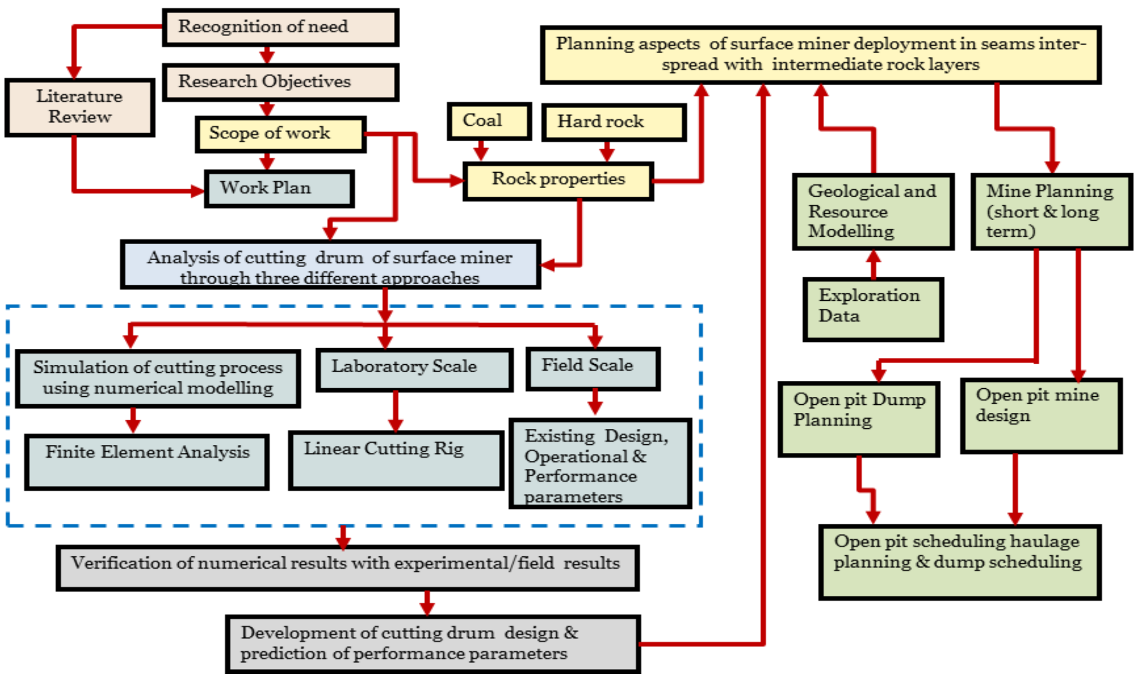

Fig. 4 : Outline of the research methodology

4. IMPROVED DRILLING AND BLASTING PRACTICES TO PREVENT DILUTION OF COAL QUALITY DUE TO BLASTING

In most open pit coal mines the overburden or inter burden rock is drilled and blasted to expose and then to excavate the coal seams. In case of multi-seam deposits, generally each seam is exposed and excavated separately by removing the corresponding overburden or inter-burden. An illustration of this procedure is shown below in Fig.1. In case of steeply dipping multi seam deposits upper seam is exposed by drilling, blasting and excavating the overburden. Once the upper most seam is exploited, the uneven inter-burden surface needs to be levelled first and then needs to be drilled, blasted and excavated to expose the second seam lying below. This preparation and removal of inter-burden to expose the second seam is generally un-productive, inefficient and unsafe. Same pattern needs to be repeated to exploit the third seam lying further below. The problems become more severe with harder inter-burdens and steeper seams. Figure 5 is an example of shallow dipping multi-seam deposit. Complexities are less in shallow dipping seams compared to the steeply dipping seams but nevertheless the number of cycles to expose each seam remains the same.

By drilling and blasting the overburden and inter-burdens in one cycle can provide significant productivity and safety benefits. However, blasting multiples layers of overburden requires very high level of design knowledge and implementation standards. Without this, poor implementation of multi-seam and thru-seam blasting techniques can results in significant coal loss and dilution.

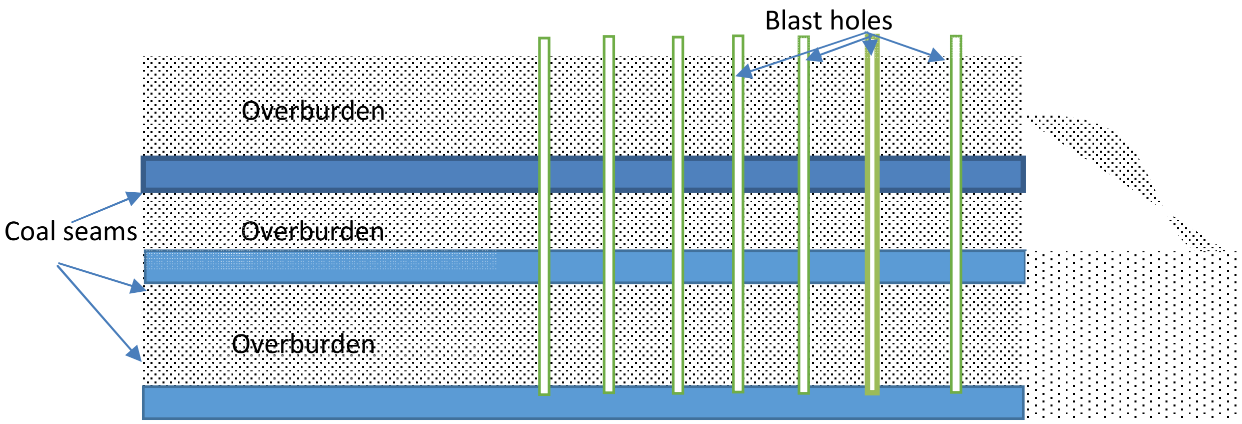

Fig. 5 : Drilling in multiple layers

Multiple overburden and coal strata can be drilled, loaded with explosives and initiators and blasted in a single cycle. Each layer can be blasted with a unique design and achieves its targeted blast result, which is different from that of the other layers. Designs in each layer generally differ in explosive type and powder factor, inter-hole and inter-row delays, direction of initiation and initiation time and position, making this method distinct from conventional throw/ cast seam blasting. No throw is achieved in the overburden while coal losses and pulverisation are reduced, leading to increased coal seam recoveries.

In most cases the overburden and coal cannot be excavated without prior blasting operations. Conventional drill and blast practices are used in both the overburden and coal, with each of these being mined in a separate cycle. Each layer is cleared and prepared, surveyed, drilled, loaded with explosives, initiators and stemming and blasted.

Particularly in coal operations, overburden blasts may be undertaken as throw/cast blasts or stand-up blasts to achieve productivity gains. After complete excavation of the remaining over burden, the recoverable underlying coal seam is drilled and blasted as a separate event, usually with quite different blast design parameters more suited to the recoverable coal. In particular, the blasts in these layers are usually designed to minimise unwanted crushing, damage and displacement of the recoverable coal. Similarly, the subsequent layers of inter burden below the upper recoverable mineral seam(s), and further recoverable coal seam(s) are usually also drilled and blasted in separate respective blast cycles. The cast blasting generally employs high explosive powder factors and blast timing that favours forward displacement of the muckpile. The overburden is drilled with large diameter holes, typically 229 - 311 mm, on a correspondingly large pattern. High-energy bulk explosives are used to maximise muckpile throw and fragmentation in the critical areas for excavation; usually the toe and key cut regions. This creates coal damage. Restricting coal loss in throw blasting has been an area of active research for many years. Techniques such as providing a buffer of imported waste material in front of the coal seam, as well as several modified drilling and explosive loading methods have been trialled over the years with mixed success. While throw blasting has undoubtedly increased coal mine productivity by moving much of the overburden into final spoil, there are still a number of drawbacks with the conventional practice. The major problem is coal dilution and loss. Furthermore, each separate blast cycle includes the steps of blast surface and face preparation, surveying and marking hole collar locations, drill rig location at each blasthole collar, drilling, hole depth measurement, explosive charge and initiator determination and loading, stemming, pit clearance and firing followed by post-blast clearance and clean-up operations.

Through-seam (multiple layer) blasting is different from throw blasting as through-seam blasts are specifically designed to minimise lateral movement of all of the material in order to avoid any disruption of the coal seams, except possibly in a vertical sense. Explosive powder factors in through-seam blasts are thus generally low. Furthermore, through-seam blasting does not use blast initiation timing that may promote forward or sideways movement of the material, such as that used in throw blasting. Another major distinction is that in conventional through-seam blasting the delays between adjacent holes and the direction of blast initiation are designed to be the same for each layer blasted. Therefore, a huge gap still exists and research is required to design and implement such type of blast for getting clean coal.

5. ENERGY USE AND GREENHOUSE GAS (GHG) EMISSIONS MANAGEMENT IN COAL MINING

Energy efficiency, environmental care and carbon footprint disclosure are surfacing to the top of the agenda in the mining and minerals industry. Carbon emissions, effluent and waste, as well as water conservation are key concerns for mining companies against a backdrop of increased reporting requirements. Energy costs are typically between 20% and 40% of a mining facility's operational expenses. Improving energy efficiency and reducing greenhouse gas (GHG) emissions are priorities for any industry including mining industry as a way to limit impacts to the environment and to help reduce operational costs at the mine-site. It is important to develop an Energy Use and GHG Emissions Management Protocol consisting of the following indicators that seek to confirm whether an industry has established a comprehensive system for energy use and GHG emissions:

- Energy use and greenhouse gas emissions management systems
- Energy use and greenhouse gas emissions reporting systems
- Energy and greenhouse gas emissions performance targets

For this protocol, an industry must show that its management system includes assigned accountability from senior management, as well as demonstrate that they have a process in place to ensure that energy data is reviewed regularly and well-integrated with operator actions.

Industries are also expected to provide energy awareness training and have systems in place to track and report energy use and GHG emissions data for both internal and external reporting.

For the above, it is essential to develop Energy and Environmental (E&E) Profile of the Indian Coal Mining Industry to benchmark energy use for various mining technologies by estimating the average energy consumption of key equipment used in coal mining. There is very little data available on Indian coal mining industry for energy use by specific mining process, equipment type or fuel type utilized. Hence it is proposed to conduct a study with various models of typical equipment required for various types of mine operations (e.g. longwall mine, semi-mechanised bord & pillar mine, bord& pillar mine with continuous miner, surface mines with Dragline / Shovel / Trucks / Surface Continuous miner, etc.) and the energy consumption of each major equipment unit.

While the E&E Profile provides detailed data for the estimated energy consumption of each piece of equipment required in a typical mine, it is also important to focus on the average energy consumption of similar equipment types to estimate the potential for energy savings for a given process grouping the similar equipment into categories based on their process use: blasting, dewatering, drilling, digging, ventilation, material handling, crushing, grinding, and separations. Thus the analysis will help in identifying the equipment categories which provide the greatest opportunities for energy savings in the Indian coal mining industry.

Though Indian coal mining industry is less energy intensive, particularly in the underground sector, implementing various energy saving measures like Optimization of fuel consumption in dump trucks and excavators, Use of High capacity, efficient diesel engine for dump trucks and excavators, Improvement of maintenance of HEMMs, Introduction of energy efficient motors, Power factor and maximum demand control etc. will improve energy efficiency to some significant level. Energy benchmarking and Targeting will help in improving energy efficiency in mines.

6. CO_2 SEQUESTRATION AND CARBON CAPTURE AND STORAGE (CCS)

The emission of enormous amounts of CO_2 through combustion of coal, petroleum, natural gas etc. results into the environmental problem and global warming. In addition, emission from coal and shale beds increases greenhouse gas (GHG). The CO_2 sequestration provides a significant option to mitigate CO_2 emissions, contributing towards our pledge to Paris climate change agreement to reduce our emission intensity by over 30 % by 2030 compared with 2005 level. The first stage towards India's goal of becoming a non- CO_2 emission country can be achieved cost effectively on a large scale without greenhouse gas (GHG) emissions, if the resultant CO_2 can be securely geologically stored in coal and shale beds. For CO_2 sequestration (geological storage) R&D efforts are required to develop a sound basis for monitoring and verification. This will deliver assurance of long-term storage security and establish standardized site certification guidelines for policy makers, regulators and industry. The project will identify gaps in the existing monitoring and risk assessment methodologies and will develop and test a number of new and innovative techniques, focusing, amongst others, on such technological risks as well as surface leakage, even at very low rates. The project will test and improve existing methods and develop new technologies for the CO_2 sequestration

7. UNDERGROUND COAL GASIFICATION

Underground coal gasification (UCG) involves injecting steam and air or oxygen (O_2) into a coal seam from a surface well. The injected gases react with coal to form a combustible gas which is brought to the surface in a production well, cleaned and used as a fuel or chemical feedstock. A cavity is formed as the coal burns and the roof is allowed to collapse. Coal is the major source of energy all over the world including India. However, it is not technically feasible or economically viable to mine all coal resources and this is where UCG (underground coal gasification) finds its usefulness. UCG has been practiced, though off and on, since the last 50 years by almost all major coal producing countries but it could never become the major energy source. UCG refers to gassifying a coal seam in-situ and bringing the resulting synthetic gas (syngas) to the surface. The syngas is a mixture of hydrogen, CO, CH_4, CO_2 and higher hydrocarbon and has calorific value of 850-1100 kcal/m^3. There are many advantages of the syngas as it has great downstream utilisation potential, such as for power generation through integrated gas combined cycle (IGCC) or in the fertilisers and chemical industries. In general, UCG can operate at up to about 80% efficiency that is, the amount of the syngas energy recovered at the surface is about 80% of the original heating value of the coal feedstock.

Challenges

- The danger of contamination of underground water,
- Non-availability of suitable drilling technology, and
- Failure to administer proper control over gasification process

However, with the efforts put in by many countries over the years, the technology of UCG has matured for commercial application. There is growing interest internationally in the technology of UCG as a means to access low grade and inaccessible coal reserve and convert them commercially and competitively into the syngas with potential applications to power, fuel, and chemical production. The quality and quantity of syngas production depends on

- Type of coal
- Physiochemical properties of coal
- Occurrence of depth
- Thickness of the bed
- Hydrogeological conditions
- Deposit tectonics
- Methane presence in the bed
- Angle of inclination of coal bed

Opportunity

In India the experience of UCG is minimal. However, many deeper coal seams and deeper lignite deposits not economical to mine by conventional mining techniques are good prospects for UCG. Large number of abandoned mines and some shallow coal deposits with difficult geo-mining conditions can use UCG gainfully. India faces the challenge of overcoming existing legal and regulatory framework quickly, identifying the right coal and lignite resources for production of synthetic gas on a sustained basis at a cost which is competitive.

The government of India has also identified 8 coal blocks for the development of underground coal gasification. Such projects may also bolster India's efforts to meet its clean energy commitments. India has pledged to reduce its emissions intensity of its gross domestic product by 33-35% by 2030 compared with 2005 levels. This technology didn't progress well in India, but it can progress if there have been proper research to encounter certain challenges especially environmental challenges, such as groundwater contamination with this technology.

Initiatives and Developments in India

1. UCG was taken up in 1980 by ONGC and CIL, with technical assistance from then USSR.

2. In 1984-86, ONGC drilled holes to study the prospects of UCG in deep lignite/sub-bitiminous coal deposits in the state of Gujrat. The project did not proceed further due to lack of technological support.

3. Under the initiative, then USSR selected three out of 13 coal/lignite blocks for generation of additional geological, geophysical, hydro-geological and geotechnical data. On the basis of data only one block (Merta Road Lignite Deposit) was found technically feasible for the UCG.

4. A project was taken up by CMPDIL, with technical support from the USSR to enable pilot study at Merta Road Lignite Deposit. Although found suitable, but the project was stopped due to concern about ground water contamination.

5. With new advancement in technologies, UCG is again in focus and number of companies such as NLC, RSPCL, ONGC, CIL/CMPDIL are pursuing its development on a limited scale to prove the viability of the technology in Indian geology.

6. CMPDIL has generated data through exploratory drilling in Kasta block in the Raniganj coalfield under a joint venture project with ONGC.

7. ONGC will also conduct pilot scale studies in near future.

8. In December 2015, India approved its underground coal gasification policy and the Government of India has also identified 8 coal blocks for the development of underground coal gasification in an attempt to help boost India's energy security.

Thrust Areas

- To identify and mitigate the environmental concern associated with the UCG and geological and geo-technical characterisation of coal seam for the technology to be implemented. Interaction of the underground reactor with the surrounding strata needs to be better understood to facilitate selection of appropriate sites, and target seams, and to ensure the gasification process can be controlled to prevent the escape of pollutants. Hydrogeological information will be particularly important in this respect.

- The guided drilling technology currently available is suitable for the envisaged deep UCG applications, but its accuracy, reliability, repeatability and cost has yet to be established in practice and needs further research and study.

- Quantifying the gas flow rate and heating value in the operating plant with the optimisation of cost economics as UCG operations have major uncertainties.

- Use of CFD techniques to review effects of cavity shape, geometry and strata dip on flow processes in the reactor

- Laboratory studies to establish tests suitable for evaluating the likely gasification and pyrolysis performance of coals of different composition and rank. The possibility of testing confined coal samples under conditions of high pressure and temperature to simulate deep UCG processes could also be investigated

- Laboratory investigation on the effect of thermal stress on typical seam roof rocks. should be experimentally investigated in the laboratory and seam characterisation method for assessing drillability, possibly involving measurements and laboratory testing on cored samples

Application of UCG will be more useful for the deposit of low quality coal at deeper horizons.

8. Application of modern technologies for effective environment management in coal mining

Historically India has had access to ample amount of coal with low stripping ratio. Available coal deposits of today are becoming deeper and more complex and increasingly encroach upon populated areas and the local environment, resulting in need to focus on environmental issues. The impact of mining on the environment can be broadly classified into the followings:

- Physical Impact

- Biological Impact

- Social Impact

While the physical impact of mining includes degradation of land, air pollution, water pollution, Noise pollution etc. the biological impact includes destruction of fauna and flora, soil erosion etc.

Mining operations today are consistently failing to achieve required efficiencies of mine reclamation in terms of managing the overburden waste, afforestation, maintaining air and water quality, land use etc. Inadequate mine environment management during and post mining operations due to wrong or sub-optimal physical and biological reclamation process causes a huge environmental footprint and detrimental from clean coal technology perspective.

Mine environment management is a continuous process that goes on progressively throughout the life of mine leading to final closure of mining leaving the site in a most environment friendly and economically viable land pattern for the community.

Current mine environment management practices in India are based on long standing practices for creating an Environment Management Plan (EMP / Mine Closure Plan) at the start of a mining operation to gain statutory approval. While these original EMPs have then been used throughout the life of the mine to form the basis of environment management of the mine there is hardly updation of EMPs in a dynamic manner and application of modern technology to treat the new information made available during the course of mining for effective environment management.

Adopting scientific approach, best mine environment management practices and deployment of internationally recognized information technologies has potential to drastically reform the mining leading to efficient, environment friendly and safe mining and post mining environment and economically viable land use pattern.

Application of advance mine environment planning and monitoring technologies have potential to improve mine environment management and can contribute significantly towards CCT.

Utilization of fly ash to fill the void left out of mining voids is another area of concern from CCT perspective.

A large number of Mega and Ultra Mega Power Plants (+1000 MW Capacities) are operating near the pit heads. They generate huge amount of fly ash which are difficult to dispose-off.

While the void created by mining could be utilized for backfilling of fly ash along with mine waste, this requires a proper scientific study from environment and safety perspective.

Thrust Area:

- Technology driven dynamic mine reclamation management solution, and
- Inclusion of fly ash management as part of mine design and engineering exercise.

9. INTEGRATED MINE PLANNING AND OPERATION TO ACHIEVE OPTIMUM PRODUCT QUALITY

Mine Planning is a continuous process to integrate seamlessly with operation and beneficiation. Scheduling the production of optimum quality coal is extremely important for the maintaining the efficiency of down-steam activities such as beneficiation, gasification, liquefaction, combustion etc. Mining operations are becoming complex and volume of data is increasing. More options are required to be evaluated to maintain the supply of consistent quality coal from the mine.

Usage of modern and dynamic mine planning technologies could be an enabler to achieve such objectives. Advance mine planning and scheduling solution are built on advance mining logic that provides better control while adapting the unique characteristics of each mine. It can generate a number of alternate coal quality options suiting to the requirement, compare multiple scenarios, identify production and quality bottle necks and improve forecasting accuracy. They are also built on aggregation logic that can incorporate updated geological data in the mine plan and generate the revised quality schedule in no time without repeating the whole process.

While ensuring the coal quality, such tools has also the ability to integrate beneficiation with mining for better control and overall efficacy of the system minimizing the wastage of coal.

THRUST AREA

Application of technology driven integrated mine planning and operation system to improve overall efficiency and minimizing the wastage.

CONCLUDING REMARKS

Clean coal technology ranges from mining to beneficiation, combustion, gasification, liquefaction, increasing efficiency, which clearly indicates that it is not a singular technology. The first step towards achieving the objectives of clean coal technologies is efficient and environment friendly mining of coal. However, coal mining has not received adequate attention in the area of pursuing clean coal technologies. Considering the massive future energy generation program in India through fossil fuels, intensive thrust on R& D activities in mining as a primary component of clean coal technologies is required to conform to the requirements of International protocol on GHG emission.

THRUST AREAS IN MINING FOR CLEAN COAL TECHNOLOGY

1. **Methane Drainage Prior to Mining and Ventilation Air Methane**
2. **Controlling mine fire, underground and surface**
3. **Reduction in dilution of coal quality using selective mining methods such as application of Surface Miner for production of coal**
4. **Improved drilling and blasting practices to prevent dilution of coal quality due to blasting**
5. **Energy Use and Greenhouse Gas (GHG) Emissions Management in coal mining**
6. **CO_2 Sequestration and Carbon capture and storage (CCS)**
7. **Underground Coal Gasification**
8. **Application of modern technologies for effective environment management in coal mining**
9. **Integrated Mine Planning and Operation to achieve optimum product quality**

Note on Coal for Non-Power End Uses – Steel Industry Focus

Dr. T. Venugopalan
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1. INTRODUCTION

During the last ten years, Indian Steel Industry has grown rapidly to become the third largest steel producer in the world. With the steel growth continuing unabated, India will soon achieve the distinction of second largest steel producer in the world. Since the introduction of economic reforms in early 90's Indian Steel Industry has continuously upgraded the Technology and Machinery so much that many steel units in India can stake claim as modern and state of the art in product, processes and competitiveness There have been substantial improvements in the areas concerning product quality, productivity, consumption norms, energy consumption and environment. These developments are attributable to beneficiation of raw materials, utilization of large proportion of agglomerates in iron making and adoption of processes / technologies for the improvement in the productivity and efficiency. Investments are made to address the regulatory measures related to energy consumption, CO_2 emission and environment.

2. COAL TECHNOLOGIES

A major concern for the Indian Steel Industry is the non-availability of good coking coal. The reserves of coking coal worldwide are limited and in India, It is available only in the State of Jharkhand and whatever available also qualifies to be only as Medium Coking Coal. Therefore it becomes essential to work on projects which will enable the utilization of non-coking coals in iron and steel production. Some of the potential areas for research are listed below:

1. Conversion of non-coking coals to coking coals: This will involve an in depth study leading to the development of binders, which will help in the production of good quality BF coke from inferior coals.

2. Development of Reactive Coke: It is a national program in Japan and JFE has carried out a substantial research in this area. By this, weaker or non-coking coals are converted into coke with good reactivity and the gas generated in the BF due to solute loss reaction is made available for indirect reduction in the stack.

3. Injection of hot Coal Gas in BF: This will reduce the Coke Rate and alleviate the problem of coal ash (Research in Russia)

4. Use of lower varieties of coal and reduction in energy for coke making (It is a national program in Japan under clean coal technologies).

5. Development of Smelting Process: Alternative iron making processes aim at the production of hot metal (liquid iron) utilizing non-coking coals, steel plant wastes and lean iron bearing materials. Russia developed a process called ‘Romelt’ and they could not commercialize the process for different reasons. Research laboratories and Engineering companies developed alternate processes to address some of the remaining issues of Romelt Process. Due to the continued research and investment in the development of ‘Smelting’, new processes such as

COREX and FINEX have got developed. There is still ample scope for the development of a suitable smelting process which is suitable for the Indian raw materials. Success in this area will reduce the dependence of the Industry on Coking Coals.

6. Research in Washing of Coals

   a. Indian coals have high ash, but BF needs as low ash as possible in view of hot metal quality and process efficiency. When the washery aims at lower level of product ash, there is a considerable drop in the overall coal yield. There is ample opportunity to improve the coal yield by proper characterization of the raw material, adoption of the right flow sheet, development of suitable environment friendly frother and collector chemicals, optimization of the process parameters and measures to recover the liberated coal from the tailings.

   b. Water is becoming increasingly scarce and development of dry beneficiation techniques which will reduce the dependence on water for washing is another area of research.

7. Use of alternate fuels

   a. Bio Mass: It reduces the carbon intensity of the iron making process. With the right production and processing techniques, Bio Mass can certainly replace part of the carbon requirement and this will help in reducing the CO_2 emission.

   b. Plastics: Its use in the Iron and Steel industry is well proven. Collection of plastics seems to be the major issue.

   c. Coal Gas: Production of coal gas / synthesis gas from the waste coals will help to reduce the coal / coke consumption.

   d. Coal Bed Methane: Methane is evolved during the mining of coal. The gas is poisonous and also leads to mine accidents. Hence there is a need to extract the gas prior to the start of the mining activity. Extraction of the gas and thereby making the mine free from gas will give following benefits.

      - Opportunity to use the gas for power generation or for reduction in iron making furnace.

      - Improvement in mine safety

      - Reduction in GHG emission, since the age old practice of infinite dilution of CH_4 before letting out is avoided.

8. Research in the area of coal characterization: Coal for the production of good quality coke needs a thorough understanding on

   a. Coal macerals

   b. Reflectance

c. Ash constituents

d. Reactives / coal softening behavior

At present most of the suppliers and coal users give importance only for the ash percentage. Purposes of use of carbon in iron and production are given below.

- Reducing agent in iron making
- Permeability of the BF burden
- Source of energy in power generation

Quality of coal required depends on where it is used. Coal for coke making should have reactives which are aromatic. Injection coal in BF needs to have the optimum level of high volatile matter and good combustibility. Coal for power generation, should possess good combustibility, which is ensured by presence of reactives, which are aliphatic. A complete characterization of the various Indian coals with the end use in mind and suitable research to improve the coal performance in the intended application will be of great help to the Industry.

Beneficiation of Indian Coals: Challenges and Opportunities

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1. INTRODUCTION

Coal will continue to play a major role in economic development of India particularly contributing significantly to metallurgical and energy sectors. India is heavily dependent on coal for meeting its energy requirement, which is at present met to the extent of about 60%. The significant resources of coal available in India in comparison to other fossil fuels have enabled this valuable mineral to remain at the heart of country's energy scene. Commercial energy consumption in India has grown from a level of about 30 to 60% of total energy requirement in the last four decades. The production of India in last five years is given in Table 1. It has grown at a rate of 7.2% during the last two decades as against the world average of mere 2.2%.

Table 1 : Production and Import of Coal of India

Million tonnes

Year	Coal Production	Coking coal import	Non-coking coal import	Total import
2011-12	539.95	31.80	71.05	102.85
2012-13	556.40	35.56	110.23	145.79
2013-14	565.77	36.87	129.99	166.86
2014-15	612.44	43.72	174.07	217.78
2015-16	653.56	43.50	156.39	199.88

2. WORLD SCENARIO

The major coal producer countries in the world are China, USA, India, Australia, Russia, South Africa, Germany, Poland, Kazakhstan, Columbia, Turkey, Canada, Ukraine, and Greece. The top three coal-consuming countries are China, USA, and India, which together account for more than 70% of world coal usage. The coal production of different countries is given in Table 2.

3. COAL BENEFICIATION TECHNOLOGY USED BY DIFFERENT COUNTRIES

Different beneficiation technologies are used in for coal cleaning and quality improvement by different countries. The beneficiation practice varies based on coal characteristics of the region. A brief overview of the beneficiation practices followed in different countries is presented in Table 3. The beneficiation methods are more or less similar but there are different processing challenges based on coal origin and quality.

Table 2 : Production of Coal in Different Countries

Million tonnes

Country	Coal Production	Year
China	3890	2013-14
USA	922	2013-14
Australia	532	2015-16
India	613	2014-15
Indonesia	458	2013-14
Russia	358	2013-14
South Africa	260	2013-14
Germany	186	2013-14
Poland	137	2013-14
Kazakhstan	109	2013-14
Colombia	89	2013-14
Turkey	71	2013-14
Canada	69	2013-14
Ukraine	61	2013-14
Greece	49	2013-14

4. PROBLEMS IN INDIA COAL

India has coal reserves of around 301 billion tonnes as on 1.1.2014. Out of this total reserve around 260 billion tonnes comes under non-coking coal and remaining part comes under coking coal. Most of the coal reserves in India are low quality due to the drift origin. The quality is not maintained but deteriorated due to mechanised bulk mining and exploration into poor quality seams. Most of the non-coking coals have high ash content varying from 40-50% with high near gravity materials. As a result, this coal has poor washability characteristics. The **coking coal** is beneficiated but the quality is not easily met. In the Indian context, number of reasons is there as to why the desired quality of the product is not achievable. Here is a short list.

1. Most of these washeries are very old and built around 1960. Due to technical issues, these washeries do not meet the requisite quality norms specified by the industries.

2. The Indian coking coal characteristics are totally different. The importance of media with respect to physical and chemical characteristics in the process has not given due importance.

3. At present, nineteen coking coal washeries are operating in India under Coal India, SAIL and Tata Steel. Till today, most of the washeries are designed in the conventional manner and restricted to treat a particular size.

4. As all coking coal is being used for only coke making, some size reduction of coal may be done for further liberation. Suitable equipment for coarse as well as fine circuits have to be developed to maximize the coal recovery.

5. The media from indigenous magnetite ore is required to be developed to meet the desired quality in the washery.

Table 3 : Beneficiation Technologies Adopted for Coal Cleaning by Different Countries

Country	Production Million Ton	Cleaning Method			Dewatering Methods	
		Coarse mm	Fine I mm	Fine II mm	Coarse	Fine
China	3890	-100+50 Jigs	-50+0.5 HMC	-0.5 Flotation	High frequency vibrating screen and centrifuge	Pressure and Vacuum filters
USA	922	-100+12 HMV & Jig	-12+1 HMC	-1 mm Spirals, Flotation (-0.15 mm)	Basket type centrifuge	Vacuum filter, Drying
Australia	532	HMC, HMV, and Jig	Spirals and Flotation in Jameson cells		Basket type centrifuge	Vacuum filter
South Africa	260	HMC, HMV, and Jig	Spirals and Flotation cells		Centrifuge and screens	Vacuum belt filter
Canada	69	HMC, HMV, and Jig	Spirals and Flotation cells		Centrifuge and screens	Vacuum belt filter
Russia	358	HMC, HMV, Cyclone	Spirals and Flotation cells		Centrifuge and screens	Vacuum belt filter
India	613	+1 mm HMC, HMV, and Jig	-1 mm Spirals and Flotation cells		Centrifuge and screens	Vacuum belt filter

Beneficiation of **non-coking coal** in India was not given due importance till last decade due to its low value or not able to meet the cost of the process. The beneficiation strategy for non-coking coal needs a special approach from that of coking coal because of very high ash content, complex mineralogy, and the prevalent practice of end use. In the present scenario, only few washeries have been set up in India to wash the non-coking coal which is able to produce a coal limited to ~30% ash from as high as 45-50% ash. Today the biggest concern of these washeries is low yield and the rejection of fine coal materials. The ultrafine coal particles in some of the cases is rejected which create environmental issue in plant surrounding.

In the present scenario, non-coking coal can be used extensively in metallurgical purposes i.e., coal dust injection in blast furnace, DRI, Corex, Finex, Romlet and other reduction smelting processes apart from power plant. To meet these demands, there are some stringent specifications and one such important criterion is the low ash content in coal i.e. 10-12% ash. Therefore, the existing technology has limitation to produce coal having ~10% ash for any metallurgical purposes.

Due to deterioration of coal quality and shortage of coking coal in the country, inferior grade of coking coal of high ash percentage and non-coking coal that are available in plenty can be used for iron & steel sector, cement industry, thermal power generation and other industries by pretreatment process through coal preparation and beneficiation. New technologies can be adopted to beneficiate such coal and these include the following.

- Liquid fluidized heavy media bath with required quality media
- Column flotation technology
- Advanced dewatering process
- Chemical and biological leaching

These technologies can be implemented for removal of ash and sulphur content from Indian coal during beneficiation.

Lot of beneficiation studies have been carried out by several academic and R&D organizations. The following organizations have done considerable amount of research on coal characterization, processing and utilization.

- CSIR-IMMT, Bhubaneswar
- CSIR-CIMFR, Dhanbad
- CSIR-NML, Jamshedpur
- CSIR-NEIST, Jorhat
- R&D Division of Tata Steel
- RDCIS, Ranchi
- CMPDI, Ranchi

- ISM Dhanbad
- IIT Kharagpur

The research activities have been focused on utilization of the Indian high ash and high sulphur coal for power and steel sectors. Recently, a detailed beneficiation study was carried out for both coking and non-coking coals from different resource bases in India to achieve 10% ash coal by deep beneficiation, mainly for metallurgical purposes, by some of the above R&D Institutes. The project was funded by Ministry of Steel, Govt. of India. The beneficiation studies were carried out at different sizes and size ranges from laboratory scale to pilot scale level.

5. BENEFICIATION OF INDIAN COAL

In all over the world, it has been observed that the coal is crushed to particular size, then it is classified into different size fractions.

- For more than 5 mm up to about 100 mm size, the coal in some of the places treated by jigs. Here the extent of beneficiation depends on the liberation of coal particles. When the liberation size is high and near gravity material is less particularly in the density range of 1.4 to 1.7, jig will give better metallurgical performance. Otherwise, heavy media vessel and heavy media cyclone are the appropriate technology.
- Spirals are used to effectively treat intermediate size -1+0.5 mm fraction.
- For the finer fraction i.e -0.15 mm, the spiral concentrator, flotation cell, Jameson cell and column flotation are used. Dewatering of coal is quite challenging for the finer fraction and for this purpose high frequency vibrating screen, centrifuge, vacuum and pressure filters are used.
- In Indian contest more or less, same technology is used. However the beneficiated product does not meet the quality demand with respect to the metallurgical performance. Some of the technical issues and solutions are highlighted in both coking coal and non-coking coal beneficiation.

(i) Coking coal

As per Indian practice the coal is crushed to below 13 mm size. The -13+0.5 size fraction is treated in heavy media cyclone in two times to generate the concentrate, middling and reject. The below -0.5 mm size, is treated by flotation method. In heavy media cyclone, magnetite is used as media. The quality of magnetite media used in India is of poor quality except Tata Steel. It contains good amount of clay minerals, which increases the viscosity of the slurry and it affects the separation performance. The ultra-fine particles are high and Fe value is less than 65%. The size of the media and Fe content play the vital role for desired media preparation. The size of the particle should be below 45 micron and -45+30 micron size range should be around 85% and below 30 micron should be 15%. Fe content in the media should be within 70-71%.

As the Indian coal has low liberation size and high near gravity materials, the top size and size range may be optimised to improve the separation efficiency. Lot of carbon value goes in the middling. It is needed to recover by crushing to the lower size fractions. In overall flotation circuit in coal beneficiation plant, metallurgical performance is not the desired level. The following reasons may be attributed for the observed reduction in flotation efficiency:

(i) Oxidation of coal surface,

(ii) Liberation size,

(iii) Insufficient of bubbles in the cell,

(iv) Requisite flotation reagent dosages.

During oxidation of coal surface, hydroxyl groups are formed on the surface. The coal surface becomes more hydrophilic. It does not allow the collector reagents to coat on the surface. In such cases, appropriate alcoholic reagents must be added to remove the hydroxyl group from the coal surface. This practice improves flotation efficiency. By crushing and grinding, the liberation size can be improved. In mechanical cell, due to erosion of stator and rotor, the requisite bubble size generation decreases. The additional facility may be added by introducing sparger in the cell to provide more bubbles for flotation. Based on the characteristics of coal, the flotation reagent dosages must be optimised in the plant. The chemical leaching of fine coal can be carried out to reduce the ash content of imported coal. However the cost economics must be ascertained to establish feasibility of the process and particular attention must be paid to ensure that there is no alteration in coal properties.

(ii) Non-coking coal

In Indian non-coking coal, the near gravity material is high. The beneficiation of non-coking coal should be done by heavy media process. It should be treated in heavy media bath to reject the gangue minerals which contains more than 80% ash. The product of heavy media bath can be directly used for power generation. This reject can be used for backfilling of the mines.

The heavy media bath product can be retreated in heavy media cyclone to produce low ash coal for metallurgical purpose and the reject can be used in the power plant. Here the beneficiation of coal needs good amount of water. Hence to reduce the water consumption, after crushing the coal at particular size, it may be classified at 6 or 3 mm. The -6/3 mm size may not be treated. It may be directly used in the power plant. The +6/3 mm size may be treated in heavy media bath to reject high ash particles. As the product and reject are coarse particles, the dewatering is easy. The product and reject carry less moisture on the surface. By this way, the overall consumption of water can be drastically reduced.

Wet processing of coal requires huge quantities of water. This gives an opportunity for dry beneficiation of coal. These techniques include sorting, electrostatic separation, magnetic and mechanical separation. These processes depend on the differences in physical properties between coal and gangue minerals such as density, size, shape, luster, magnetic susceptibility, electrical conductivity, radioactivity, etc. Air dense medium fluidised bed separation (ADMFBS) process, pneumatic jig, and FGX are used commercially for beneficiation of coal in dry process. Apart from these, lot of research is underway to treat fine particles of coal in electrostatic separator. Advantages of the dry beneficiation are given below:

- Water requirement of the industry will be reduced

- Water pollution due to effluent slurry could be avoided
- Taillings pond could be avoided
- Additional requirement of equipment for dewatering of coal will not be required
- Specific cost for transporting coal will be less.

Till today, the separation efficiency in dry beneficiation is not up to the mark. It needs lot of research to develop the process at a commercial scale to treat Indian coal.

It has been observed that some of the coal mines particularly in Mahanadi Coal field, the coal deposits are banded type. The alternative layer of coal and shell are there. The thickness of the layer is high. The selective mining can be done in this mine by surface miner. The coaly layer contains the ash percentage only in the range of 20-25% whereas the shelly layer contains the ash percentage around 70-80%. It does not require any physical beneficiation. The coaly layer can be beneficiated to produce less than 10% ash coal by heavy media cyclone, spiral concentrator, and flotation process. Both product and reject can be used for metallurgical purpose. This type of mine should be preserved by Govt. of India for metallurgical industries so that the import of coal can be reduced.

6. NON-COKING COAL TO COKE

At present, India is producing 90 million tonnes of steel per annum. Around 70% of total production comes through blast furnace route. The blast furnaces need coke as the fuel as well as the reducing agent. India has less reserve of coking coal. The attempt should be made for conversion of low ash non-coking coal to coking coal. This will be a major initiative toward substitution of imported coal.

Coking coals differ in properties from their non-coking counterpart particularly in terms of plasticity and fluidity. Furthermore, coking and non-coking coals differ with respect to the hydrogen content in their molecular structure. It is assumed that lack of hydrogen content leads to non-agglomerating behaviour of coal particles. Typically coking coals have high hydrogen content of more than 5.5%.

Non coking coals can be utilized for coke making by the following processes:

1. Hydrogenation of coal
2. Blending with high grade prime coking coal
3. Blending with carbonaceous materials
4. Using inorganic/organic binder for agglomeration

Hydrogenation of coal requires high temperature (300 to 700 °C) and pressure (3 to 20 MPa) for the reactions. By this method, non-coking coal is structurally changed to coking coal that can be then used for coke making. Non-coking coal can be blended with prime coking coal to produce coal blend which could be used for making good quality coke. Another way of utilizing non coking coal is by blending it with carbonaceous materials like pitch, waste plastics, molasses, sawdust, coconut shell, etc. to improve the hydrogen content and plasticity property of coal. Yet another way of utilizing non-coking coal, is to use inorganic binders like clay materials to make agglomeration of the coal particles. Finally, non-coking coal can also be used to prepare ferro-coke. Essentially, non-coking coal/Low volatile coal can be mixed and blended with iron ore fines in the coke oven to produce ferro-coke. It needs lot of R&D efforts to optimise the design and operating parameters.

7. CONCLUSIONS

1. For power sector, high ash non-coking coal can be beneficiated by two or three product basis to maximize the recovery of carbon values. The low ash product can be transported over long distance to power plant from pit head and high ash product can be utilized in the captive power plant at the pit head. The reject (more than 75% ash) should be used to refill the mines.

2. The coking coal should be beneficiated at lower size to maximize the carbon value in the concentrate and minimize the middling content in the process. The ultra fine coal should be treated by advanced flotation technique to increase the additional yield in the coking coal concentrate.

3. The selective mining for non-coking coal should be done wherever possible by surface miner to reject shale material at the mine site.

4. The combination of selective mining and beneficiation process for non-coking coal should be adopted to provide around 10% ash for metallurgical purpose.

5. Conversion of non-coking coal to coke is the need of the hour. R&D initiative must be taken to achieve this target using low ash non-coking coal by improvement of molecular structure of coal or adding inorganic and organic binders or blending with prime coking coal.

6. Ferro-coke may be another alternative to utilise non-coking coal and iron ore fines used as raw material in blast furnace.

Cutting edge technologies: Clean coal technologies

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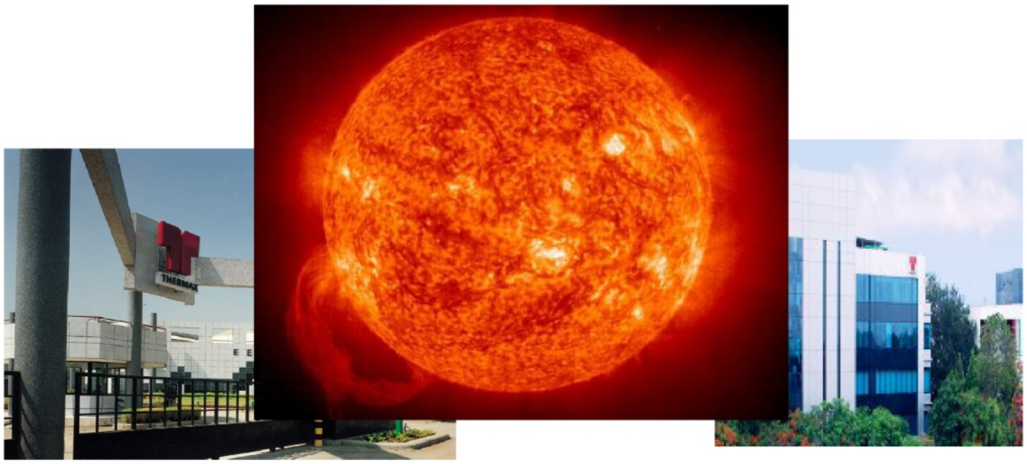
India’s fine balance between climate change and its millennium development goals

Dr. R.R. Sonde



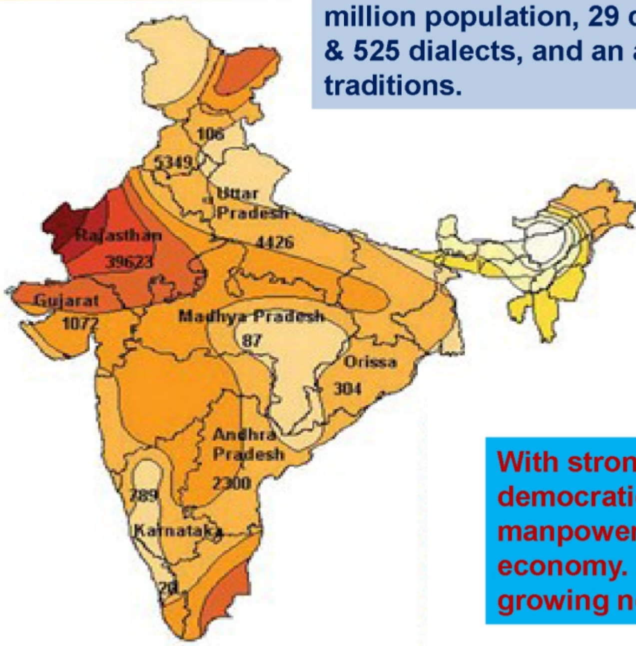
Coal post COP 21 Scenario

Dr R R Sonde

Executive Vice President, Research, Technology & Innovation Center

Formerly with Atomic energy Commission & NTPC Ltd.

India a country with subcontinental proportion and 1200 million population, 29 different federal units, 25 languages & 525 dialects, and an amazing array of rich and diverse traditions.



With one of the fastest growing world economy and at 2.24 trillion dollar economy (PPP) it stands at the sixth largest one. At PPP it is fourth largest

With strong institutions and well ingrained democratic principles, India has a young manpower ready for creating new age economy. Energy is crucial for India’s growing needs

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India’s energy security and growth agenda

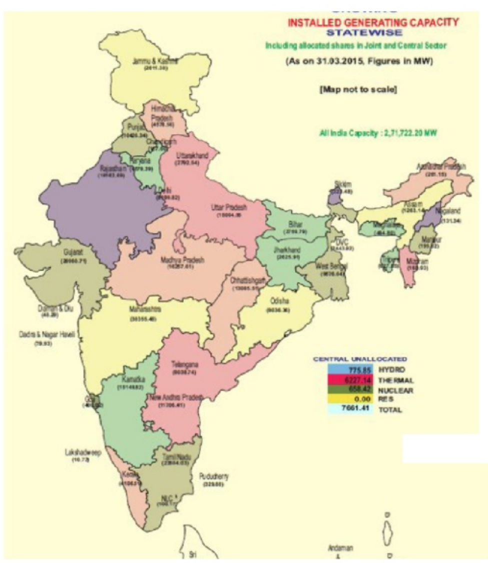
- Eighty percent of India’s oil is imported, 88% of gas is sourced from outside.
- India’s per capita energy consumption is one fourth of global average (380 kg of oil)
- With 270 GW of power generating capacity, its per capita electricity consumption is 870 kWhr and is slated to double in next ten years
- India has taken a very steep emission reduction commitments under COP 21. Signed it just a week ago.
- Coal is the only fossil fuel which India has a super abundance at 320 billion tonnes

INDIA’S FOCUS IS THEREFORE ON DEVELOPING CLEAN COAL TECHNOLOGIES

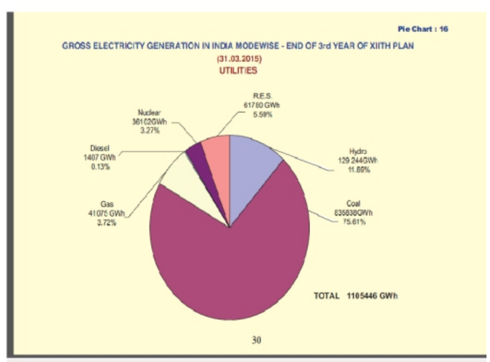
THERMAX Vibrant Years

INDIA’S PRIMARY ELECTRICITY NEEDS

272 Giga Watts of power generating capacity and near 1100 trillion units of annual generation is led on the back of coal



Distribution of power capacity ; Central – State- Private (IPP)

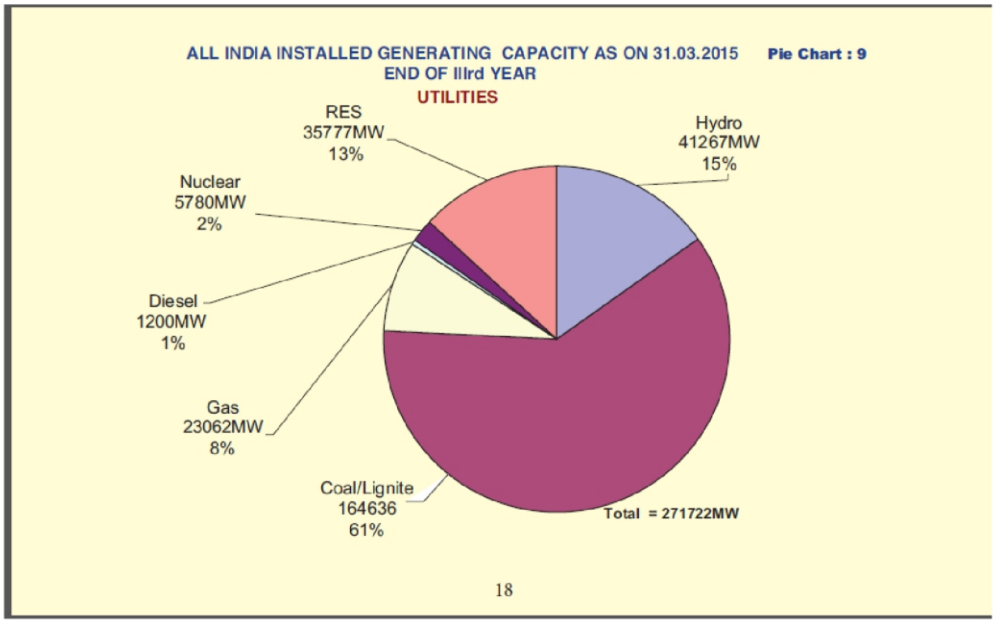


Units of electricity generated based on different primary energy resources. Coal all the way

THERMAX Vibrant Years

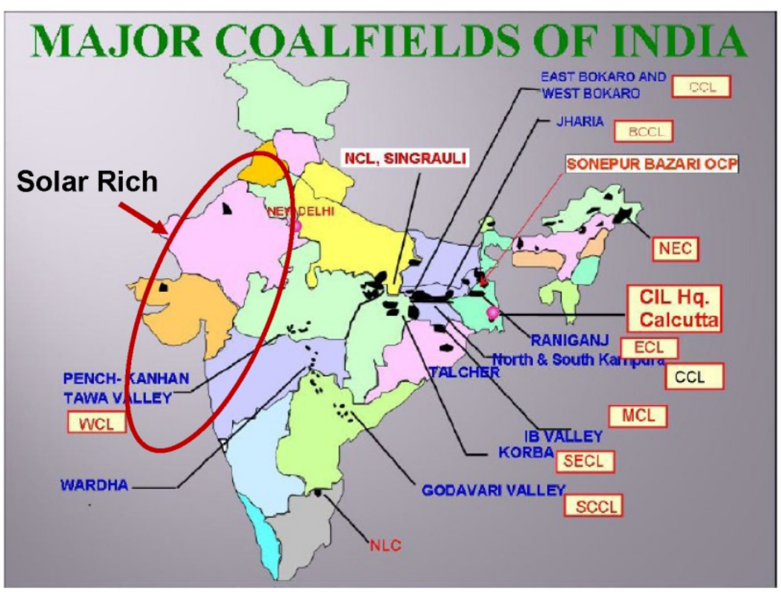
DOMINANCE OF COAL

At 61% capacity, it provides 73% of energy annually



INDIA'S COAL BELT

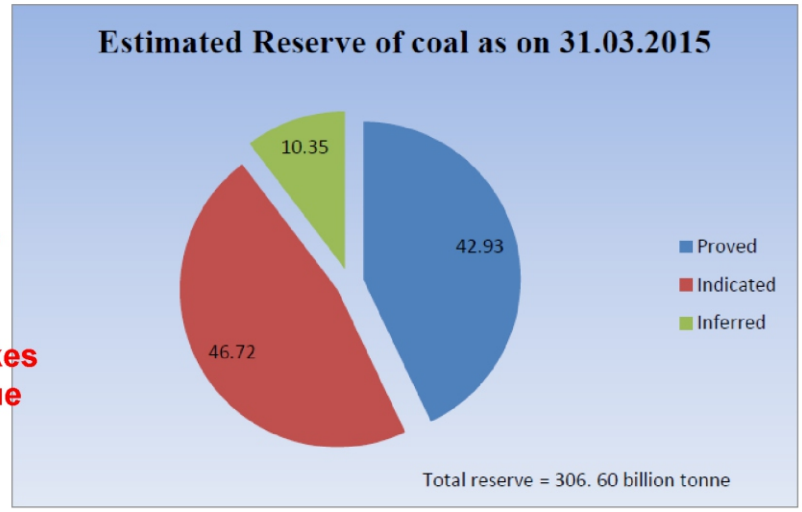
India has an interesting geography. Coal and solar can act in complimentary fashion



ABUNDANCE OF COAL

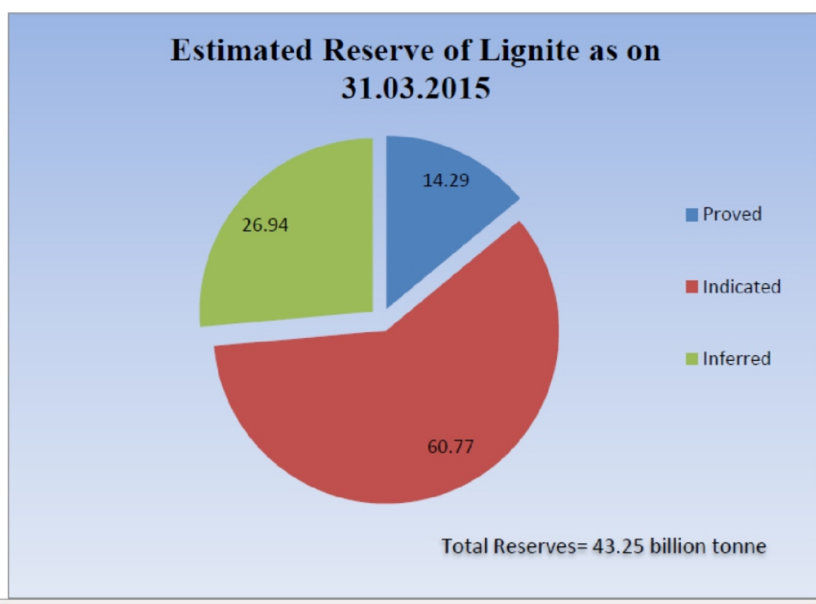
And here is the criticality of coal in India's scheme of things. Some coal seams are tough, low thickness and forest cover on top

High ash, morphology with higher inertinite content makes it very unique



Sub bituminous, six categories and low sulphur makes it combustion friendly but tough on particulate matter

Lignite is another primary energy source



High ash, Tropical temperature pose additional challenges

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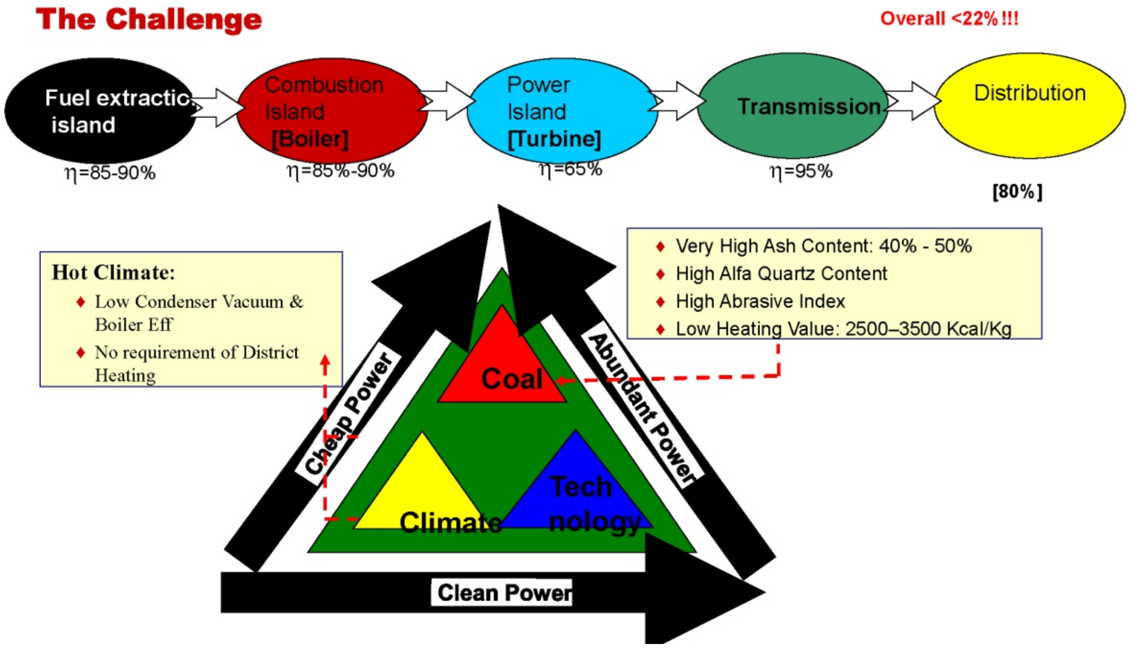
Clean Power

Producing clean power with coal, even today, is a challenge

The Challenge



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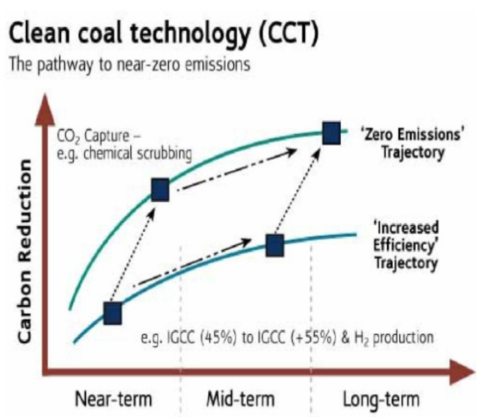
Clean coal technologies: Indian context

Energy Technologies
Future Delivered



A **Fact File:**
India has already built 175 Gw of coal power at utility scale + 35 Gw of coal power at Captive scale

Coal based process boilers amounting to 80 Gw have already proliferated in the system

B **Emissions due to SPM, SOx, NOx, Hg and RSPM are posing huge problems at local level**

C **Coal quality is deteriorating and blended coal from imported origin is also very low quality posing unburnt carbon nuisance**

D Finally CO2 emissions remains to be addressed

We need new GOALS, New Paradigms and Bold implementation Programme

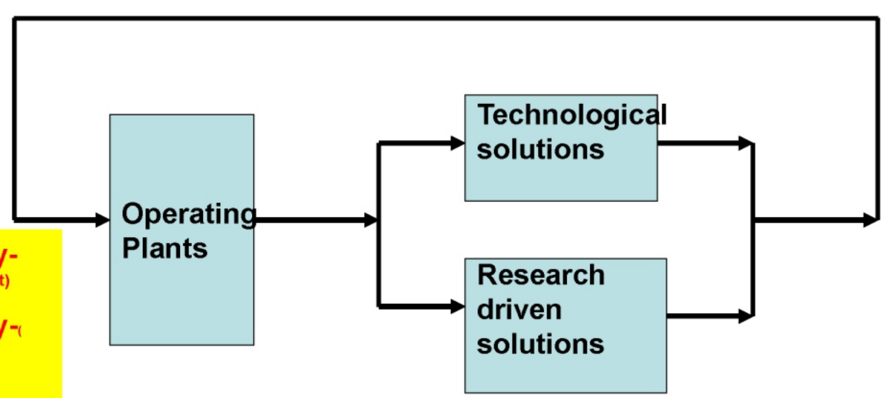
This is true even at global level.

SEVEN GOALS FOR CLEAN COAL TECHNOLOGIES

Goal 1: Enhance efficiency

Set high efficiency from the operating plants. This means use of advanced tools to keep the process optimum

Lowest hanging fruit in clean coal technology pathway. Reduce specific CO2 emission to 0.82 kg of CO2 per kwhr.



- **Efficiency-** (15% improvement)
- **Reliability-(** •20% improvement)
- **Emission** (12% improvement)

We have to move from know-how to know –why domain in power plants using advanced tools

Development of on line plant optimization tools (goal1)

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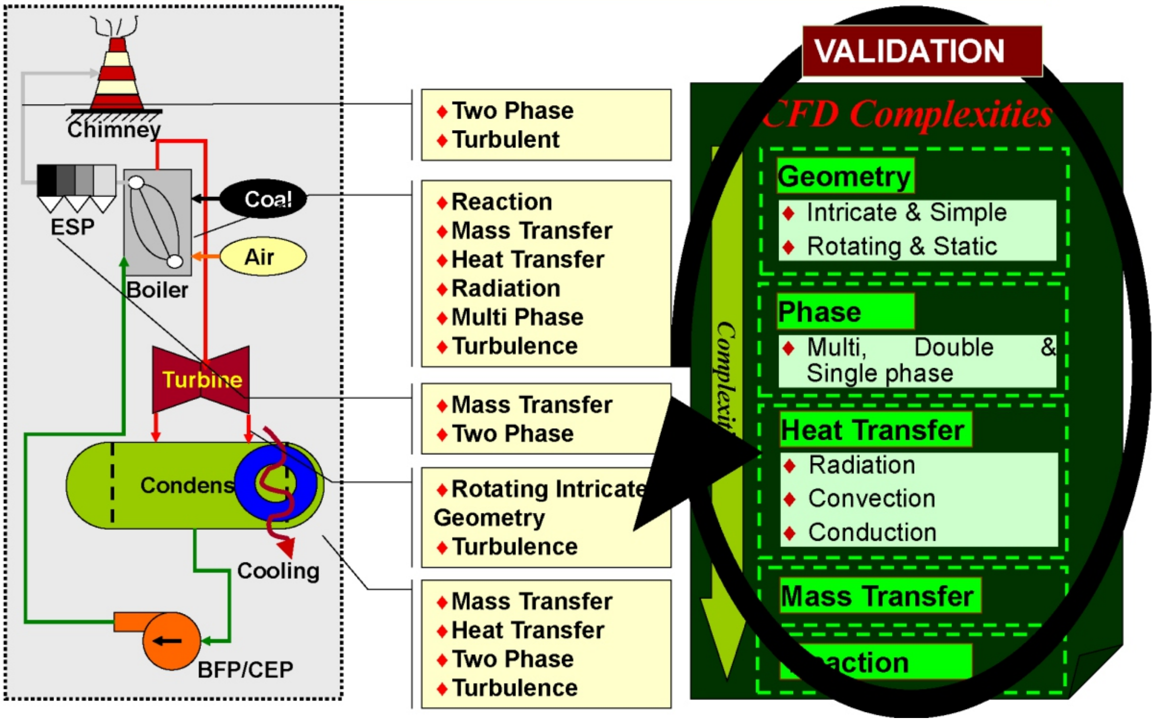
Use of new sensors, data based AI models, CFD simulations



Efficiency Improvement : Low grade waste heat recovery; Goal 1

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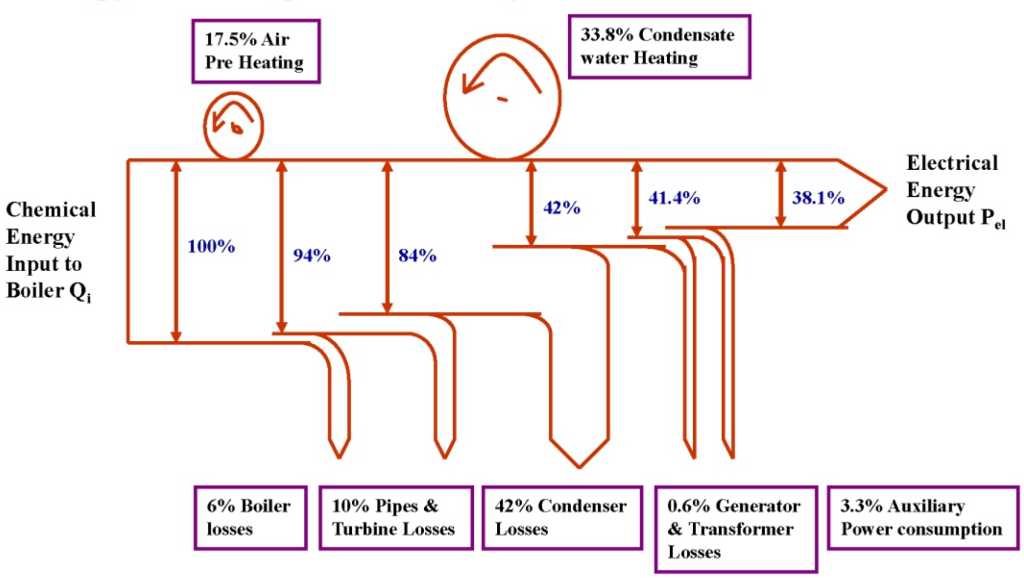
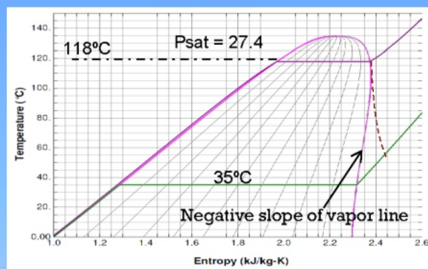
Energy flow Diagram: Ideal Cycle



Organic Rankine (ORC) can convert low grade heat into electricity

Modern bottoming cycles: Organic Rankine

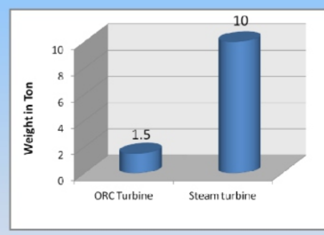
Isobutane



Organic Rankine Cycle

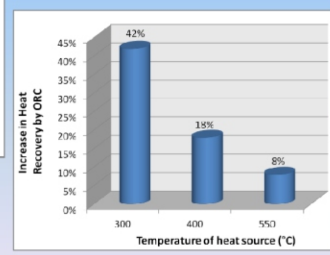
- Organic Rankine Cycle turbine uses a binary fluid to generate Electricity.
- These fluids have a negative slope of vapor line and hence can be used a lower temperatures of operation
- Give higher efficiency than steam turbines at temperatures of 120°C to180°C

Thermax ORC Turbine system for 300 kWe Installed at IISc, Bangalore



ORC is lighter and occupies less space

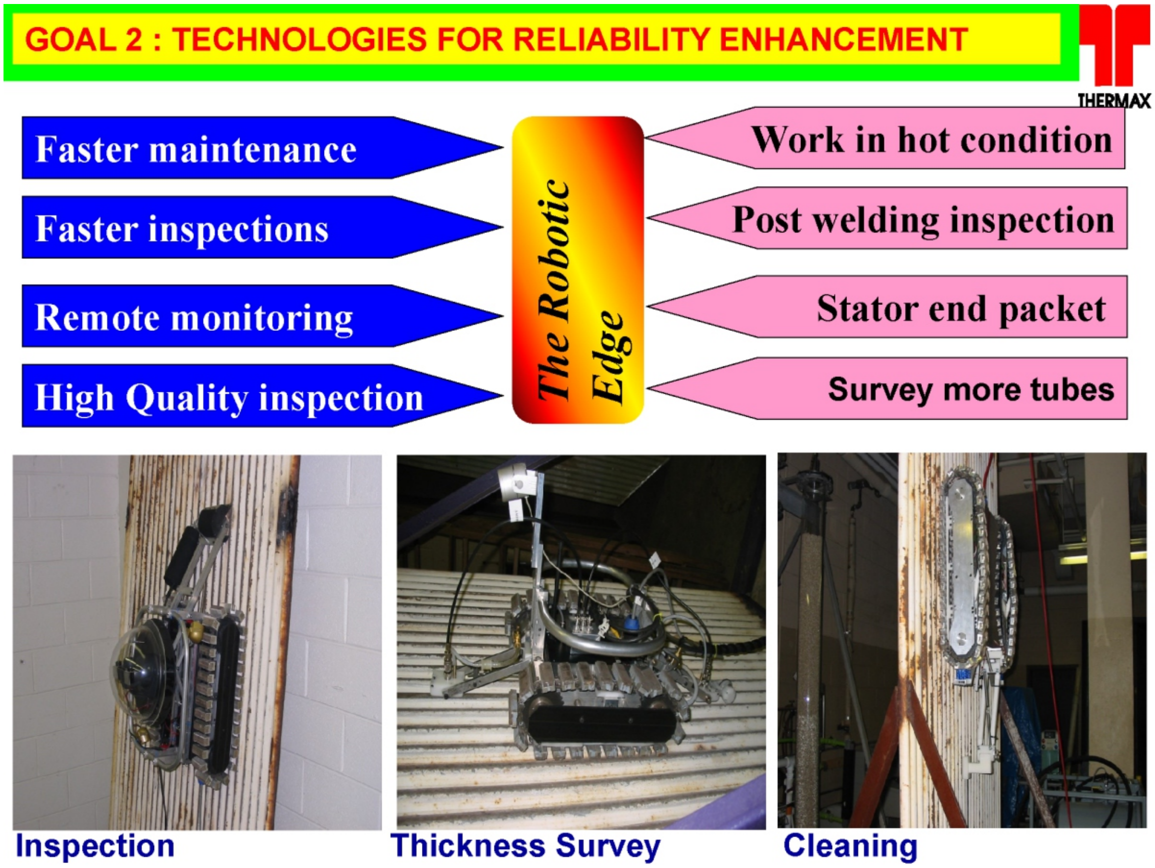
Heat Recovery to Electrical power at 150°C



ORC Delivers more heat than Steam

LOW GRADE WASTE HEAT TO POWER
Developments drive technology to meet market demand

Generating 10-300 kW power from waste heat: ORC power from flue gas / low pressure steam



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Goal 1 and Goal 2 can together enhance the efficiency and plant load factor (PLF) by at least 7.5% and can enable reduction in CO2 emission. It also means enhancement of capacity by 20,000 MW !!

TECHNOLOGIES FOR EMISSION CONTROL: GOAL 3

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Indian Scenario

Problem Basket

- **Very High Inlet Dust Burden** [70,000 mg/NM3]
- **Very High Ash Resistivity** [10^{13} –10^{14} ohm/cm]
- **Very Low Sulfur** [0.3% - 0.5%]
- **Very Exit Gas Temp** [140C-180C]

The Drivers

- **Impending Stringent Environmental Norms**
- **Cheap Power & Economic Solutions**

Probably the Solution is 'Integrated Emission Control'

RSPM, SOX, NOX, MERCURY (retrofit for many possible)

EMISSION NORMS : BECOMING STRINGENT

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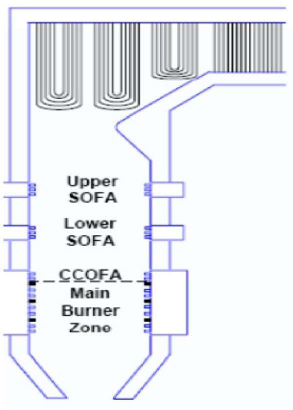
	OLD NORMS	NEW NORMS (mg/Nm³) Installed before 31.12.2003		Installed after 01.01.2003 & upto 31.12.2016		To be installed from 01.01.2017
Unit Size	All	< 500 MW	$\geq$ 500 MW	< 500 MW	$\geq$ 500 MW	All
SO_2	Dispersion through Chimney	600	200	600	200	100
NOx	No Standard	600		300		100
SPM	100	100		50		30
Mercury	No Standard	x	0.03	0.03		0.03

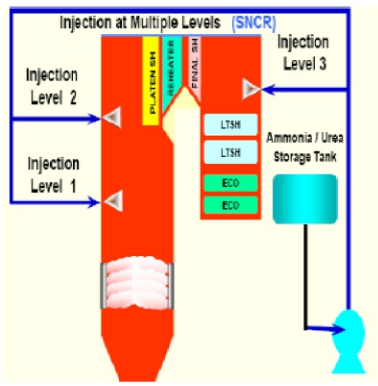
Retrofit technologies

DeNOx Technologies

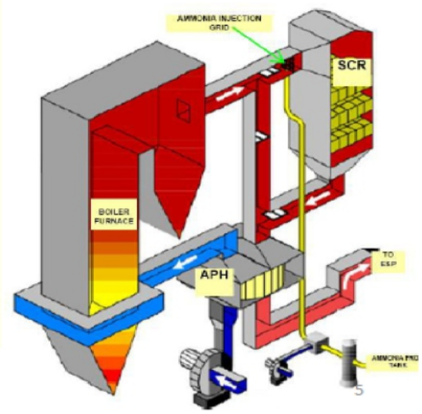
Combustion Modification



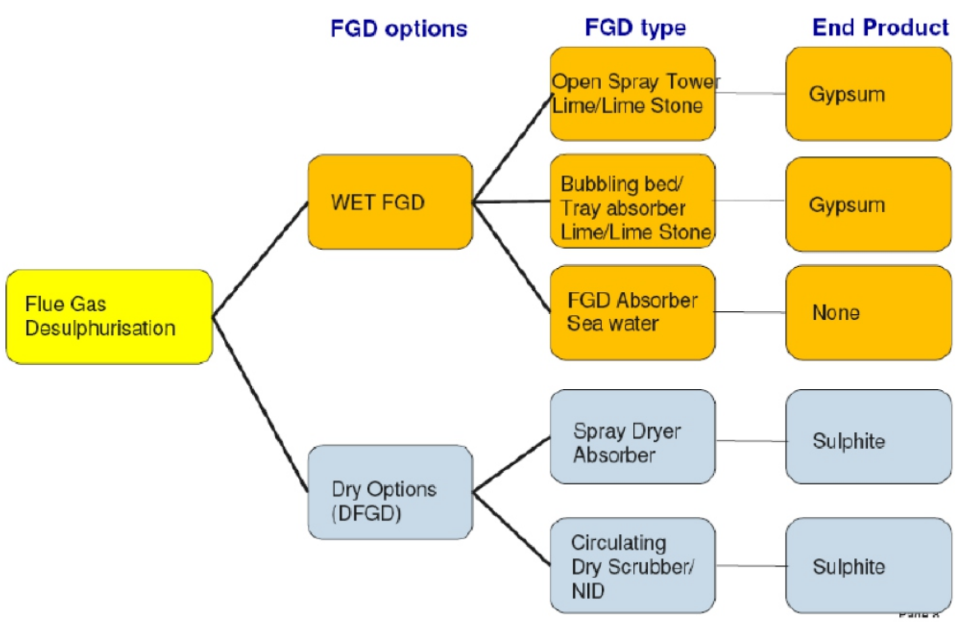
Selective Non-Catalytic Reduction (SNCR)



Selective Catalytic Reduction (SCR)



DeSOx Technologies



GOAL 4: WATER REDUCTION TECHNOLOGIES

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Water – Energy nexus is posing a huge challenge in India. We need multi pronged efforts to handle this crisis. Water consumption per unit of power produced should be set at less than 2 m3/kwhr, and, for meeting this target, new water technologies should be deployed.

1. Water pinch technologies
2. Membrane, CDI and many new emerging separation technologies
3. Water recovery from flue/fuel
4. Hybrid cooling system

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Goal 3 and Goal 4 will enable much purer clean air and better availability of drinking water

GOAL 5: WASHING OF COAL AND DESIGN OF NEW COMBUSTION SYSTEMS

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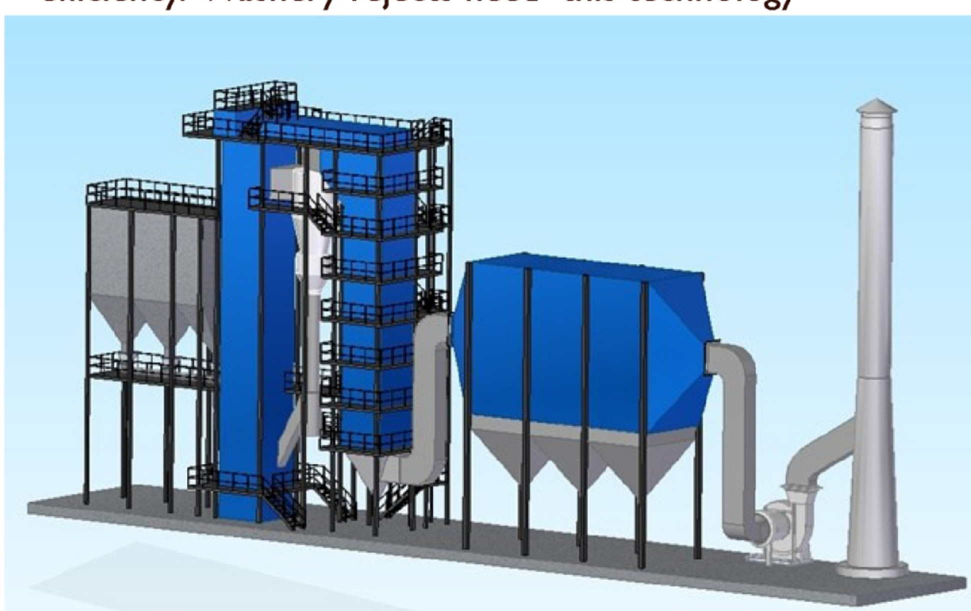
Coal quality deterioration and use of multiple types of fuels demand new combustion technologies even at small scale (at 10-50 TPH scale)

BOILERS FOR LOW QUALITY COAL; Goal 5

Boilers may have to designed with CFBC concept to handle poor quality fuel with very high carbon conversion efficiency. Washery rejects need this technology



E2F2™ SUPERCIRC ™ BOILERS

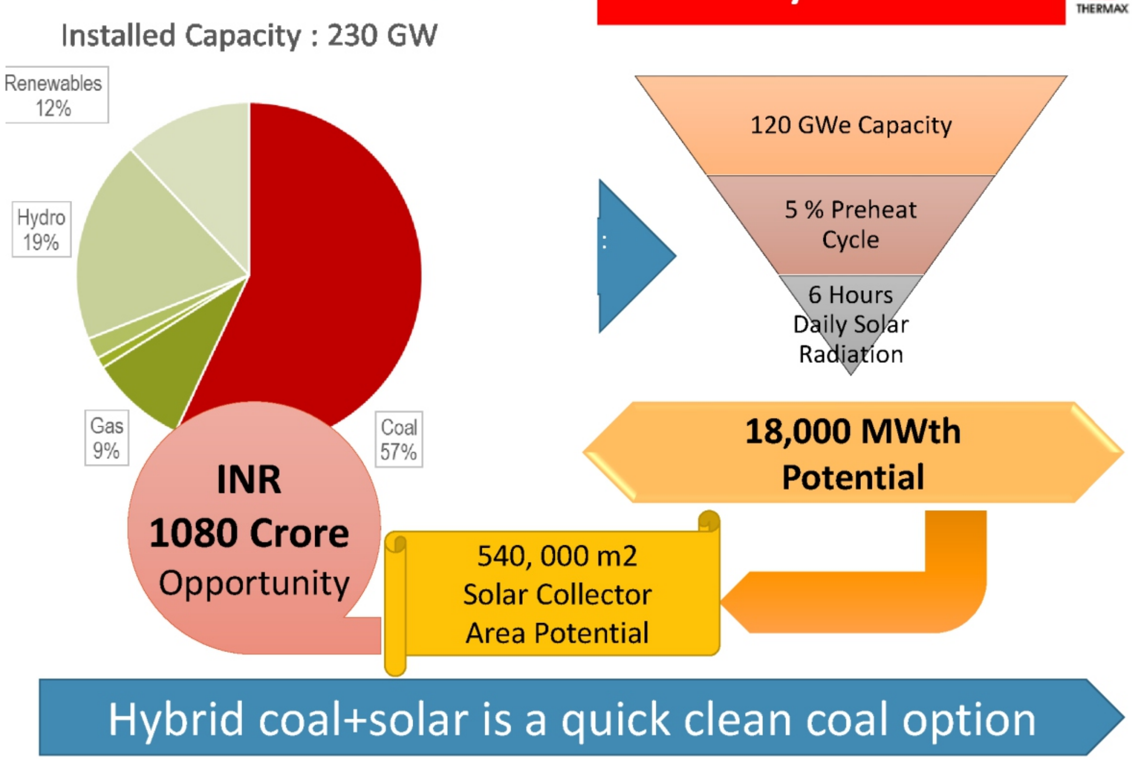
The bedrock of SUPERCIRC ™ is based on the following E2F2 goals

1. Efficiency – High efficiency (Higher conversion and low UBC) 84% + for low quality fuels

2. Emission- Lower emission (low Nox by NOVALOOP™ combustor design, Low Sox by in situ lime addition and SPM by ESP)

3. Fuel flexibility – Co firing with biomass (as per different regions) Special design for blended fuels from fuel feeding to combustor design

Goal 6: Solar integrated Power Preheat Cycle



Hybridization : 500 MW

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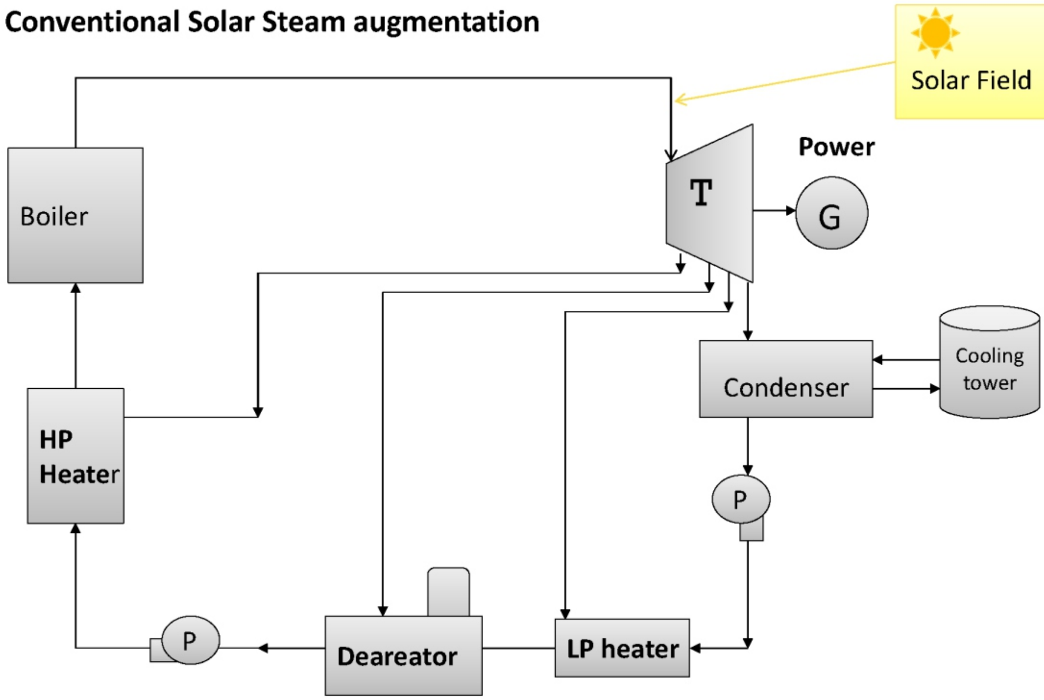
Conventional Solar Steam augmentation



Smart Hybridization : 500 MW

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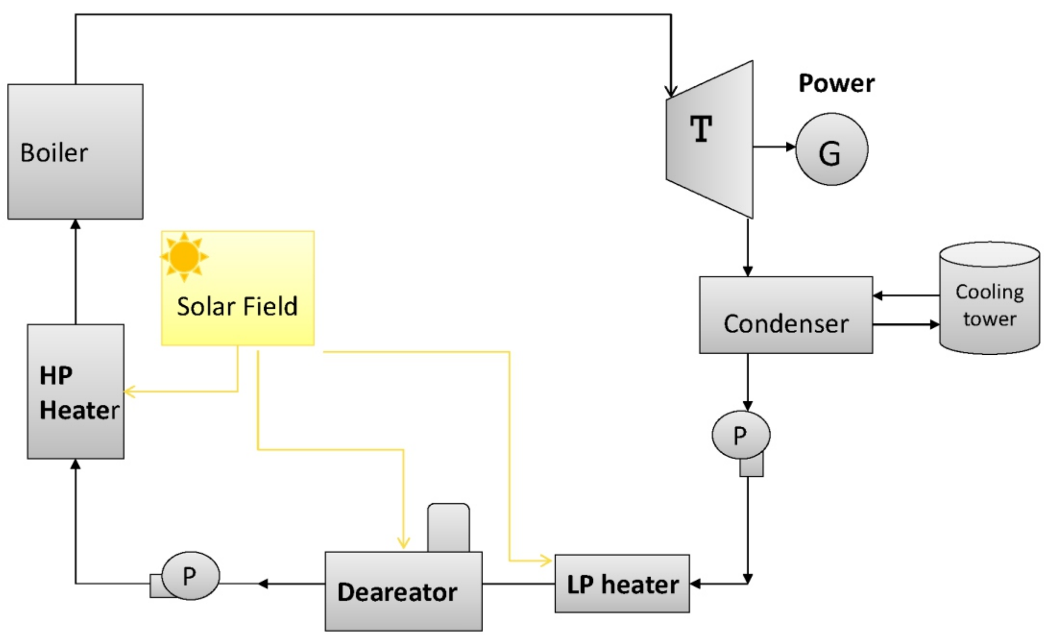
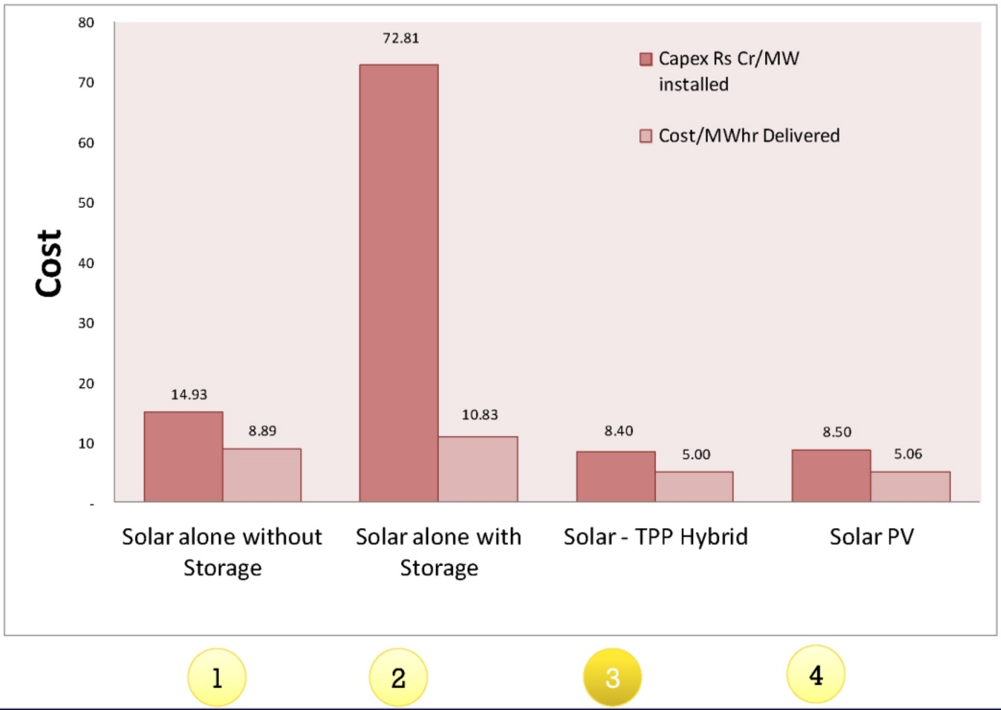
Replacing all Turbine extraction with Solar



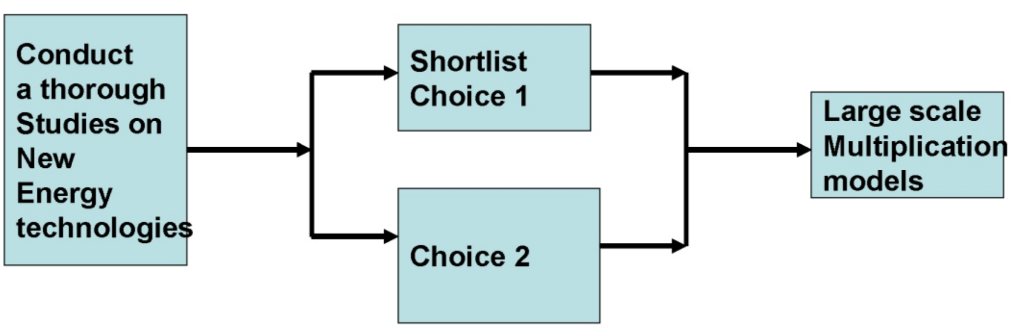
Smart Hybridization most cost effective Solar



Goal 7: New Clean Coal Technologies

Critical analysis is necessary for bringing insight into the best option for India considering the nature of coal and climate and manufacturing capabilities

Oil and gas for transport, industrial and kitchen applications, demand new fuels like ethanol, methanol, DME etc. Coal with appropriate CO2 capture can become back bone of such liquid fuels for India



How do we build robust new IP platforms?

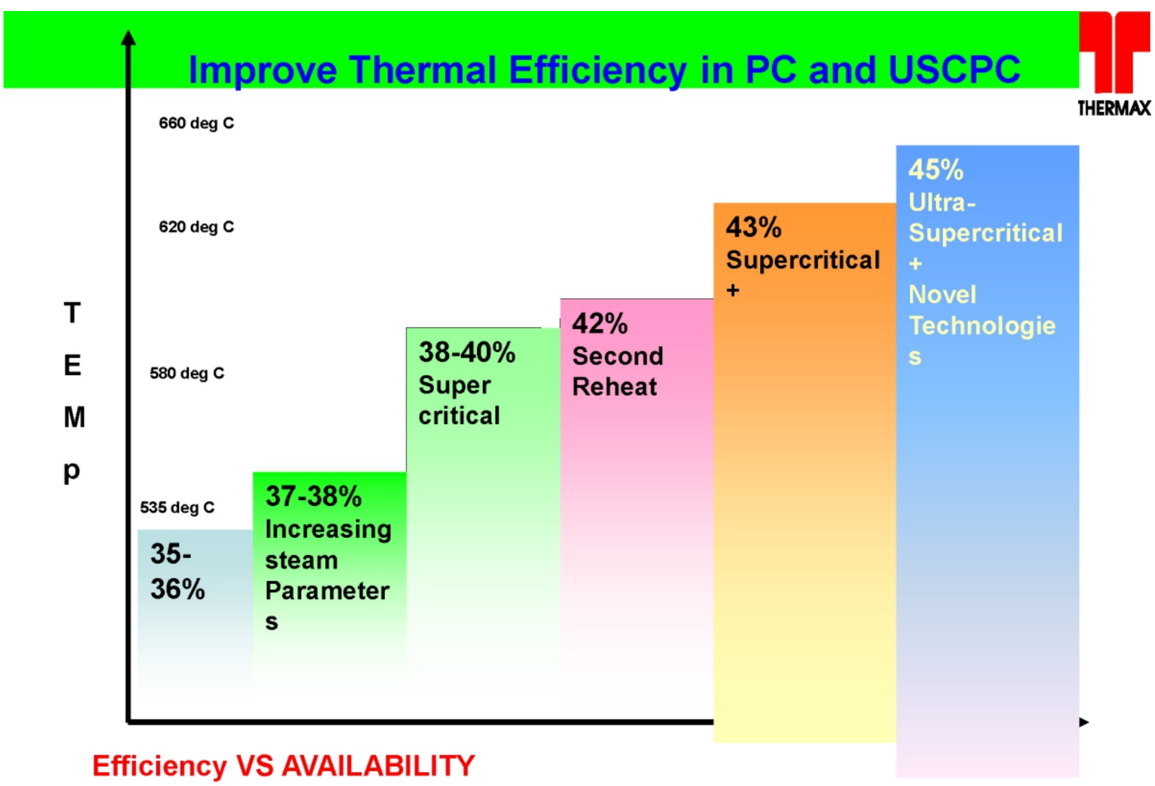
COAL TO POWER GENERATION TECHNOLOGY PROGRESSION IN INDIA

Evolution of Unit Size and Efficiency for Coal Based Plants in India

Period	1950s	1960s	1970s	1977	1983	Uder Constrn.
Unit Size	30 MW to 50 MW	60 MW to 100 MW	110 MW to 120 MW	200 MW to 250 MW	500 MW	660 MW
Turb Inlet Pressure / Temp	60 ata 480° C	70 to 90 ata 490 to 535° C	130 ata 535° C	130 ata 537° C	170 ata 537° C	247 ata 537° C
Reheat Temp.	No Reheat	No Reheat	535° C	537° C	537° C	565° C
Turbine Cycle Heat rate (kCal/kW-hr)	2470	2370	2060 to 2190	1965	1945	1900
Gross efficiency (%)	29	30.5	33 to 35	37.2	37.6	38.5

620 – 690 C advanced ultra super critical technologies Cost + New materials + Reliability

The high ash coal and the morphology of coal were adequately NOT factored in the design and technology. Over the years, the coal quality has deteriorated substantially resulting in huge challenges



Efficiency VS AVAILABILITY

Critical aspects on Indian coal (high ash, high alpha quartz) need to be understood in terms of its impact on plant AVAILABILITY

COAL TO GAS TO LIQUID AND CO-GENERATION SYSTEMS
FIXING CO2 BY RENEWABLE HYDROGEN

COAL GASIFICATION IN OUR UNDERSTANDING IS THE HOLY GRAIL

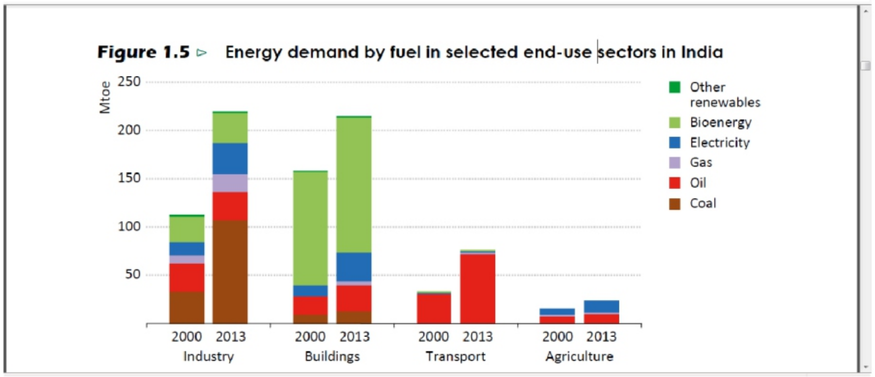
CHANGING PARADIGM FOR INDIA

As solar penetration will happen in electricity sector with storage also included, coal in India will assume larger importance to liquid fuels.

Coal to methanol and FT fuels will be the new changing paradigm

Distributed energy usage via fuel cell based power systems running on Methanol will push CO2 fixation terrestrially than geologically. This will create a very positive way to manage CCS

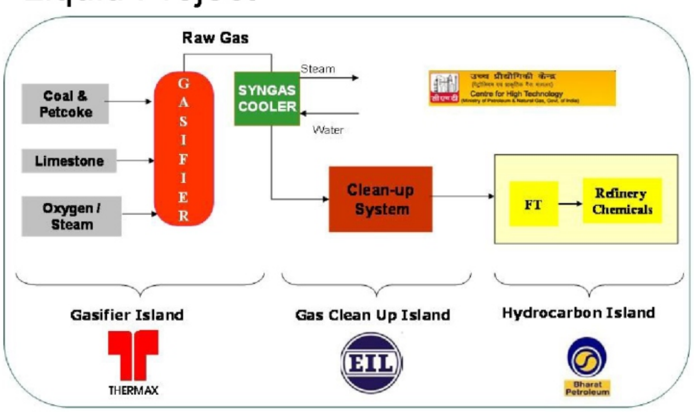
Electricity forms just about 12% of the total consumption when all energy consumption is converted to MTOE – million tonnes of oil equivalent.



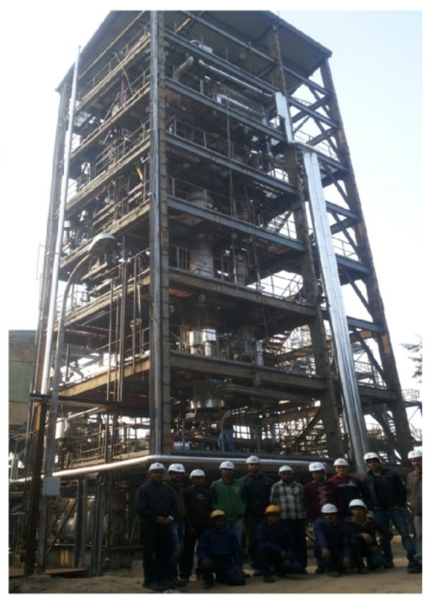
OIL SUBSTITUTION IS CRUCIAL FOR INDIA AND COAL CAN FILL THAT SPACE. CLEAN COAL GASIFICATION TECHNOLOGY IS A COMPELLING REASON FOR INDIA

Thermax's Developments : CTL Gasifier

High Pressure Gasifier for Coal to Liquid Project



High ash Indian coal , Lignite and petcoke. Operated till 4 bar



Gasification plant

THERMAX - CONFIDENTIAL

Thermax's Developments : CTL Gasifier

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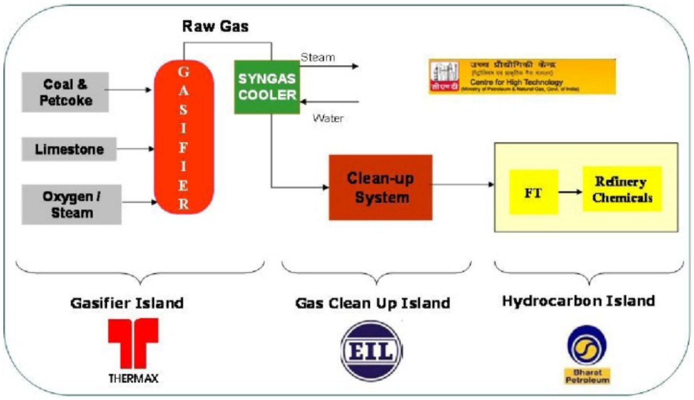
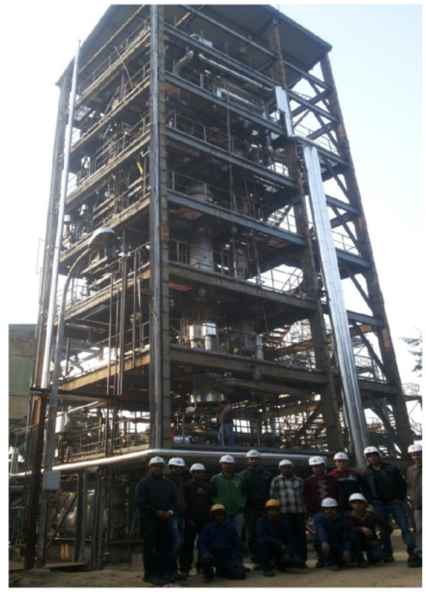
High Pressure Gasifier for Coal to Liquid Project



High ash Indian coal , Lignite and petcoke. Operated till 4 bar



Gasification plant

CFBG 1 MW Pilot Plant (INDO-EU FP7)

THERMAX

- Fluidized bed Gasifier for high ash coal
- High pressure solid feeding and Ash withdrawal arrangement
- Syngas cooler + Venturi scrubber for ash cooling and particulate removal
- Filter press to remove ash to recycle water to venturi scrubber
- N2 generation from pressure swing adsorption plant (PSA)
- Syngas combustor to check burnablity of syngas

Syngas Characteristic Measurement Facility

Gas Chromatography (GC) facility for measurement of syngas composition and tar

Gas sampling system for Syngas and tar near to syngas combustor

Particle Samples

Syngas flame observed from view port

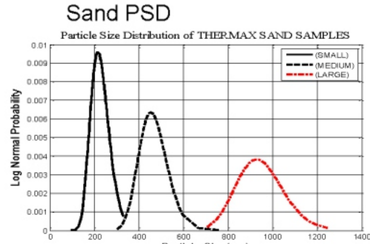
Cold flow Fluidized bed Set up

Column dimension

- Dia: - 150 mm
- Height: - 8000 mm

Air flowrate:
400 m3/hr @
3000 mmH2O

Sand PSD

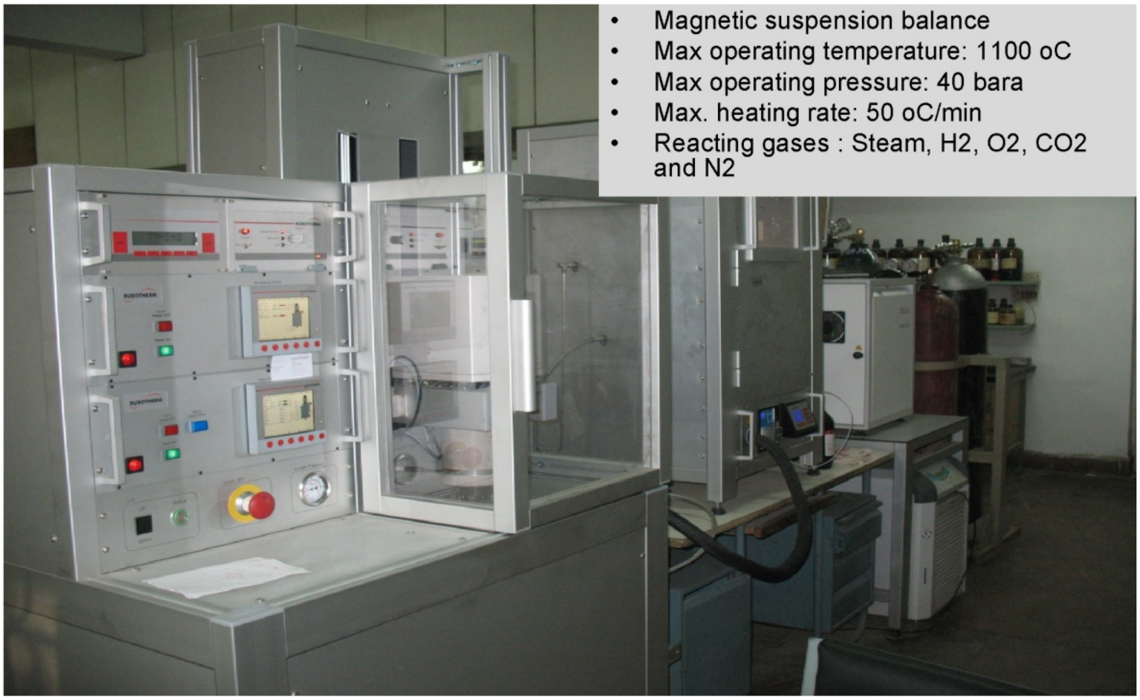


Samples	Large	Medium	Small
Geometric Mean Dia.	940	462	223
Standard deviation	1.11	1.14	1.20

Fuel Characterization: HPTGA

THERMAX

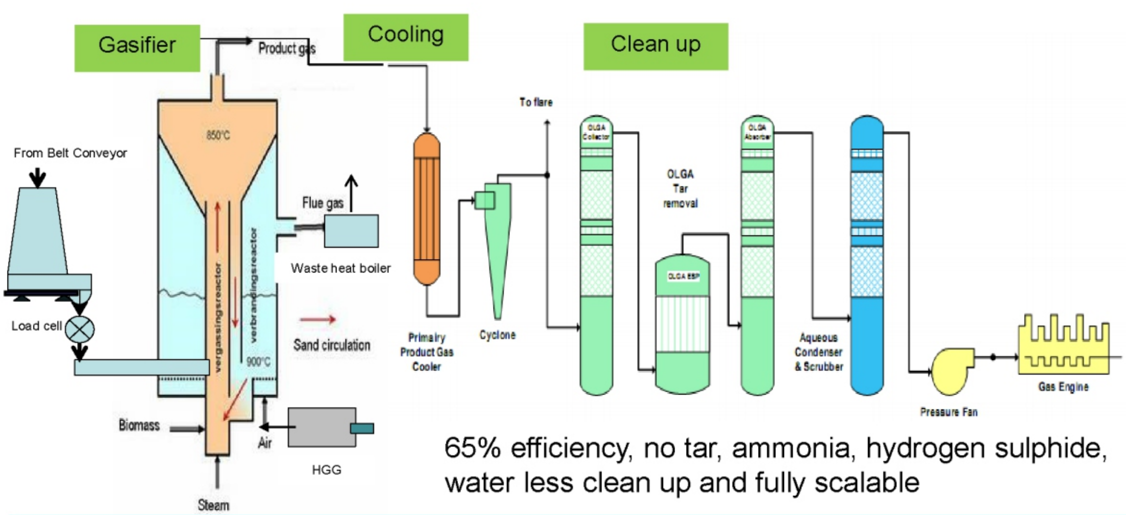
- Magnetic suspension balance
- Max operating temperature: 1100 oC
- Max operating pressure: 40 bara
- Max. heating rate: 50 oC/min
- Reacting gases : Steam, H2, O2, CO2 and N2



Biomass – agro residue / MSW gasification using indirect gasification technology

THERMAX

Best-in-class technology for methanol production



65% efficiency, no tar, ammonia, hydrogen sulphide, water less clean up and fully scalable

Capacity: 1 MW_e Power + 1 MW_{th} steam (+ 1MW_{th} eq. hot water)

Syngas CV = >3000 kcal/Nm3

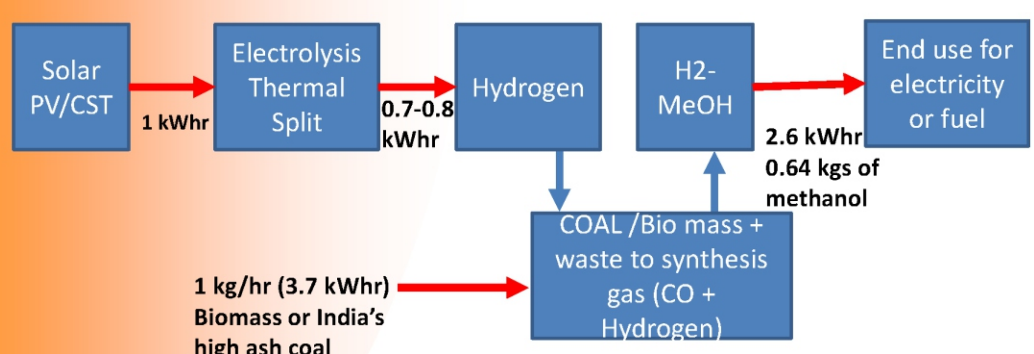
1 MWe Power Plant Ruchi Soya Ind. Ltd. At Washim in Maharastra

THERMAX

Plant is under commissioning stage

COAL + SOLAR TO METHANOL BY HYBRID DESIGN

Renewable plus Waste biomass (plus fossil to begin with)



Hybridising solar with biomass or fossil greatly enhance the yield and efficiency to methanol conversion. Efficiency is boosted nearly double by this process.

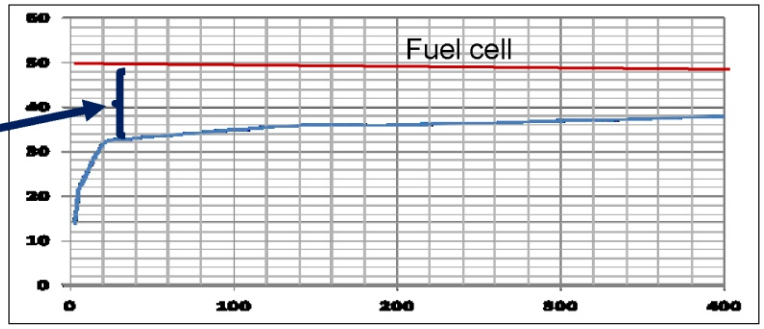
Fix CO_2 terrestrially using hydrogen from splitting water using solar and generate methanol as a fuel.

THERMAX 50 Vibrant Years

HYDROGEN BASED ECONOMY REALIZED VIA METHANOL/ BIO FUELS

THERMAX

Methanol enables this efficiency enhancement

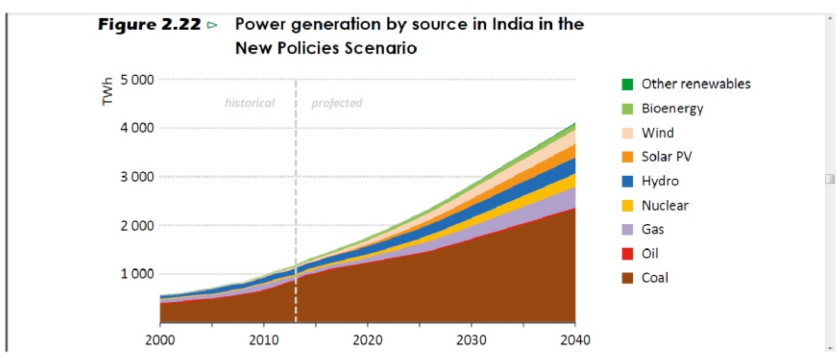


Fuel cells will become ubiquitous as small and distributed power generating plants and fuel will be methanol generated from clean coal gasification systems

ONE MORE TIME: COAL WILL STILL DOMINATE INDIA'S ENERGY NEEDS AND TRUE AT GLOBAL PLATFORM

THERMAX

Even in 2040 Coal will dominate India's energy systems and clean coal technologies proposed under seven goals will manage coal and CO2.



International collaboration will be the need for meeting this challenge

CONCLUSION : WHAT IS PROPOSED?

THERMAX

I

- On line power plant optimization / reliability enhancement tools
- Retrofit SOX, NOX and SPM abatement technologies
- Waste heat recovery systems (ORC+ Heat Pumps)

II

- CFBC designs for biomass blends + coal washeries rejects
- CSP Integration with Thermal Power Plant

III

- Coal gasification and methanol based economy

Thank You!

THERMAX

Hybridization With Solar Thermal
The Green Steam Initiative

Injecting Solar Thermal Heat into Coal Fired Power Plants: Clean Coal Technology

A review of research needs.

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Table of Contents

1. PREAMBLE

The Round Table on "Clean Coal Technologies in India: Current Status, Demands and Aspirations - Pathways to Achievements" was held on June 10, 2016 at New Delhi at the behest of the DST. Pursuant to the talk on injecting solar-thermal heat into coal power plants to offset coal burning, it was suggested that a team be put together to study this **Hybridization** option with a view towards identifying national priorities for research and support in this regard. This report is the result of that effort. It is a first step in an endeavour that is particularly suited for India's economic needs and geo-strategic constraints.This initiative is based on concepts discussed in detail in our paper titled "Solar Thermal Technologies as a Bridge from Fossil Fuels to Renewables" published in the journal *Nature Climate Change* in 2015.

For the purposes of this report, this strategy will be called the **G**reen **S**team **I**nitiative (GSI).

2. INTRODUCTION

The concept of injecting solar thermal heat into coal fired power plants has already been implemented on a small scale at select thermal power stations around the world. Notable plants listed on the SolarPACES webpage[1]are the Martin-Next-Generation-Solar-Energy-Centre in South Florida (with installed solar capacity corresponding to 2% of the 3.8 GW plant), Kogan Creek Solar Boost in Australia (6% of 750 MW), ISCC Kuryamat in Egypt (15% of 140 MW) and ISCC HassiR'Mel in Algeria (17% of 150 MW). This approach incrementally reduces consumption of coal in thermal power plants, and can ultimately *displace* fossil fuel firing altogether (see Fig. ***1***). A comprehensive techno-economic analysis[2] of this approach has shown that it is *always* more profitable than carbon-capture-and-sequestration (CCS) for equivalent greenhouse gas mitigation and that it can become competitive with coal fired power provided the cost of the solar collectors drops to about 25% of the current. This strategy is especially attractive for India because all components necessary to execute it can be *indigenously* manufactured and provides and *evolutionary* mechanism for coal power plant operators to transition to renewables. If properly implemented, we can see a solar-thermal takeover of coal power plants and the Indian economy can be the world pioneer in transitioning to renewables while simultaneously giving a welcome boost to India's industrial base: well in keeping with the "Make in India" initiative.

In view of the potential, it is essential to develop a comprehensive roadmap of the way ahead. This includes gathering together competent and dedicated teams of scientists, engineers, economists and civil servants to work through the implications of various aspects: ranging from research needs to technological and manufacturing constraints to policy and regulatory frameworks.

This report is a brief overview of the anticipated research developments that must occur for this strategy to be feasibly implemented. The report is divided into several sections. Each section, which is about a page and a half in length, deals with a particular area of research that the authors

[1]CSP Projects Around the World. *SolarPACES* at http://www.solarpaces.org/csp-technology/csp-projects-around-the-world

[2]Dalvi, V. H.; Panse, S. V.; Joshi, J. B. "Solar Thermal Technologies as a Bridge from Fossil Fuels to Renewables" *Nature Climate Change 2015(doi: 10.1038/NCLIMATE2717.*

consider to be of considerable importance to the overall success of the GSI (Green Steam Initiative).

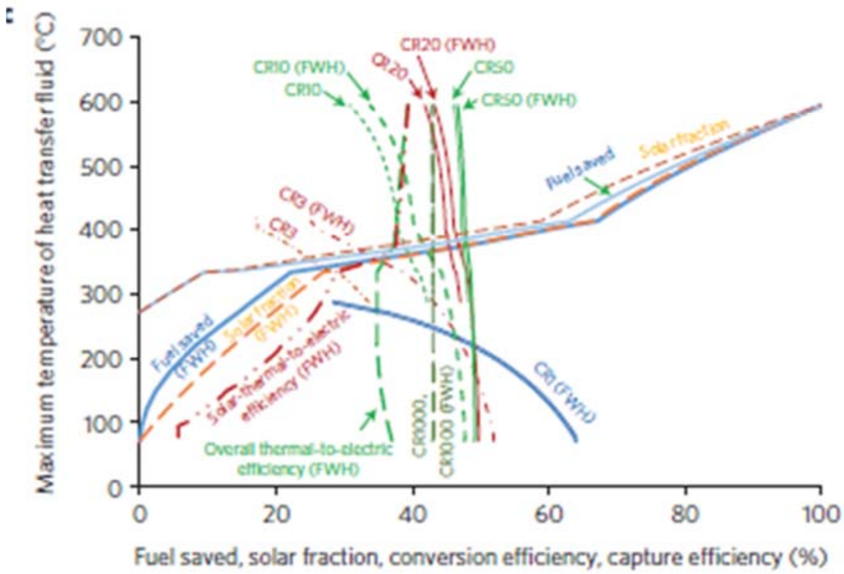

Fig. 1 : Taken from Ref. 2. A summary of the potential of the GSI. If the temperature of the heat transfer fluid coming from the solar field remains at the current level of 400°C, as much as 57% of coal firing can be offset from a sub-critical Rankine cycle power plant. All coal firing can be offset if the solar field exit temperature reaches 600°C. Here is potential for a solar-thermal takeover of coal fired power plants

3. REVIEW OF AVAILABLE RESOURCES

A vitally important part of this effort is a comprehensive, nationwide survey of solar *and* land availability in the vicinity of current and future power plants. Several excellent studies have already been made available by the Ministry of New and Renewable Energy (MNRE)[3] and the National Renewable Energy Laboratory (NREL)[4] of the United States. It is now necessary to match this data with location of coal plants with additional data of topography, settlements, vital infrastructure, water bodies, nature preserves etc so that the executors of GSI can not only be saved unnecessary surprises but also be able to develop thoughtful workarounds keeping in mind the various constraints. A good example of such an endeavor is the work by Turchi et al[5] which investigated solar *boost* potential of coal power plants in the United States of America.

However, it is not sufficient to merely present analysis of gathered data. It is vitally important that the primary data files be cleaned and uploaded onto an online database with an easy to us, well documented API (Application Programming Interface) so as to facilitate access to and analysis of that data by a large number of researchers. To this end, software must be commissioned that minimizes effort of raw data collection, classification and backed-up storage.

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[3]http://mnre.gov.in/sec/solar-assmnt.htm
[4]http://rredc.nrel.gov/solar/new_data/India/about.html
[5]Turchi, C. S., Langle, N., Bedilion, R. & Libby, C. Solar-augment potential of US fossil-fired power plants. (National Renewable Energy Laboratory, 2011). at http://www.osti.gov/bridge

Further, decentralized data gathering mechanisms should be set-up so as to remove a critical barrier between data-generation and its storage and dispersal.

An important outcome of such an exercise would be either one or both of the following: (1) a protocol to evaluate the suitability of a site for GSI which takes into account various aspects of the problem (civil work necessary, land acquisition issues etc) and assigns a weightage to each and/or (2) a well-trained machine learning algorithm or expert system that incorporates said insights. The protocol/algorithm must be updated regularly to keep pace with developments in technology or legal frameworks.

This task would be best suited for a team of economists, surveyors, civil-servants and statisticians or data-scientists. Since such a team is most likely to be found in institutes of management, the schools of management of the various Indian Institutes of Technology around the country as well as the Institutes of Management can be tapped their expertise. However, in the Indian context, given its extensive network of power plants and long history of operation, the task can be managed almost entirely by the National Thermal Power Corporation of India.

(**Note:** As an example of the expected output of this endeavor, please see the Environment and Health Atlas for England and Wales[6]. It is a comprehensive study of lung cancer presented in a very intuitive, interactive and informative format. Such tools are invaluable in making informed decisions.)

4. MEASUREMENT/ESTIMATE OF ELECTRICITY PRODUCTION ATTRIBUTABLE TO SOLAR

The main aim of the GSI is to inject solar heat into coal plants in order to offset an equivalent quantity of coal firing. To help the initiative in its initial period, it is necessary to offer a subsidy or incentive for power plants that decide to incorporate solar heating. An important question then is how much of the produced electricity is attributable to the solar fraction. This is by no means a trivial problem. The electricity produced from solar heat is a function of temperature and point of injection (as shown in Ref. 2) and the relationship is highly convoluted. Since the two heat-streams (from coal and from the sun) are ultimately mixed and power is generated in the turbines from the resulting steam, it is not currently possible to have a direct measurement of the solar contribution to the electricity. In other words, the two electricity sources are not segregable. One method that has been investigated is an indirect estimate of the solar contribution by measuring inlet solar-heat inputs and using a model of the power plant[7]. However, if this is used for attracting government subsidies, it may be possible for the plant to unwittingly commit fraud by modifying/upgrading their equipment: in other words, the plant will require clearances from one more regulatory authority for perhaps even routine maintenance or refurbishment. This itself may be a cause for concern for several plant operators.

An alternative model (though not without its pitfalls) may be to issue monthly coal "rations" to the plant which it can forgo in exchange for an increased tariff on *each* unit of electricity

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[6]http://www.envhealthatlas.co.uk/eha/Lung/

[7]Zhai, R., Yang, Y., Zhu, Y. & Chen, D. The Evaluation of Solar Contribution in Solar Aided Coal-Fired Power Plant. Int. J. Photoenergy 2013, e197913 (2013)

produced for that month. The virtue of this system is that it shifts the regulatory bureaucracy to the procurement division which is better equipped to handle it. The obvious drawback, of course, is that the plant is tied to the coal supply authority and cannot buy from the open market.

This is a problem that requires very serious and thoughtful attention from a range of stakeholders in the GSI. The entire GSI actually hinges on being able to fairly reward power plant operators who invest in shifting to solar-thermal heat.

This is a problem to be solved by multidisciplinary teams of electrical, mechanical, chemical and instrumentation engineers, software developers, power plant operators, civil servants, economists and statisticians. It calls for a collaboration between a highly regarded institute of technology and a well-connected business school: both of whom must have years of work on industrial projects. It could also fall almost entirely within the purview of the National Thermal Power Corporation of India.

5. THERMAL STORAGE

Since it is the stated goal of GSI to mitigate greenhouse gas emissions by eliminating or offsetting coal firing, it is essential to supply solar-heat to the plant even when the sun is not shining e.g. at night or during cloudy weather. For this, additional heat has to be collected during sunlit hours and stored for later supply. The technology for solar-thermal storage is *still* in development stage. Although several innovative approaches have been envisaged[8] the most widely deployed solar thermal storage solution is the "two-tank indirect" version[9] where an organic heat transfer fluid (HTF) is used to collect solar radiation and this is transferred to molten salts for storage. The "cold" molten salt waits in a cold tank till the sun rise and is then cross exchanged with the hot HTF and stored in a hot tank (hence 2-tank indirect). The hot tank fluid is cooled by raising steam as required and returned to the cold tank. 99% of solar thermal storage systems reported on the SolarPACES website use this type of storage.

The GSI, however, is *not* constrained by considerations that limit the choices of conventional solar-thermal power plants (also called Concentrating Solar Power or CSP). For instance, a major consideration for CSP is the high freezing point (~200^{o}C) of the eutectic mixture of nitrate salts used for thermal storage. There is a real danger than the salts may freeze during off-hours. This consideration no longer applies to GSI plants since the coal firing can supply enough heat to keep the salts molten if required. It is therefore essential to develop solutions from "ground-up": taking a hard look at very new (albeit familiar) systems.

From Ref. 2, we can get a quick feel for the numbers involved in solar thermal storage. For a 500 MW sub-critical Rankine cycle power plant (coal fired) the solar collector area would be ~670 hectares on 1340 hectares of land. If heat were stored in the 2-tank indirect system, the quantity of material stored (for 18hours of storage at 400^{o}C) would be 175 MTons i.e. about 257000 m^3.With this storage, as much as 50-60% of coal firing can be offset by solar assuming currently

[8]http://www.renewableenergyworld.com/articles/print/volume-18/issue-110/features/thermal-renewable-energy/commercializing-standalone-thermal-energy-storage.html

[9]Kelly, B. & Kearney, D. Thermal Storage Commercial Plant Design Study for a 2-tank Indirect Molten Salt System: Final Report, May 13, 2002-December 31, 2004. (National Renewable Energy Laboratory, 2006).

mature solar-radiation-harvesting technologies. Without this storage, coal-firing offset would drop by a quarter: to only 12-15%.

Terrafore Technologies LLC[10] have developed a number of tools and technologies for solar thermal storage at various temperature levels: it can serve as a benchmark for open source technologies in thermal storage. The International Energy Agency has published a Technology Roadmap for Energy Storage[11] in 2014: the first one of its kind, indicating the increasing importance of energy storage in the renewables sector. In both cases, an interesting option is using thermal storage to improve efficiency of *existing* power plants e.g. peaker plants.

It is important to put together a team of mechanical engineers, chemical engineers, physicists, material technologists, chemists, piping engineers, instrumentation engineers and economists to first gain an insight into the problems accompanying solar-thermal storage and develop tools and protocols to evaluate and implement various options. Among the tools to be developed, a reliable simulation tool for various storage options (thermocline, air-solid, two-tank etc) would be invaluable.

6. INTEGRATION AND INTERFACE WITH POWER PLANT

The success of the GSI will depend, to a large extent, with the facility with which solar thermal technologies interface with existing Rankine cycle technologies. This calls for a careful and judicious study of existing (and planned) power plants to determine the most optimum solar-thermal injection strategy.

The Fig. ***2*** (taken from Ref. 2) shows several options by which solar thermal heat may be injected into the working fluid (water-steam circuit) of a Rankine cycle power plant. One strategy is to preheat feed water from the condenser entering the boiler: effectively touching the regenerative part of the Rankine cycle. This requires low temperatures, hence low concentration-ratio (hence less expensive) equipment. However, the bleed steam freed up cannot be used in the turbines (which have a low-turndown) but has to be employed separately e.g. to drive some process heating or cooling or to drive the regenerator of an amine based carbon capture and sequestration unit[12]. This is however somewhat disruptive of the plant's steam cycle and may require sophisticated process control systems for proper execution.

The other alternatives are to inject solar heat into the boiler or the superheaters. The main advantage of this is that the working fluid cycle remains essentially unaffected: some additional control schemes to regulate coal firing may need to be put in place.

The major challenge in injecting solar heat into any point of the working fluid is in developing adequate control mechanisms: e.g. for diverting a quantity of working fluid into the solar-driven heat exchangers rather than the coal fired heat exchangers.

[10] http://www.terraforetechnologies.com/

[11] https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergystorage.pdf

[12] Note that this is notably different from using solar thermal to generate steam to derive the reboiler of a post-combustion capture unit (e.g. http://arena.gov.au/project/hybridisation-of-concentrated-solar-thermal-with-carbon-capture-and-storage/)

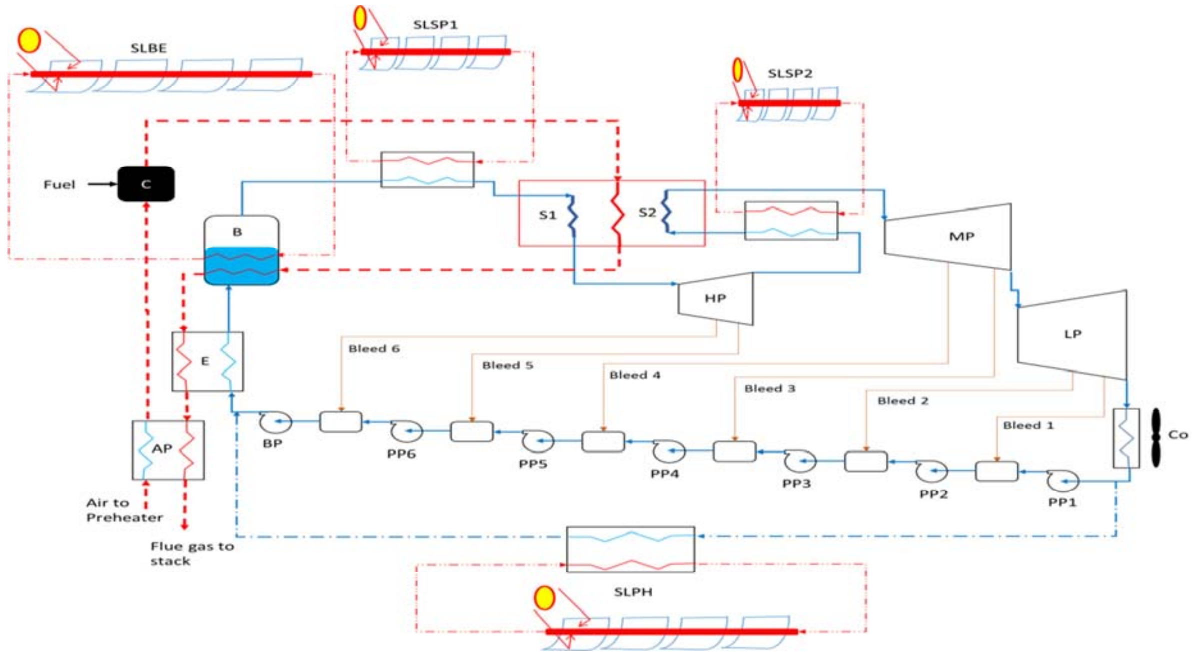

Fig. 2 : Strategies for solar thermal heat injection in to a Rankine cycle power plant (figure taken form Ref. 2). Co = condenser, AP = Air Preheater, E = Economizer, B = Boiler, C = Combustion Chamber, S1/S2 = superheaters, HP/MP/LP = High, medium, low pressure turbines, PP = Feedwater Pumps. SLPH = Solar Pre-heating. SLBE = Solar for Boiler and Economizer, SLSP = Solar for Superheating. The figure shows how solar heat may be used to pre-heat boiler feedwater (freeing up bleed steam for other purposes), or supplement coal firing in the boiler and the superheaters. Not shown is the strategy to preheat air entering the combustion chamber

One additional injection strategy that holds some promise is heating the air entering the combustion chamber with solar radiation. This presents its own problems since air is a notoriously poor heat-transfer medium. However, it has benefits including *minimal* disruption of existing infrastructure, much more facile process control, and very contained consequences in case of failure.

The process design and execution of these strategies need to be worked out in detail by teams composed of instrumentation and process control experts, power plant operators, energy cycle experts, mechanical and maintenance engineers.

7. EQUIPMENT DESIGN

While strictly part of section 7, this is complex and important enough to warrant a focused discussion. The equipment, primarily heat exchangers, used to inject solar thermal heat into the power plant has to be modular, extendable and able to function efficiently with high turndown ratios. This is to facilitate two aspects of GSI:

(1) **The multi-time-scale intermittency of solar radiation:** Solar radiation has cycles lasting over hours, days and months. Though thermal storage can offset much of the intermittency of the diurnal cycle, the yearly cycle cannot be so offset: e.g. no meaningful radiation can

be harvested during the monsoons. During off-seasons, the power plant must operate entirely in conventional mode. During peak seasons, given enough penetration of solar-thermal technologies, the plant may operate primarily in the Green Steam mode. The equipment installed must facilitate this *transition* with minimal disruption of operations *while running hot.* The GSI will not be sustainable if the plant requires a shut-down every three-six months or so.

(2) **The aspiration to take over from coal firing:** Eventually, it is the objective of the GSI to restrict coal firing to only some months of the year when solar harvesting is poor e.g. monsoons. The equipment installed must therefore be designed to be modular and extendable.

This is practically virgin territory for research and development. The conceptualization, design, deployment and control of such equipment is well within the purview of physicists, and mechanical and chemical engineers: however, it does require an *ab-initio* approach rather than working from existing templates. Concept development, designing, simulation, testing and validation of such devices will require teams of very experienced physicists, chemical, mechanical, maintenance and instrumentation engineers with support from software developers.

8. PROCESS SIMULATION, CONTROL AND PREDICTION

Process control is critically important for the success of the GSI. The sun is notoriously intermittent and the energy input from the solar-thermal part can fluctuate considerably (even when thermal storage is considered). There may be several times in the year when the flow of energy from the solar field drops to zero while, once fully GSI is fully in place, there may be several days when the solar field is the primary heat input.

It is therefore essential to develop instrumentation and process control mechanisms to handle a transition from 100% coal firing to almost 100% solar input over a period of a few hours at most.

Given that a power plant is a tightly integrated system and further that the swings in question are large (hence non-linear effects) a dedicated process control effort is necessary to develop the tools and protocols to implement GSI.

The control strategy cannot always be based on feed-back alone. Since the solar insolation is a parameter that can be estimated very quickly and accurately, a component of predictive control is both feasible and desirable.

This calls for robust and reliable dynamic models of the power plant, the solar field and the thermal storage section. It is especially desirable that they be put on a platform that can be quickly modified and tuned to each individual power plant and solar field.

This is a task best handled by a team of chemical and mechanical engineers, power plant operators, process control and automation experts and computer software developers and experts in the field of solar thermal technologies.

9. OPERATION AND MAINTENANCE

For the success of the GSI, it is important to operate the solar collection field optimally and to maintain it at its optimal performance.

Robust but inexpensive solar-tracking algorithms and hardware (sensors, motors) are required, not just for tracking the sun, but also for taking preventive action against damage due to strong winds and/or sharp changes in solar insolation (which can cause thermal stresses on the receivers).

Further, since dust is a major cause of poor performance of the solar field, it is essential to clean the reflecting surfaces daily. Here, an automated cleaning system would be invaluable.

A further, perhaps bimonthly or six-monthly task, will be to remove and replace damaged reflectors.

10. SOLAR COLLECTOR AND RECEIVER

The heart of the solar field is the collector (or concentrator) and the receiver. Solar radiation incident on the collector's face is reflected in such a way that it falls on a device with much smaller surface area through which flows a heat transfer fluid (HTF). Hence the HTF is heated by the concentrated solar radiation and used for various applications downstream.

A very detailed breakdown of costs is available via the International Renewable Energy Agency's Cost Analysis Series[13]. For the most common type of solar installation (the 50 MW Andasol type parabolic trough plants), the Fig. ***3*** shows a typical cost breakup.

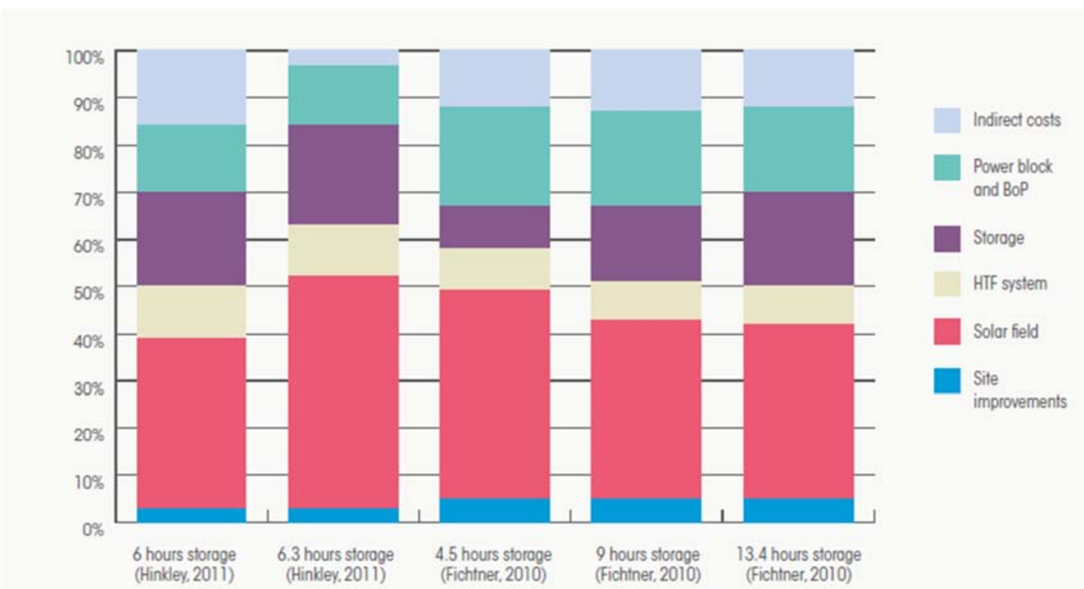

Fig. 3 : A cost breakup of standard parabolic trough power plant (taken from Ref. 13). The solar field account for 30-50% of the total cost of the plant

[13] http://www.irena.org/documentdownloads/publications/re_technologies_cost_analysis-csp.pdf

Clearly the solar field: mirrors, receivers, supports, foundation etc are critical techno-economic components of the conventional solar thermal plant. An advantage of the GSI is that the power block and miscellaneous overheads can be merged into the costs of the main plant itself, leaving only the solar field.

A breakdown of the solar field itself is shown in Fig. ***4***. While the solar field costs about $275/m^2 of aperture area (the plant requires 510,000 m^2 of collector area), the cost of the collector+receiver proper (with foundation) is about $200/m^2. This cost, imported into India, rises to about $300/m^2.

It may be possible to drop this latter number down to below $75/m^2-aperture. The benefits of this are apparent from Table 1 where it is clear that a solar field of $75/m^2 of aperture can compete with coal without subsidy.

This requires deployment of multi-disciplinary, innovative teams of engineers, fabricators, physicists, chemists and economists to come up with ways to rigorously achieve cost cutting. The tools necessary for this are:

1. **Simulation Tools:** A very fundamental analysis of the requirements of the collector is necessary to determine the best and lowest cost method of achieving it. An *essential* tool in this regard is a multi-physics software environment that *combines* structural warping analysis with a ray tracing engine and a heat-transfer and fluid flow engine to determine the effect of various stress on optical and thermal performance. Such a tool, with an intuitive user interface, will allow rapid development of very efficient and low cost collectors and receivers.

2. **Evaluation Tools:** It is essential to set up protocols to rapidly evaluate and characterize prototypes so as to determine the source of inefficiencies and eliminate them. Among these tools should be (a) tools the determine optical efficiency (b) tools to determine thermal efficiency (c) tools that can determine overall efficiency under working conditions.

3. **Manufacturing:** An essential component of low-cost deployment is the ability to mass manufacture the device with minimal waste. Tools necessary for mass manufacture of critical parts must be developed or adapted from other tools.

4. **Installation:** For a painless deployment, the system should be designed so that it can be shipped disassembled and a small team without specialized equipment can assemble it on site to specifications.

	Cost (2010 USD million)	Share (%)
Labour cost: Site and solar field	62.4	17.1
Solar field	11.3	3.1
Site preparation and Infrastructure	21.2	5.8
Steel construction	9.1	2.5
Piping	6.4	1.8
Electric installations and others	14.4	4.0
Equipment: Solar field and HTF and system	140.3	38.5
Mirrors	23.1	6.4
Receivers	25.9	7.1
Steel construction	39.0	10.7
Pylons	3.9	1.1
Foundations	7.8	2.1
Trackers (hydaulics and electrical motors)	1.6	0.4
Swivel joints	2.6	0.7
HTF System (piping, insulation, heat exchanges, pumps)	19.5	5.4
Heat transfer fluid	7.8	2.1
Electronics, controls, electrical and solar equipment	9.1	2.5

Fig. 4 : Taken from Ref. 13 Shows the breakdown of the solar field itself for a 50MW parabolic trough conventional solar thermal plant. The aperture area of the plant is 510,000 m^2

Table 1 : Taken from Ref. 2. Economic analysis of solar-thermal aided coal fired power plant (50% fossil fuel offset). p_e = cost of main plant, c_{coal} = cost of coal, s_e = selling prices of electricity, s_e^s = feed in tariff ,r_{conv} = return on investment of conventional plant, $r_{sol-aid}$ = return on investment of solar aided plant

p_e	c_{coal}	s_e	f_s	p_s	s_e^s/s_e	s_e^s	r_{conv}	$r_{sol-aid}$
$/kWe	$/kg	$/kWh		$/m2ª		$/kWh	%	%
1000	0.09	0.05	0.5	300	1	0.05	9	3.4
1000	0.09	0.05	0.5	300	3	0.15	9	11.2
1000	0.09	0.05	0.5	150	1	0.05	9	5.9
1000	0.09	0.05	0.5	150	3	0.15	9	15.6
1000	0.09	0.05	0.5	75	1	0.05	9	11.0

11. MATERIALS

A very important research field is materials for solar thermal systems. The materials should be low cost but high performance. These include:

1. **Reflectors:** Inexpensive, high reflectivity materials that can withstand humid, abrasive environments with thermal cycling. Currently the best is thick (>6mm) glass with Ag or Al backing[14] (see also Fig. ***5***).

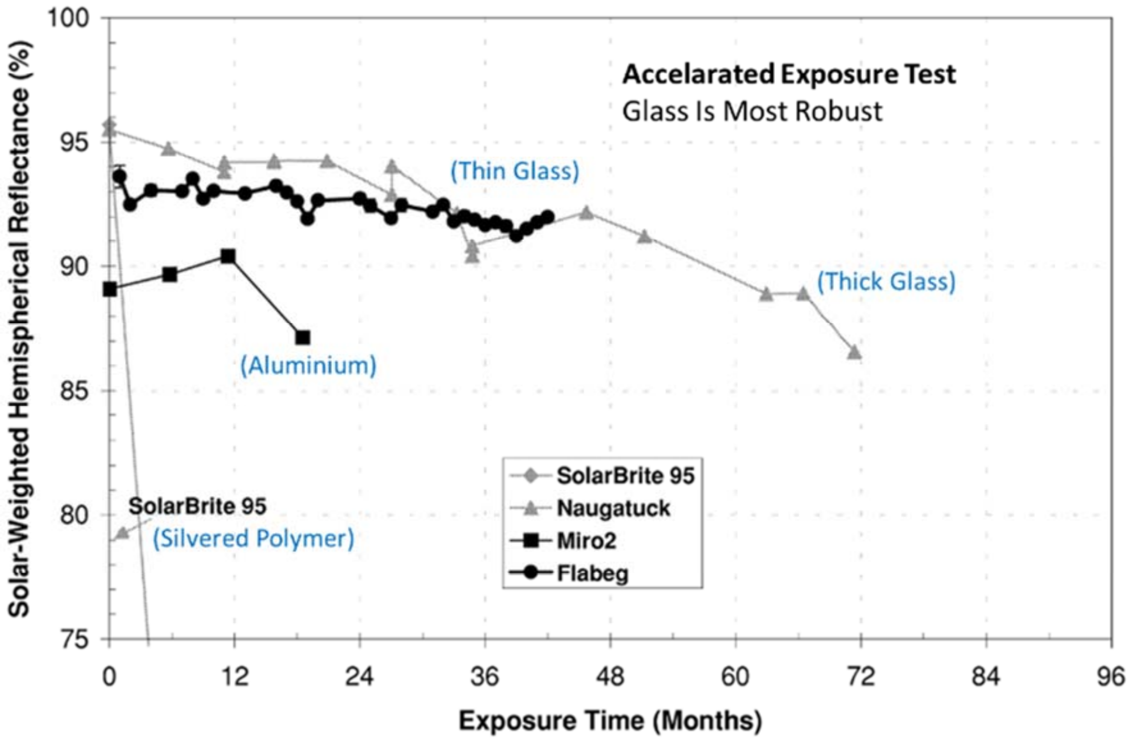

Fig. 5 : Taken from Ref. 14. Accelarated exposure tests for various types of reflectors. Thick glass backed with a reflective coating is clearly the most robust, followed by thin glass. Promising alternative, lightweight reflectors like aluminium sheets and silvered polymer sheets show rapid degradation when exposed

Lighter, more mechanically stable reflectors that don't require as much supporting steel will make a big difference to the cost of fabrication and installation.

2. **Selective Coatings**: For the receivers, solar selective coatings that are robust to thermal cycling and oxidative environments. Aside from the normal cermets and electrodeposited oxides, attempts should be made to exploit fundamental understanding of radiation on matter[15].

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[14] Fend et al *Solar Energy 74 149-155* 2003 doi:10.1016/S0038-092X(03)00116-6

[15] Chen and Sun *Solar Energy Materials and Solar Cells* 2010 doi:10.1016/j.solmat.2009.11.028

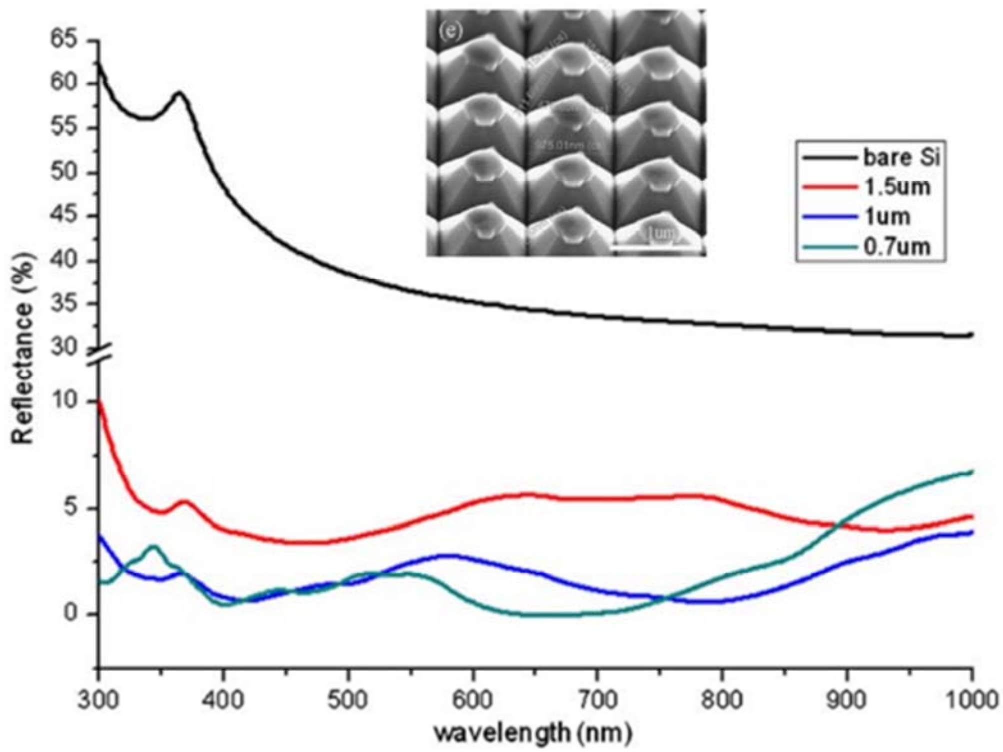


Fig. 6 : Taken from Ref. 15. An example of how physical morphology of a surface can have dramatic effects on reflectivity. A reasonably reflective surface can be made to be highly absorbing by judiciously corrugating it

3. **Heat Transfer Fluids:** It is very important to develop inexpensive liquids that have low-viscosity but also low vapour pressure for temperature ranges from room temperature to 800^{o}C. The of the extant heat transfer fluids, Dowtherm A (an eutectic mixture of diphenyl and biphenyl oxides) is stable and has low vapour pressure from room temperature upto 400^{o}C: but it is also expensive (see Fig. ***4***). An eutectic mixture of sodium and potassium nitrates and nitrites forms a molten salt that is stable upto 800^{o}C but freezes at 220^{o}C. There is no liquid that can hold its integrity from room temperature upto 800^{o}C.

   The other important development would be additives (e.g. nanoparticles) to existing heat transfer fluids that would greatly increase heat-transfer coefficients without a commensurate increase in viscosity.

4. **Thermal Storage Materials:** Thermal storage is currently restricted to the two-tank indirect method where solar heat is stored as sensible heat of a molten salt (see section 5). Alternate thermal strategies e.g. thermocline storage, chemical storage etc need to be developed. Fig. ***7*** shows how only molten salt storage is currently considered commercially viable: and even then a high capital risk.

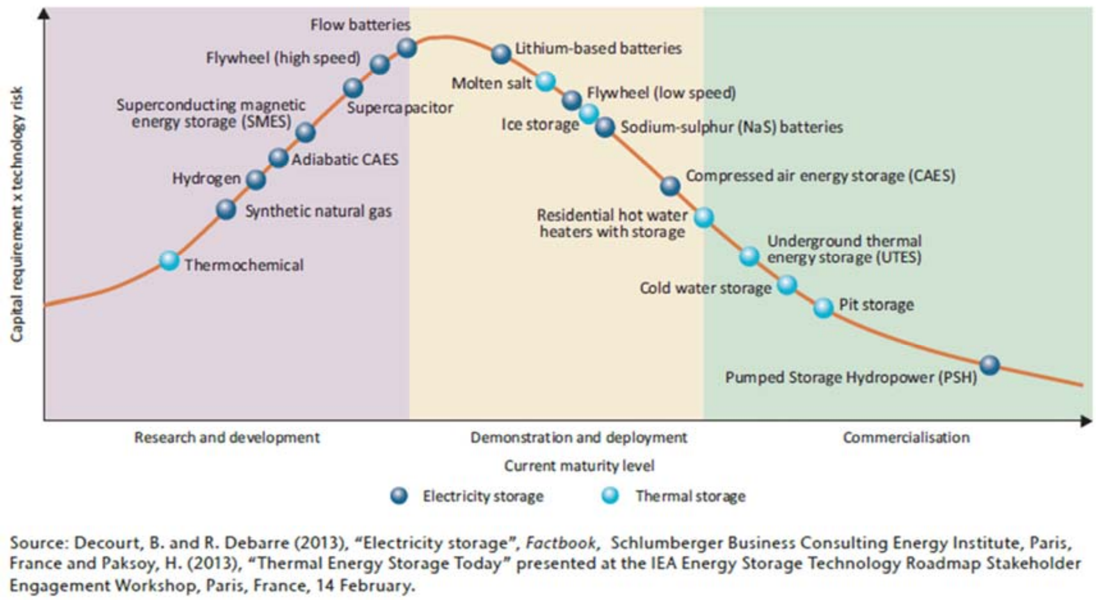


Fig. 7 : Taken from Ref. 13. The figure shows the maturity of various energy storage systems. Of the thermal storage systems, only molten salt storage is mentioned among the high-temperature heat storage technologies suitable for power production (the others are low temperature storage for space heating/cooling applications)

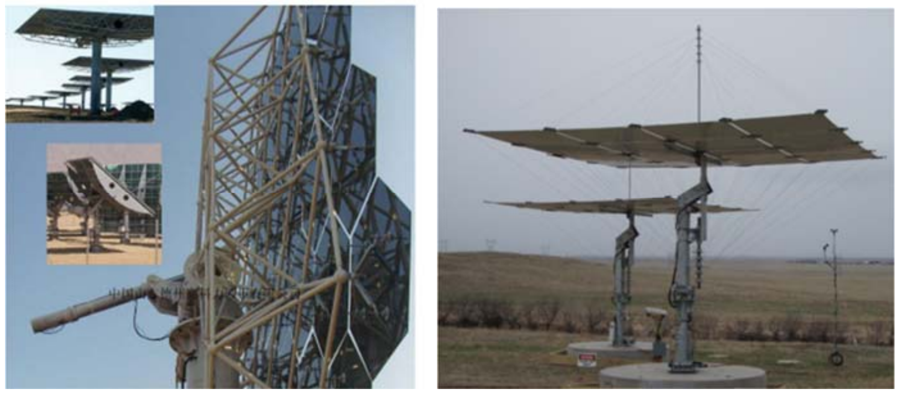
There are several ideas on how to improve thermal storage and more are being developed[16]. A number of excellent ideas for coupling low-conductivity phase change materials with high-conductivity metal matrices have been worked on[17]. However, the two-tank indirect has been the gold-standard for at least a couple of decades (if one includes the SEGS systems of California) and the time is ripe for a revolution in this area.

5. **Structural, civil and piping and insulation materials:** An often overlooked, but very important part of the solar thermal power generation ecosystem are the ancillary materials including those forming the support frame, the foundation and grouting and the materials of the fluid conduits. Normally, the support is mild steel, the foundations are concrete and the pipes are also mild steel: and the other materials are built around these. However, with careful, first principles consideration of the constraints it may be possible to substantially replace or reduce the quantities of the materials involved. An excellent example is the *suspension heliostat*[18]which makes optimal use of the properties of steel (see Fig. ***8***).

[16](a) Gil, A. et al. State of the art on high temperature thermal energy storage for power generation. Part 1—Concepts, materials and modellization. Renewable and Sustainable Energy Reviews 14, 31–55 (2010). (b) Medrano, M., Gil, A., Martorell, I., Potau, X. &Cabeza, L. F. State of the art on high-temperature thermal energy storage for power generation. Part 2—Case studies. Renewable and Sustainable Energy Reviews 14, 56–72 (2010).

[17]Fernandes et al *Energy* 2012 doi:10.1016/j.energy.2012.01.024

[18]*Bender, A. "Final Technical Progress Report: Development of Low Cost Suspension Heliostat"2012 http://www.nrel.gov/docs/fy13osti/57611.pdf*



Material Intensive Conventional Trussed Heliostat

Lightweight “suspension” heliostat.

Fig. 8 : Taken from Ref. 18. Suspension heliostats (right) make optimum use of the tensile strength of steel thereby reducing steel requirement by 60-65% over the steel-heavy trussed design (left)

This presents an opportunity for *material* scientists because it may be possible to reduced use of steel even more by developing materials that have *high-tensile* strength in just one direction: such developments are possible with polymers (spider-webs are the “state of the art” in this case).

Other fields that could benefit from additional research are development of cheaper piping, insulation and use of cheaper foundation and grouting materials (preferably from industrial wastes).

12. CONCLUSION

The Green Steam Initiative offers the possibility to leap-frog the industrialized nations into a sustainable, renewables heavy economy which strengthens our industrial base and provides opportunities for growth and development to our rural regions. It is also important from a strategic perspective: since every component of the Green Steam Initiative (save some of the electronics) can be indigenously manufactured using tools available to fabricators even in taluka places.

India has had a revolution in agricultural production and in milk production. It is ripe for a revolution in power production.

An Integrated Approach to Energy and Environment in the Coal Sector

Prof. Raman Srikanth

1. BACKGROUND

In May 2016, India had a total installed power generation capacity of 303 GW, in addition to the grid-connected captive power generating capacity of 41 GW (of which 60% is coal-based), while the peak demand in India was only 153 GW. Even at the height of summer (May 2016), at a National level, the energy deficit in India was only 0.6% while it was 0.8% in terms of peak demand. In fact, CEA has predicted that there will be a small energy surplus in 2016-17 due to the lack of growth in demand vis a vis generation. This is evident from the declining level of the Plant Load Factors (PLF) of coal-fired power plants from 78.6% in FY 09 to 62.3% in FY 16 (CEA, 2015; MOP, 2016). However, power shortages in several parts of India continue either due to (a) inadequate transmission/transformation capacity or (b) inefficiency of old power plants for which Life Extension and/or Renovation & Maintenance programs have been delayed or (c) poor financial health of the power distribution entities, or (d) a combination of all three factors.

Coal continues to be the mainstay of India's energy, fueling more than 60% of the installed electricity generation capacity in the country, while coal-based power plants produced more than 75% of the + 1100 Billion units (1100 TWh) of electricity generated in FY16. This trend will continue into the foreseeable future since 80% of the power generation capacity added in the XIIth Plan till date is coal-based. Even if Government of India (GOI)'s plan to enhance renewable energy capacity to 175 GW by 2022 fructifies, the total renewable capacity in 2022 will still be less than the current coal-based generation capacity of 186 GW.

The poor efficiency of India's coal-fired power plants (32.8% compared to as has been studied by various agencies, including the CEA. CEA has identified 144 coal-fired units for improving their energy efficiency and thereby reduce coal consumption under the Perform, Achieve, and Trade scheme of the GOI (Press Information Bureau, 2015). A more efficient plant will not only use lesser quantity of coal but will also emit lesser volumes of pollutants than a similar plant operating at lower efficiency.

India's thermal power plants are predominantly fueled by coal produced from coal mines within the country. As a result, India is the third largest producer of coal in the World today, after only China and the US. Out of the 575 Mt of coal used for power generation in India during, 494 Mt were procured from domestic sources (primarily, from Coal India and Singareni Collieries), while another 81 Mt of coal were imported, primarily by coastal power plants (Ministry of Power, 2016a). Therefore, the umbilical cord between coal mining and power generation in India is quite strong.

In order to cater to the increasing demand for electricity, GOI has developed an action plan to double coal production by 2020 most of which will be from surface mines that exacerbate the environmental impact of coal. While the projections of 1.5 Bt of coal requirement in India are being debated, there is an urgent need to accelerate work on a holistic and actionable Energy and

Environment policy for the Coal Sector which will address India's growing needs for energy while aiming to mitigate the environmental impact of coal mining and utilization in India. This calls for new policy initiatives as well as capability building at the National and State Levels, which can be funded by the clean environment cess currently levied @ Rs. 400 per ton of coal, which has contributed Rs. 25,000 crores per annum to the National Clean Energy Fund in FY 16 and is expected to contribute more than Rs. 40,000 crores per annum by 2020.

Sustainable development and inter-generational equity require that a part of this fund should also be used to implement measures leading to reclamation & restoration of coal mines and rehabilitate the host communities. While most persons will agree with this over-arching goal, India needs to develop, policies, statutes, organizations, and procedures to achieve this goal.

2. INTRODUCTION

India has made the following INDCs (Intended Nationally Determined Contributions) during the 21st Conference of the Parties in Paris during December 2015:

- To reduce Emissions Intensity of India's GDP by 33 – 35% by 2030 from the 2005 level;
- To achieve 40% cumulative electric power installed capacity from non-fossil fuel-based energy sources by 2030, with the help of technology transfer and low-cost international finance;
- To create additional carbon sink of 2.5 – 3 Bt of CO_2 equivalent through additional forest and tree cover by 2030.

Government of India (GOI) has announced the following key action plans to achieve these commitments:

- Increase in Renewable Energy Capacity to 175 GW by 2022 (from a level of 43 GW as on 31 May 2016);
- Annual additions to Solar (3 GW in FY 16) and Wind (3.4 GW in FY 16) to be accelerated;
- Set up an International Solar Alliance in collaboration with France;
- Promote Solar Energy Parks on "plug and play" model, with ready land, transmission capacity, etc.;
- Clean Energy Cess (50 Rs/t in 2010; 400 Rs/t in 2015) imposed primarily to promote renewable energy;
- Construct "Green Energy Corridors" to strengthen National Grid, evacuate renewable energy, and facilitate load balancing at the National Level thereby increasing viability of renewable energy;
- Utilize bankable power PSUs like NTPC to procure & bundle solar power with its own cheaper coal-based power from power plants older than 25 years in order to enhance viability of solar power projects being established by NPTC in various States;
- Mandate targets to enhance energy efficiency of 144 old coal-based power plants;

- Utilize the Compensatory Afforestation Fund (approved by Parliament in August 2016)which is expected to accumulate more than Rs. 6000 crores per annum (of which 90% will be transferred to the respective States)to be used primarily for the regenerationof forestsand wildlife protection;
- Mobilize the National Green Highways Mission which is expected to sequester about 1.2 Mt of carbon annually by developing tree cover along National Highways at a cost of 1% of the cost of any contract awarded by NHAI.

3. PREDOMINANCE OF COAL IN THE ELECTRICITY SECTOR IN INDIA

However, all the above actions also have to be balanced with the overarching goal of Power to All by 2020. As per the Ministry of Power's reply in the Rajya Sabha on 05 May 2016, India's annual per capita electricity consumption has increased from 884 units in 2011-12 to 1075 units in 2015-16. However, it is still less than a quarter's of China's per capita consumption, and as per IEA's 2015 report titled, "India Energy Outlook," about 240 million people in India (of which 220 million live in villages) do not have access to electricity.

India's increase in electricity generation (along with associated transmission and distribution facilities) has been predominantly based on coal. Coal accounts for more than 60% (186 GW) of the 303 GW of IPP-based generation capacity in India (CEA, May 2016). This excludes the grid-connected captive generation capacity of 41 GW of which more than 60% is based on coal.

As per CEA data, 80% of capacity addition during 12th and 13th Five-Year Plans will be from coal-fired power plants. Coal-fired generation capacity of India is expected to peak at + 230 GW by 2020 and coal will account for about 70% of total electricity generation (down from 76% today), even if:

- No power plant other than those under construction (80.865 GW) is taken up, except as a replacement for +25 Yr. units which are also inefficient in coal and water usage;
- Old, inefficient and polluting units with a total capacity of about 34 GW are retired when it is either not technically feasible to upgrade them to meet current environmental norms or it is not economically viable to extend their useful economic lives further.

On the other hand, with 14% of India's installed capacity, renewable sources accounted for only 6% (66 BU) of the 1091 BU of electricity generated in India during FY 16. The key reasons for this mismatch between installed capacity and actual generation are likely to be:

- Inherent intermittent nature of renewable sources;
- For example, in one study of renewable energy sources in Gujarat (PwC, 2016), solar energy varies up to 67% between months, while wind power varies by up to 357%;
- Need for load-balancing due to mismatch between renewable energy generation and cyclical power demand in India even on a daily basis;
- Inadequate transmission capacity in the grid to evacuate renewable power at its peak;
- Reluctance of cash-strapped SEBs/Discoms to honor high-cost renewable energy PPAs signed in the past when cheaper coal-based power is available on the spot market.

Therefore, even with GOI's plan to enhance Renewable Energy Capacity to 175 GW (from 43 GW today), the predominance of coal-fired power generation will continue for the foreseeable future in India. Further, the following key facts (based on FY 16 data) demonstrate the strong linkage between power generation and coal mining in India.

- Coal is produced from 573 coal and lignite mines in India.
- Out of 546 Mt of coal used for power, 455 Mt comes from 560 coal mines in India, while the balance is imported.
- Seventy-Two percent of 612 Mt coal produced in India (91% by PSUs) is supplied to power plants.

CIL and SCCL are executing projects to enhance coal production capacity to > 1 Bt by 2022, primarily to cater to the power sector. Specifically, against the National target of 724 Mt of coal in FY 17, CIL alone has a target of 599 Mt, a jump of 60 Mt from 539 Mt in FY 16.

4. KEY CHALLENGES AT VARIOUS STAGES OF RESOLUTION IN INDIA'S COAL SECTOR TODAY

Till recently, coal shortages were endemic at various power plants in India and even inland power plants in Chhattisgarh/Haryana were importing coal due to inadequate supplies by CIL. However, over the last two years, a number of steps have been taken by GOI and CIL in conjunction with various coal-bearing states to convert the shortage to a surplus. Many forest and environment clearances that were held up earlier were granted, and long-delayed land acquisition in certain projects was also achieved due to better coordination between GOI and the States through the "Pragati" portal and other interactions.

As a result, CIL has recorded a cumulative production increase of 74 Mt in FY 15 and FY 16 (PIB, 2016), a far cry from the stagnation of the previous two years. This has also led to a reduction of nearly 11 Mt in coal imported for power generation in FY 16 as compared to FY 15. The significant improvement in CIL's performance over the last two years has enabled many Government-owned power plants to continue power generation from plants linked to their captive coal mines which have not produced any coal from 1 April 2015.

Coupled with the improvement in the financial health of CIL and Singareni over the last few years, converting the supply shortfall to a surplus has also resulted in CIL making progress in the following areas which used to be problematic in the past.

4.1. Coal Quality

As per current MOEF norms, power plants located at a distance of more than 500 km from their coal supply are mandated to use coal with < 34% ash. Out of 465 Mt contracted in Fuel Supply Agreements (FSAs) by CIL, 200 Mt needs to be washed to < 34% ash to meet the current norms (MOC, 2015). Though PSUs supply more than 72% of their coal production to power plants, Government has not thought it fit to impose any restriction on the coal supplier who is in a superior position not only to construct the washery (ideally, within the mining lease area), but is also better placed to design and operate the washery, since the variations in the characteristics of the coal to be processed in the washery can be predicted by the coal miner (based on his production schedule and washability data), rather than the by coal user, who is more than 500 km away from the pithead.

However, CIL has only 15 operational washeries with a total capacity of 38 Mt, out of which only 15 Mt of washed coal was dispatched by Coal India in FY 16. The huge gap between the requirement and supply of coal (< 34% ash) has forced the power plants to depend on various private players, thereby creating scope for major illegalities (primarily, in the name of rejects). While this scenario was forced on Coal India when they were starved of capital, GOI has announced plans to construct 15 washeries, nine for thermal coal (95 Mt) and six for metallurgical coal (19 Mt) to be commissioned from 2017 onwards.

While CIL has started setting up washeries on a BOOT model, many more washeries are needed to enable its key customers (power sector) to meet MOEF norms, while many of the existing washeries have to be replaced to replace the outdated flowsheets and obsolete technology which were not designed to take process coals having vastly different characteristics than what they were designed for. Most of these washeries will need CFBC power plants to generate power from rejects (+60% ash) at the pithead itself to avoid transporting such high-ash material.

4.2. Logistics

Although coal constitutes the major commodity (by far) carried by Indian Railways, only 55% of the 539 Mt of coal produced by CIL in FY 16was carried by rail. Therefore, environmental impact of coal transport by trucks needs to be minimized by enhanced rail capacity.CIL subsidiaries and IRCON/Indian Railways are jointly undertaking construction of three major railway lines, viz., 93.5 km long Tori – Shivpur line in Jharkhand, 52 km long Jharsguda – Barpalli line in Odisha and 300 km (East and East-West) railway lines in Chhattisgarh in SPVs with the respective State Governments. These lines which will be commissioned in phases from FY18 onwards will enable coal projects with a total capacity of + 140 Mt to come into production. Similarly, Singareni is also constructing new railway lines to connect new projects to the main line.

In the past, most of the coal projects have come up without an integrated approach to logistics resulting in inevitable road transport creating its own social and environmental issues. Road transportation is not only costlier than rail transport over long distances, but also creates a greater impact on the environment as well as the country's foreign exchange reserves due to oil imports. Therefore, it would be very useful if the Ministry of Coal tasks the Central Mine Planning & Design Institute (CMPDI) to work with RITES to conduct route surveys and prepare detailed project reports of all sidings required to link the upcoming identified projects in the next 10 years so that the construction of logistics facilities matches with the coal projects. While CMPDI has already taken steps in this direction by making conceptual master plans for several major coalfields of India, this work has to be taken to its logical conclusion in cooperation with Indian Railways and the State Governments.

It is heartening to note the better coordination between Indian Railways and CIL and the State Governments in this area. However, this spirit of cooperation should be institutionalized so that perspective planning for railway linkages proceeds together with coal projects, and road transportation is avoided as much as possible in the National Interest.

4.3. Peripheral Area Development to move towards Inter-Generational Equity

As a result of the Amended Mines & Minerals (Development & Regulation) Act (or MMDR Act) which has been notified on 12 January 2015:

- Coal miners have to contribute to District Mineral Foundation (DMF) Trusts from 20 October 2015 at the rate of 30% of the royalty for mining leases granted prior to 12 January 2015 and 10% of the royalty for mining leases granted after 12 January 2015;

- It is estimated that annual DMF Contributions at their peak will amount to Rs. 800 Cr for Jharkhand, and Rs. 400 Cr each for Telangana, Chhattisgarh and Odisha;

- As per the MMDR Act, the contributions by the miners to a DMF Trust are to be used to, "*minimize/mitigate adverse impacts, during and after mining, on the environment, health and socio-economics of people in the mining districts*."

However, the challenge is to implement the DMF Rules in letter and spirit through effective coordination between panchayats, elected representatives and the District Administration, for which dedicated organizations have to be created and trained to deliver outcomes in a timely manner. Progress in this critical area is very slow, and needs to be accelerated by all mineral-producing States.

5. LAND ACQUISITION, REHABILITATION AND RESETTLEMENT

India has 2.4% of the World's surface area and sustains 17% of the World's population. More than 90% of the 612 Mt of coal produced in India in FY 16 was produced from surface (or opencast) mines, which have greater effect on the environment (land, air, and water) and on the host communities. This trend is likely to continue in the foreseeable future, since the contribution of underground mining in CIL (producing more than 80% of India's coal production) has reduced from about 47 Mt in 2004-05 to 34 Mt in 2015-16.

Coal is site-specific, and surface mining requires huge areas of land for mining, waste dumping, logistics. Most virgin coal reserves are either located in forests or in close proximity to populated areas. While many attempts have been made for introduction of mass production technologies in India's underground coal mines, success is still eluding us due to variety of reasons, both natural and man-made. Therefore, the dependence on surface mining will continue in spite of its greater impact on the land, water, and air environments as well as on local communities.

On the other hand, agitation against land acquisition for mining and allied activities continues to stall many projects. While CIL and Singareni have the most attractive land compensation and **Rehabilitation and Resettlement (**R & R) policies in India, GOI has also taken several steps to reduce the resistance to land acquisition over the last two years. Specifically, the Land Acquisition and R & R Act (or LARR Act) has been notified to cover PSUs owning coal mines from 1 January 2015, though they can still notify land to be acquired under the central Coal Bearing Areas (Acquisition & Development) Act (or CBA Act) of 1957.

However, capacity for Social Impact Assessment (SIA) which is mandated by the LARR Act is limited in India. Further, the critical task of updating the land records in the coal-bearing areas and implementing Rehabilitation & Resettlement (R & R) plans with the consent of 70% of

Project-Affected-Persons (PAPs) are tasks that will truly stretch the capacity of the District Administration in the coalfields as well as that of coal mining companies

During the last 2 – 3 years, several new policies have been translated to Laws, Rules, and Structures, to promote inter-generational equity and facilitate development of the Mining Sector in general and the Coal Sector in particular. While capacity building is required at various levels of government and the coal companies to implement these policies effectively, we can say that at least India is progressing in the right direction.

6. ENVIRONMENTAL CHALLENGES OF COAL-FIRED POWER PLANTS

Shortly after the Hon'ble PM's announcement of "Zero–Defect and Zero-Effect" goal for India's manufacturing sector during his Independence Day address on 15 August 2014, on 07 December 2015, the Ministry of Environment & Forests (MOEF) notified updated norms for water consumption and emissions for existing and proposed/under-construction coal-fired power plants. These norms cover both water consumption and gaseous pollutants.

6.1. Water

India has 4% of the World's fresh water resources and 17% of the World's population. The main objectives of the National Water Mission are: conservation of water, minimizing wastage, and ensuring its more equitable distribution.

Water availability has already become a crisis in several parts of India. However, some of the older coal-fired power plants of India consume huge amounts of water. Specifically, thermal power plants discharge 80% of wastewater discharged by all industries (Central Pollution Control Board, 2001). As per the Hon Power Minister's reply to a query in the Lok Sabha on 05 May 2016, all units of Parli power plant in the Beed district of Maharashtra had to be shut down temporarily in June-July 2015 to ameliorate the drought situation. Similarly, power plants located in other drought-prone areas of India in 2016 (e.g., Raichur power plant of Karnataka, and even the Farakka and Barh power plants of NTPC on the banks of the Ganges) were closed temporarily due to lack of sufficient water to operate them in a prevailing drought. However, the temporary outage of these units did not create any shortage in power supplies since enough surplus power from other, hitherto, partly utilized power plants could be pumped in through the National Grid to meet the shortfall.

As per the norms notified by the MOEF on 7 December 2015, all plants with Once-Through-Cooling (OTC) have to install cooling towers and reduce water consumption to 4 m^3/MW within two years of the notification. Stricter norms have been fixed for the newer power plants to be installed after 1 January 2017 for various environmental parameters, including water consumption (2.5 m^3/MW), which are eminently achievable.

For example, a 2012 CEA report on the "Minimization of Water Requirement in a Coal-based Thermal Power Plant" indicated that specific water requirement for an existing, sub-critical, power plant with cooling tower(s), water consumption should be limited to 3 m^3/MW after ash disposal commences in wet mode. More recently, a water audit conducted by TERI in 2010 and 2015 on an existing power plant has demonstrated that the specific water consumption could be brought down from 4.85 m^3/MW to 3.21 m^3/MW after several technological and operational improvements were implemented. The same study also indicates the further scope to reduce specific water consumption to 2.3 m^3/MW.

6.2. New emission norms

While the aforesaid norms were notified by the MOEFon 7 December 2015 after technical studies and after obtaining comments from various stake-holders, including Industry, the Indian power sector has been opposing the new emission and water consumption norms citing various reasons which had been rejected by MOEF at the draft stage of this notification. However, as shown in the following table (World Energy Outlook Special Report on Energy and Pollution), even the norms notified by MOEF in December 2015 are more relaxed than the norms already applicable in the European Union and in China.

Country	**SOx**		**NOx**		**Particulate matter (PM)**	
	Old	**New**	**Old**	**New**	**Old**	**New**
India	200 – 600	100	300 - 600	100	50 - 100	30
China	200 -400	100	200	100	30	30
European Union	200 -400	150 - 400	200 – 450	150 - 400	20 - 30	10 - 20

7. MINING AND ENVIRONMENT

While GOI has announced new environment norms for coal-fired power plants, there is no such thinking on the coal mining front. Therefore, there is a need to address the Environmental impacts of Coal Mining along with those of Coal Usage.

Coal mining impacts the environment and ecology unless carefully planned and controlled. The magnitude of the environmental impacts, however, vary with the method of mining, scale and concentration of mining activities, geological and geomorphological setting of the area, nature of deposits, land use pattern before the commencement of mining operations, natural resources etc. Some of the environmental impacts are felt immediately, while others are perceived over the long term.

In addition to the 547 Mt of coal produced from surface mines (505 Mt by CIL and 42 Mt by Singareni), the total volume of excavation required to produce this coal is also scheduled to increase greatly in the future, since the strip ratio (volume of overburden/waste removed to produce one ton of raw coal) of CIL mines is projected to increase from 2.3 m^3in FY 16 to about 3 m^3 per ton of coal in order to produce + 900 Mt by 2019-20. The total excavation (coal plus overburden) in CIL mines alone between FY 16 and FY 20 is estimated to increase from about 1500 Mm^3 to 3300 Mm^3. In addition, Singareni which is already producing about 42 Mt of coal from surface mines has also excavated 311 Mm^3 of overburden in FY 16, which translates to a volume of 340 Mm^3 of total excavation which will also increase as deeper coal deposits are developed over the short-term.

Coal mining in India is governed by a number of State as well as Central statutes related to environment. The Water (Prevention and Control of Pollution) Act 1974 (amended in 1988) and Air (Prevention and Control of Pollution) Act 1981 (amended in 1988) are primarily administered by the States through their respective Pollution Control Boards, though the CPCB deals with Inter-state projects as well as policy matters.

In 1986, the Environment Protection Act (EPA) was enacted as an umbrella legislation, which has precedence inter alia over the pollution control Acts indicated above. The Act empowers the Central Government to take all measures as deemed necessary for protecting environment, and preventing, controlling, and abating pollution. The Act lays down standards for discharge of effluents, national ambient air quality standards, ambient air quality standards, and the requirements of Environmental Impact Assessment (EIA) based environmental clearance. As per the EIA notification issued in 1994, EIAs were made mandatory for all mining projects with a mining lease greater than 5 Hectares (Ha.).

7.1. Air Pollution

Mining activities like drilling, blasting, excavation, construction of haul roads, and movement of dumpers results in fugitive emissions of particulate matter and dust. These emissions cause significant human and social impacts by causing air pollution and ecological disturbances. A few years back, several coal mining districts including Dhanbad, Korba, Angul, Talcher, Jharsuguda, and Singrauli, were classified as critically polluted.

In addition, the release of greenhouse gases by the diesel-powered equipment commonly used in surface mining also contributes to climate change. The magnitude of this contribution can be gauged from the fact that, the diesel consumed by CIL and Singareni in their surface mines is estimated to be about 1.4 Bi. liters in FY 16. Since the surface mines planned to be production by 2020 are expected to use the same technology (shovel-dumper) used by CIL/Singareni today, the volume of diesel used by these two PSU giants alone is expected to exceed 2.8 Bi. liters by 2020.

7.2. Water Pollution

Coal mining activities adversely affect the quality of water by not only lowering the pH of the surrounding water resources but also by increasing the level of suspended particulate matter and total dissolved solids. Further, the overburden excavated and dumped in outpit and inpit dump-yards also contaminates the surrounding water bodies and reduces the utility of water for domestic purposes.

While policies, statutes, and structures in India to address air and water pollution in mines are already in existence, albeit with deficiencies in monitoring and enforcement, there is one critical area where India’s policies and statutes are lagging behind, and that is in the area of mining and land reclamation.

8. LAND DEGRADATION AND LOSS OF BIODIVERSITY

Over 60 per cent of coal resources in India are estimated to be covered by forest land. Many coal blocks identified for future development to achieve the coal production targets by 2021-22 are located in or adjoining forest areas. Given the anticipated increase in demand for coal, the problem of loss of forest cover will accentuate as the need to access forest resources will increase manifold. In 2005, MOC estimated that the demand for forest land for mining will increase from about 22,000 ha in 2005 to about 75,000 ha by 2025. Loss of forest cover not only impacts the biodiversity and natural ecosystems, but also compounds the problem of climate change, as there are fewer sinks available for CO_2, and consequently reduced carbon sequestration. Further, forest areas in many coal producing states are sources of non-timber forest products on which the local tribal communities depend for their traditional sources of livelihood, which is also a vital reason for their resistance to mining projects.

8.1. Current status

CAG in 2011 conducted a performance audit of CIL and its subsidiaries with a view to assess whether the companies were fulfilling their responsibilities under the EPA and other environment-related statutes in an effective and efficient manner. As per the findings of the report, no mine closure plans were prepared for mines which were to be closed within 2 to 4 years. Similar problems of implementation were found with regard to environment clearances which are mandated under EPA, since 239 coal projects in CIL have been found operating without clearances.

In a marked improvement from the above status, during a meeting of the Parliamentary Consultative Committee attached to the Ministry of Coal (MOC) held on 11 August 2016 for reviewing the Implementation of Mine Closure Plans of CIL, the Hon Minister of State (IC) for Power, Coal, New & Renewable Energy and Mines has stated that, "*CIL has identified 476 mines for closure and Mine Closure Plans (MCPs) of 445 mines have been approved till 31 July 2016.*"As per the extant guidelines of the MOC, CIL has deposited Rs. 4388 crores in an escrow account controlled by the Coal Controller forming part of the MOC.CIL has signed or is signing MoU with NEERI and the Forest Research Institute for third party audit of progress and appropriateness of MCPs, environmental audit and forestry issues.

As per the guidelines issued by the MOC in January 2013:

- The competent authority for approval of an MCP shall be the Standing Committee constituted by the MOC for the purpose of approval of the Mining Plans or even the concerned Board of a Government Coal Company;
- The total cost of mine closure is estimated to be Rs. 6 lakhs per hectare (in August 2009 prices) independent of the site conditions, and is deposited by the Mine Owner on an annual basis (with an escalation of 5% per annum) into an Escrow Account as a pre-requisite to the grant of Mine Opening Permission by the Coal Controller;
- Based on the implementation of the approved progressive mine closure plan by the mine Owner, up to 80% of the total deposited amount in the Escrow Account may be released every five years;
- The details of the final MCP along with the updated cost estimates for its implementation shall be submitted by the mine Owner to the MOC, at least five years before the intended final closure of the mine;

- Final Mine Closure activities would start towards the end of the mine life and may even continue after the reserves are exhausted and/or mining is discontinued till the mining area is restored to an acceptable level by the Coal Controller as per NEERI or CMPDI or any other institute as may be notified by the Government for this purpose;

- After the closure of the mine, the reclaimed leasehold area shall be surrendered to the State Government concerned, following a laid down procedure "*as in vogue at that point of time*."

While the aforesaid guidelines were issued by the MOC with the right goal of creating a self-sustained ecosystem, they are inadequate to achieve the stated goal inter alia in view of the following major deficiencies:

- Neither the mining plans nor the MCPs have any inputs from the local communities or other stakeholders which are obtained only at the stage of the Public Hearing (PH) to obtain an EC for the project.

- Since the Forest Clearance (FC) for the project is also obtained at a later date, the Mining Plan as well as the MCP are reduced to becoming pre-requisites to apply for the EC and FC for the project rather than being living documents that attain finality as part of an integrated mine approval process.

- Since the Coal Controller's organization is completely inadequate to the task of overseeing the implementation of the Mine Closure Plans (MCP) of 445 coal mines (in CIL alone) that have been approved till 31 July 2016, there is an obvious need for a more independent, empowered and properly-staffed Authority to review and approve the MCPs, and also monitor the performance of the mining companies towards their commitments in respect of mine closure.

- Further, neither the aforesaid guidelines issued by the MOC nor current statutes or applicable policies in India contain any stipulations on restoring land to original land use. In most cases, the mined-out land is planned to be left as a large pit serving as a water storage facility, while the external and internal overburden dumps are left as hills, (with tree plantation in the better case, and left barren in many cases). This is contrary to best practices worldwide.

- While each coal Mine Owner applying for approval or re-validation of his Mining Plans or EC is mandated to deposit money into an Escrow Account controlled by the Coal Controller, the Coal Controller is not equipped to reclaim and restore these mining areas in case the mine owner fails to discharge his responsibility.

- Further, there is no roadmap for the reclamation and restoration of abandoned mines (or mines without proper closure).

- Finally, the sheer multiplicity of Government agencies involved (MOC, SPCBs, MOEF, Coal Controller, etc.) dooms the entire process by sheer delay without any technical contribution to the Environment or to the Community.

For example, as per the Mining Plan approved by the MOC in 2006 for a large (15 Mt per annum) surface coal mine belonging to a Maharatna:

- Only 665 Ha out of a total of 2417 Ha used for mining and dumping is reclaimed after Final Closure, of which 223 Ha is planned to be used as grazing land and 442 Ha is planned to be returned to agriculture;

- However, in the current pre-mining scenario, 435 Ha are used for grazing and 1951 Ha are used for agriculture by the local villagers;

- Out of the 2119 Mm^3 of overburden excavated to extract the 500 Mt of coal, 1238 Mm^3(60%) are proposed to be dumped outside the pit, leaving three 90-m tall man-made hills occupying an area of 632 Ha which are proposed to be converted to forest.

- The final void of 596 Ha is left to become a 300-m deep water body.

To summarize, this project is returning less than 28% of the land used by the local villagers for grazing and agriculture today. As a result, this project (with an initial capital investment of more than Rs. 5000 Crores) has been stalled for more than four years, since the local villagers are not ready to accept an attractive R & R package (better than the State's own R & R package).

Since the stalling of such mega coal projects due to opposition from the villagers is bound to affect the growth of the Indian coal industry and therefore India's Energy Security, it is essential to examine world-wide best practices in regards to surface coal mine reclamation in order to achieve the **stated goal of GOI**, which is to create a "***self-sustained eco-system***."

8.2. Best-in-Class Approach to Surface Mine Reclamation

Mine closure ultimately decides what is left behind as a legacy or benefit for future generations. While in an ideal world, coal mines will close only when their minable reserves are exhausted, in the real world, mine closure may also happen due to other reasons (e.g., economic, geotechnical complications, and social issues). Several mines of the past are now a major liability to the Government as well as to the local communities, due to the threats they pose to the health, safety, and welfare of communities.

For example, National Mining Association of USA states that, the goal of sustainable development is to ensure that, "*our actions meet the needs of today without compromising the ability of future generations to satisfy their needs*."

As early as 1977, the US Congress has declared *inter alia* in its Statement of Findings and Policy in relation to the Surface Mining Control and Reclamation Act that**:**

> *Many surface mining operations result in disturbances of surface areas that burden and adversely affect commerce and the public welfare by destroying or diminishing the utility of land for commercial, industrial, residential, recreational, agricultural, and forestry purposes, by causing erosion and landslides, by contributing to floods, by polluting the water, by destroying fish and wildlife habitats, by impairing natural beauty, by damaging the property of citizens, by creating hazards dangerous to life and property by degrading the*

quality of life in local communities, and by counteracting governmental programs and efforts to conserve soil, water, and other natural resources;

the expansion of coal mining to meet the Nation's energy needs makes even more urgent, the establishment of appropriate standards to minimize damage to the environment and to productivity of the soil and to protect the health and safety of the public;

surface mining and reclamation technology are now developed so that effective and reasonable regulation of surface coal mining operations by the States and by the Federal Government in accordance with the requirements of this Act is an appropriate and necessary means to minimize so far as practicable the adverse social, economic, and environmental effects of such mining operations.

In the four decades since the Surface Mining Control and Reclamation Act (SMCRA) was passed by the US Congress to regulate the environmental effects of coal mining in 1977, this Act has had a major impact on the mining industry not only in the US but also throughout the Western World.

For example, Australia's National Strategy for Ecologically Sustainable Development (NSESD) developed in 1992 promotes economic growth that safeguards the welfare of future generations, provides equity within and between generations, protects biological diversity and maintains essential ecological processes and life support systems.

In 2000, the Australian and New Zealand Minerals & Energy Councils and the Minerals Council of Australia (MCA) jointly published the Strategic Framework for Mine Closure. This framework recognized that the industry is responsible for rehabilitation of mine disturbance in an environmentally and socially acceptable way, and developed *inter alia* the following key principles:

- Legislation should provide a broad regulatory framework for the mine closure process.
- While the completion criteria are specific to each mine and should reflect its unique set of environmental, social, and economic circumstances, the standards of rehabilitation proposed should be acceptable and achievable.
- Targeted research will assist both government and industry in making better decisions about mine rehabilitation.

In 2003, the International Council on Mining and Metals (ICMM) adopted 10 principles for sustainable development for the mining industry, which include the rehabilitation of land in conformance with approved post-mining land use.

The major coal-bearing states of Australia, New South Wales and Queensland have their own legislation which mandate that mining-affected land is left in a safe and stable condition and that local communities are not unduly affected. New South Wales's Mining Act of 1992 as well as Queensland's Environmental Protection Act in 1994, mandate the applicant for mining permits to address the issue of final voids left after mine closure with the aim of minimizing potential sterilization of post-mining land. Detailed procedures and guide books have also been developed and suitably-qualified and well-equipped regulatory bodies have been put in place.

Mine operators in Australia have also developed innovative solutions to rehabilitate final voids and several mine sites have been adapted for tourism, agricultural, and ecological uses.

9. SALIENT FEATURES OF SURFACE MINING CONTROL AND RECLAMATION ACT IN THE U.S.

Since the enactment of the SMCRA in 1977, mining companies in the U.S. have reclaimed for other beneficial uses more than 2.8 Mi. acres (1.13 Mi. Ha) of mined land, while the Federal and State Governments have facilitated the reclamation of more than 100,000 acres (40,500 Ha) of coal mines abandoned before the enactment of this Act. The over-arching mission of SMCRA is to:

- Ensure that coal mines are operated in a manner that protects citizens and the environment during mining and ensure that the land is restored to beneficial use following mining;
- Mitigate the effects of past mining by aggressively pursuing reclamation of abandoned coal mines.

To achieve the above mission, an Authority named Office of Surface Mining (OSM) has been set up at the Federal level which governs surface mining of coal mines in Federal Lands and Indian Reservations, while most States have established their own statutes and regulatory bodies adapted to local conditions. At all U.S. mining operations, detailed reclamation plans must be approved by the OSM before mining begins. Reclamation bonds are posted by mining companies to ensure successful completion of the process.

Where OSM is the Regulatory Authority, it performs the following key regulatory and enforcement functions in coal mines:

- Inspection and Enforcement to ensure compliance with Permit & Performance Standards;
- Reclamation includes the following steps:
    - Contouring of land;
    - Placement of topsoil or an approved substitute on the graded area;
    - Re-seeding with native vegetation, crops and/or trees; and
    - Years of careful monitoring to assure success.
- Evaluation of Post-mining reclamation at each phase of reclamation (backfilling and grading, topsoil replacement, revegetation establishment);
- Bond Release in three phases:
    - Phase 1 – Backfilled and graded to approved final topography and drainage established;

- Phase 2 – Revegetation established and erosion is controlled;

- Phase 3 – Final bond release—all regulatory requirements have been met.

  Ultimately, reclaimed sites are returned to many productive uses, ranging from recreation areas, economic development parks, farms, golf courses and housing developments to wildlife areas and wetlands.

- Unsuitability Determinations before mining operations are permitted based on the following laid down criteria for all or certain types of mining:

  - Reclamation is not technologically and economically feasible (mandatory);

  - Incompatible with State and local land use plans (discretionary);

  - Significantly damage fragile or historic lands (discretionary);

  - Substantially reduce production on renewable resource lands or water supply (discretionary);

  - Substantially endanger life or property on natural hazard lands (discretionary).

The findings of the US Congress in 1977 regarding the environmental impact of surface coal mines are no less true for India today at its current stage of development. Reclamation planning, environmental planning, ecological planning, and sustainable development are approaches which take an increasingly broader view of the impacts of a mining operation both in spatial and temporal dimensions.

It is critical for the Government, Regulators, and the Coal Industry to understand that, mine closure planning is an integral part of the "Mining Business," and should therefore be integrated into all stages of the coal project cycle as shown in Figure 1.

While multi-disciplinary research and development are needed to address technical aspects connected with an integrated mining and reclamation policy, innovative policies are also needed to address the overarching problem of environmental and ecological planning for post-mining development on coal or mineral-bearing lands.

In particular, new approaches are required to planning of mine operations in general, and mine closure in particular. A good rule to follow is that if an adequate closure plan cannot be developed, then the mine should not be opened. Modern mining companies, investors, and communities and Government must understand good mine closure planning will ultimately contribute to the reduction of risks and unknowns as shown in Figure 2. This understanding is in the interests of the People, the Environment, and finally the Nation.

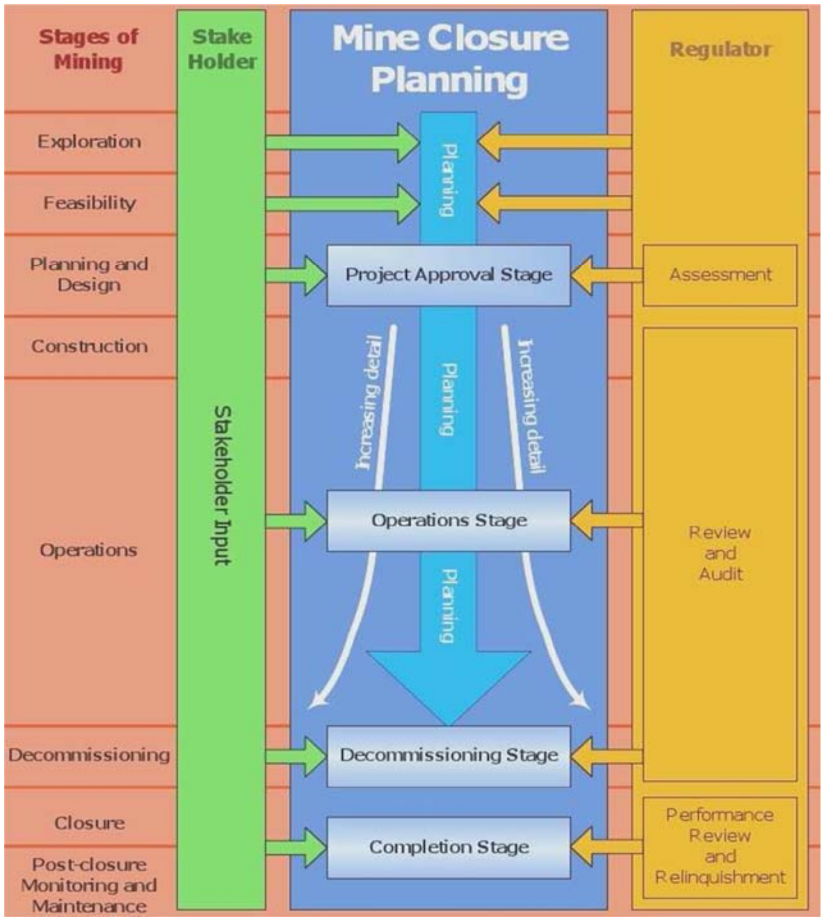
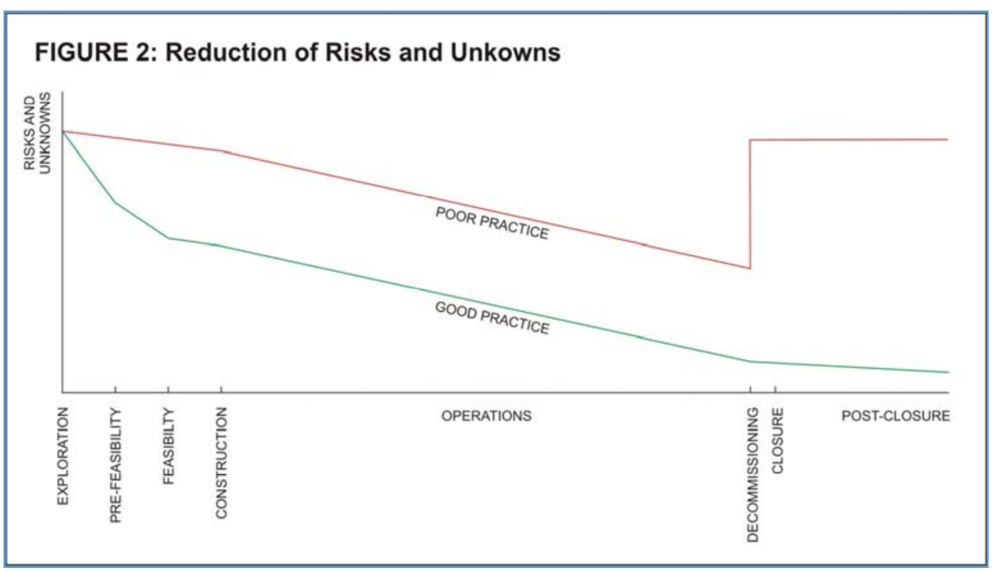


Fig. 1 : Stages of Mining – The Business is "Mining"
Closure Planning is inherently today part of the Business

Business is about Risk Management



10. SUMMARY AND RECOMMENDATIONS

On 5 March 2016, MOEF notified a new categorization of industries based on their pollution load and has included both Mining and Thermal power plants in the "Red" category, with the highest pollution index of 60 and above. However, coal will continue to be the mainstay of the Indian power sector in the foreseeable future.

Since more than 80% of coal used in Indian power plants is mined in India and GOI intends to reduce the share of coal imports further, there is a need to integrate Energy and Mining Policies with Environment Policy. This requires an integrated study by an institution carrying out multi-disciplinary policy research, which commands the respect of the Government, Civil Society as well as other stakeholders in the inter-connected fields of Energy, Mining, Society and the Environment. Therefore, the following inter-disciplinary studies are proposed to be conducted in NIAS in collaboration with institutions and organizations of repute in India and abroad to develop and recommend India-specific guidelines/code of practice/statutes in relation to the mining of coal and its usage in thermal power plants:

1. Study of the existing reclamation & environmental protection measures as well as community development initiatives in select coal mines of CIL and/or Singareni to assess their effectiveness and areas for improvement.

2. Study of world-wide best practices in regards to surface coal mine reclamation and restoration culminating in development of a Code of Practice for the Reclamation & Restoration of Indian coal mines with the objective of ensuring that the land used for a surface mine is restored to beneficial use following mining.

3. Study of the modern regulatory regimes governing surface coal mines along with post-mine closure activities (including, reclamation and restoration) to recommend an effective regulatory mechanism for surface coal mining and its environment in India, which will take an integrated view of mining operations, pre-and post-mining land usage, as well as other environmental impacts of coal mining. The urgency of this exercise is underscored by the fact that CIL alone has identified 476 coal mines for closure till date, while other coal mine owners will also have several mines slated for closure over the next few years or decades.

4. Prepare draft regulations to address the environmental impacts of surface coal mining with the overarching objective of ensuring the sustainable development of the Coal Sector (mining and utilization) while ensuring that the area used for mining is returned to a more beneficial land use after mine closure. The objective of this study is to ensure that closure planning becomes an integral part of business planning (Figure 1), which will ultimately improve risk assessment and its management as shown in Figure 2.

5. Conceptual study of the current status of select coal-fired power plants which are more than 25 years old and have been identified by the CEA or other Authorities for retirement or review, either due to the significant investments required for their Life Extension and R & M or due to their inefficient operation, with a view to determine whether these depreciated units can be replaced by more efficient and environment-friendly power plants (including solar) or whether the infrastructure created (land, water, and grid connectivity) can be used

by the State to create industrial parks on a plug-and-play model after suitable reclamation and restoration of the site. Such examples abound all over the World (e.g., the main plant building of the Bankside power plant near London is now the Tate Modern Art Gallery).

6. Based on the above studies, develop more realistic projections of the coal requirements over the medium and long term, with particular focus on the identification of technologies that India needs to develop to increase the proportion of underground coal mining which is inherently more environment-friendly and requires only a fraction of the surface area required for surface mining.

7. Study the implementation of the Pradhan Mantri Khanij Kshetra Kalyan Yojana (PMKKKY) in at least one major mining area to review the effectiveness of the District Mineral Foundation in achieving the primary objective of PMKKKY, which is to promote the sustainable development of the area and people affected by mining operations, and recommend changes (if any) required in the guidelines/statutes to improve the effectiveness of this program.

PETRO AND ORGANIC CHEMICALS FROM COAL
- Potential Areas for DST Support

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New Delhi

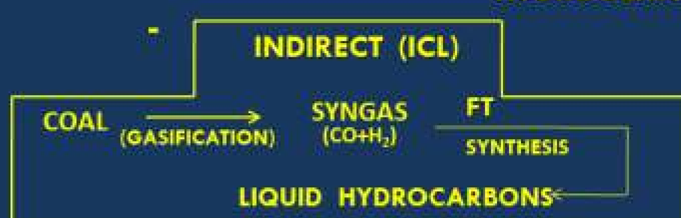
DST Meeting on
Clean Coal Technologies

26th October
2016

COAL TO LIQUID TECHNOLOGIES (CTL)

- SHARE OF COAL USED FOR CTL IN THE WORLD IS LESS THAN 50%
- TECHNOLOGIES FALLS INTO TWO CATEGORIES

- DIRECT (DCL) $\longrightarrow$ CARBONIZATION + HYDROGENATION
-

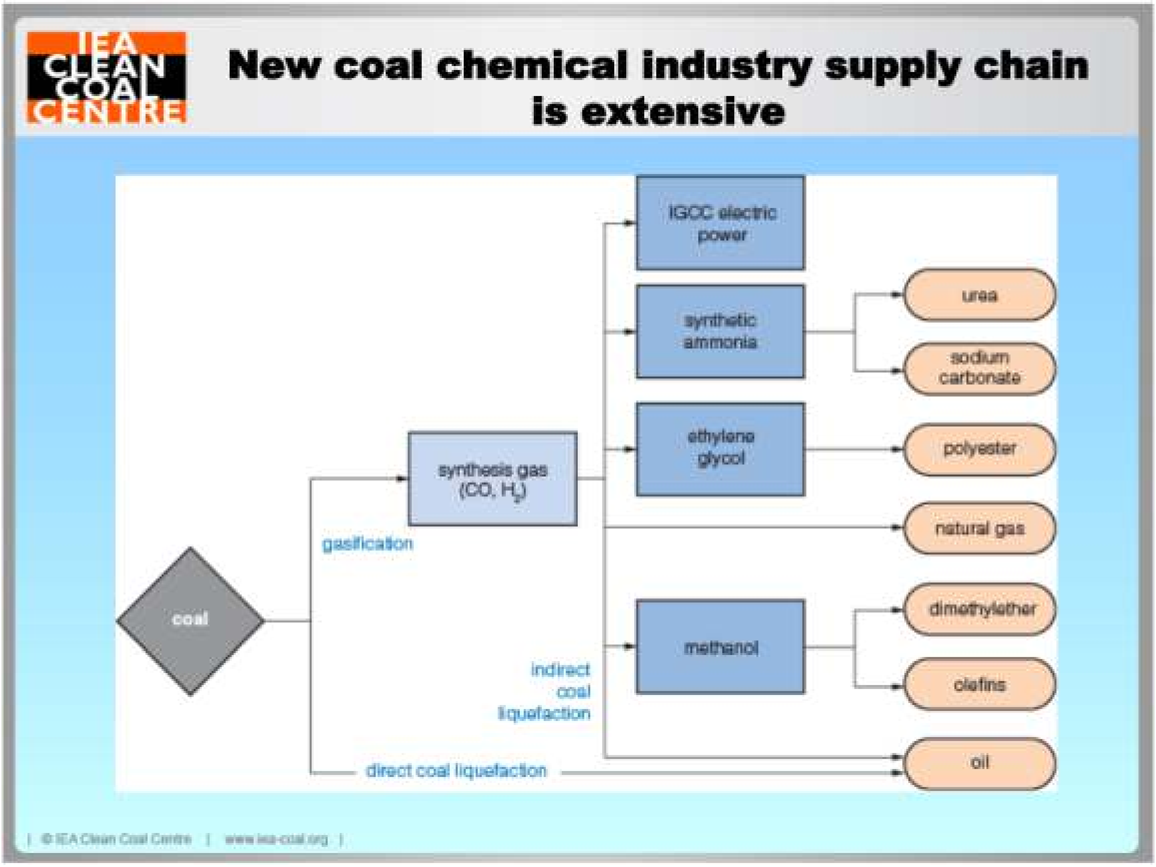


- LIQUID HYDROCARBONS HAVE HIGHER HYDROGEN – CARBON MOLAR RATIO THAN COAL
- HYDROGENATION CAN ALSO BE EMPLOYED IN BOTH DCL AND ICL OPTIONS
- CTL PROCESSES REQUIRE HIGH TEMPRATURE / PRESSURE; SIGNIFICANT ENERGY CONSUMPTION

STATUS OF CTL TECHNOLOGIES (2010)

- INDIRECT CTL BASED ON GASIFICATION FOLLOWED BY FT AND METHANOL TO GASOLINE TECHNOLOGIES ARE NOW COMMERCIALLY VIABLE
- LONG LEAD TIME IS REQUIRED FOR PLANNING, DETAILED DESIGN AND CONSTRUCTION; CTL PLANTS WITH IMPORTED TECHNOLOGY MAY BE POSSIBLE IN INDIA DURING 2018-2020
- CTL PLANTS WITH CCS OPTION WILL TAKE BEYOND 2020 TO IMPLEMENT IN INDIA
- R&D IS REQUIRED FOR COAL+BIOMASS CTL IN INDIA
- ENTRAINED COAL GASIFICATION IS YET TO ATTAIN FULL COMMERCIAL VIABILITY; TECHNOLOGY RISK IS MODERATE

GLOBALLY, INTEGRATED ENTRAINED BED COAL GASIFICATION, ADVANCED SYNGAS CLEANUP AND SLURRY BED FT SYNTHESIS ARE YET TO BE DEMONSTRATED ON LARGE SCALE



ECONOMIC AND ENVIRONMENTAL PARAMETERS FOR COAL TO CHEMICALS

Environmental Factors			
	Consumptions T/T		CO_2
	Coal	Water	Emissions
ICL	4.39	13	5.0
COAL TO OLEFINS	6.68	33	5.5
COAL TO EG	2.55	14	2.0
COAL TO SNG (T/1000 Nm^3)	2.83	6.6	2.5

Indicative economic assessment

Input coal price (US$/tonne)	Crude oil production costs (US$/barrel)	
	ICL	DCL
15	35-45	25-30
125	80-90	49-59
155	110-120	65-75

Slow start in India

- Major user of coal and a rapidly growing economy
- Very large reserves of hard coal (60Gt) and lignite (38Gt)
- Hard coal far from industrial demand regions
- Major coal quality issues
- Government driven initiatives have been ineffective but some positive activities underway
- Jindal Steel and Power Ltd developing coal to chemicals project to produce a substitute reducing gas for the production of Direct Reduction Iron in a shaft furnace

- Rashtriya Chemicals and Fertilisers Ltd, Coal India Ltd and the Fertiliser Corporation of India Ltd refurbishing several fertiliser production units

ADANI GROUP IS PLANNING
TO SETUP A MAJOR
COAL TO CHEMICALS PROJECT
UNDER POLYGENERATION
CONCEPT FOR
GENERATING SYNTHETIC ENERGY
- COAL TO UREA, SNG
- AND THERMAL POWER

AREAS FOR DST SUPPORT IN COAL TO CHEMICAL TRANSFORMATION

- CAPACITY BUILDING IN SELECTED UNIVERSITIES AND NATIONAL TECHNOLOGY INSTITUTES

ADVANCED COAL CHEMISTRY	APPLICATION ORIENTED COAL CHARACTERIZATION
COAL REACTION ENGINEERING	MODELING AND SIMULATION
INTENSIFICATION OF COAL PROCESSES	MICROBIAL COAL PROCESSING
SCALE UP OF COAL PROCESSES	ELECTRON BEAM & OTHER GAS CLEAN UP
FRACTIONATION OF COAL LIQUIDS	BASIC / DETAILED ENGINEERING OF COAL PROCESS PLANTS

POST GRADUATE AND DOCTORAL RESEARCH AND ENGINEERING STUDIES

BASIC RESEARCH CHALLENGES IN CTL PROCESSES

PROOF OF CONCEPT; DEEPER SUBJECT UNDERSTANDING; NEWER THEORETICAL OPTIONS; SCIENTIFIC FOUNDATION; SCIENTIFIC BASIS FOR APPLIED RESEARCH

- NOVEL WAYS OF BREAKING APART COAL MACROMOLECULES THROUGH ACID CATALYSIS OR ENZYMATIC CLEAVAGE
- DIRECT LIQUEFACTION OF COAL IN MOLTEN ZINC CHLORIDE TO ENHANCE SELECTIVITY TO GASOLINE
- ADVANCED UNDERSTANDING OF MOLECULAR STRUCTURES OF COAL FEEDSTOCKS AND SPECIFIC TYPES OF BONDS TO BE BROKEN

TO ESTABLISH CENTRE OR CENTERS OF EXCELLENCE FOR ADVANCED COAL CHEMISTRY AND ENGINEERING

TYPICAL FOCUS AREAS

- ADVANCED GASIFICATION PROCESSES
- CO_2 BASED DOWNSTREAM CHEMICALS
- ADVANCED TECHNIQUES FOR CHEMO-INORGANIC AND BIO LEACHING OF COALS

A DST SUPPORTED INITIATIVE IN UNIVERSITIES AND RESEARCH INSTITUTES TO BE OPERATED PREFERABLY ON PUBLIC – PRIVATE PARTNERSHIP

MOLECULAR SIMULATION OF COAL TO CHEMICALS

- MOLECULAR DYNAMIC CONCEPT FOR CHEMI-INFORMATIC ANALYSIS OF COAL PYROLYSIS
- NOVEL SIMULATION STRATEGIES TO IDENTIFY ALTERNATIVE REACTION PATHWAYS AND PROCESS INTERMEDIATES
- REACTIVITY AND CATALYTIC PROPERTIES OF NANO PARTICLE MEDIATED CATALYTIC PROCESSES
- UNDERSTANDING OF ELECTRONIC PROCESSES IN SOLUTION AND ASSESSING SOLVENT SPECIFICITY

THESE ARE ALSO ATTRACTIVE SYSTEMS FOR KNOWLEDGE INTENSIVE POST DOCTORAL RESEARCH

NEW PROCESS CONCEPTS FOR CTL

- OXIDATIVE HYDROTHERMAL DISSOLUTION OF COAL EMPLOYING WATER AND AIR TO SYNTHESIZE A RANGE OF CHEMICALS FREE FROM CO_2 AND OTHER POLLUTANTS
- ADVANCED MICROBIAL COMMUNITY FOR COAL CONVERSION TO METHANE AND OTHERS; UNDERSTANDING THE ROLE OF PROTEINS AND MULTIPLE REACTION PATHWAYS

GOOD AREAS FOR DOCTORAL AND POST DOCTORAL RESEARCH

APPLIED RESEARCH AREAS IN CTL PROCESSES

TECHNOLOGY AND TECHNIQUES DEVELOPMENT ON BENCH / PILOT SCALES ; MATERIAL ENERGY BALANCING; SCALE UP; PROCESS INTENSIFICATION

ALTERNATIVE TECHNOLOGIES

- COAL EXTRACTION WITH GREEN SOLVENTS FOLLOWED BY 2 STAGE HYDROGENATING AND FRACYIONATION TO DIESEL AND JET FUELS
- INTEGRATION OF CTL PROCESSES INTO PETROLEUM REFINERIES BY BLENDING COAL WITH PETRO FEEDSTOCKS IN DELAYED COKERS

CTL TECHNOLOGICAL OPTIONS DEPLOYABLE DURING 2020 - 2035

- CATALYTIC CONVERSION OF SYNGAS TO *ISO* BUTANOL AND OTHER HIGHER ALCOHOLS IN A SLURRY REACTOR
- ADVANCED GAS CLEAN UP TECHNOLOGIES
  - H_2S REDUCED TO PPBs; SIMULTANEOUS NO_x and SO_x
- GASIFICATION THROUGH CHEMICAL LOOPING EMPLOYING OXIDES AS OXYGEN CARRIERS; ITS INTEGRATION WITH CTL
- CONVERSION OF LIQUID FUEL BYPRODUCTS INTO HYDROGEN FOR HIGHER YIELD AND LOW CARBON EMISSION

COAL – BIOMASS – NATURAL GAS BLENDS FOR LIQUEFACTION

- BRINGS DOWN FUEL PRODUCTS LIFE CYCLE GHG EMISSIONS INTO A COMPETITIVE RANGE
- SINCE BIOMASS GASIFICATION IS A SMALLER SCALE OPERATION, ITS INTEGRATION WITH COAL ALLOWS BETTER ECONOMY OF OPERATION SCALE
- NUMEROUS OPTIONS (POLY GENERATION) FOR PRODUCING LIQUID TRANSPORTATION FUELS CAN BE EXPLORED

APPLIED RESEARCH FOR STANDARDIZING AND OPTIMIZING PRODUCT DISTRIBUTION IN CTL TECHNOLOGIES

- ETHYLENE GLYCOL FROM SYNTHESIS GAS
- OXIDATIVE DEHYDROGENATION OF CO
- COUPLING OF CO AND METHYL NITRITE TO DIMETHYL OXALATE
- HIGH TEMPERATURE VAPOR PHASE NON OXIDATIVE CONVERSION OF CI HYDROGARBONS TO ETHYLENE AND AROMATICS

CO_2 CHEMISTRY

- HYDROGENATION OF CO_2 TO METHANOL
- DRY REFORMING OF C_1 AND OTHER HYDROCARBONS WITH CO_2 TO SYNGAS
- PHOTO CATALYTIC CONVERSION OF CO_2 TO CO, METHANE, FORMIC ACID AND FORMALDEHYDE

FOCUS AREAS FOR INDIA

DST PROMOTED SEMICOMMERCIAL LEVEL TECHNOLOGY DEMONSTRATION PROJECTS IN INDIA

- NEED TO BE AN INTERMINISTERIAL INITIATIVE
  (DST + USER MINISTRIES + USER INDUSTRIES)
- PRIORITY AREAS
  - ❖ DCL / ICL PROCESSES
  - ❖ COAL TO FERTILIZER CHEMICALS
  - ❖ DRY REFORMING OF HYDROCARBONS
  - ❖ NEW IMPORTED TECHNOLOGIES

Thanking you

Maturity of Advanced Coal Combustion Technologies and the Indian Priorities

Shri M.S. Unnikrishnan

The impending ratification of COP -21, though intended to support the continuity of human life in the earth, is certainly going to exert undue pressure on the need to develop and deploy technologies that will replace the existing fossil dependent combustion technologies. India with a near total dependence on coal for its short-to-medium term power generation requirements will need to very quickly shift over to clean combustion technologies.

Coal as a source of energy is predominantly deployed by the developed world only for Power generation. The technology development in those countries – primarily in the US and to a limited scope in Europe – was focused more on cycle efficiency combined with capacity enhancement. Thus, what started at 50-60 MW individual steam generators went all the way up to 1300 MW in capacity. Alongside, the steam pressure climbed up from 21 ATA in the early stages and crossed the critical barrier in 1950's and super-critical became a normal standard from the sixties. Steam temperatures which was constrained by metallurgy, breached the carbon steel barrier into the alloy steel regime by 1930's and have reached almost 620 degree Celsius making advanced ultra-super-critical a reality.

Electricity which remained a total state subject till the advent of Indian Electricity act of 2003, was constrained by regulations and depended totally on indigenous technological development. While the first super-critical boiler of the world was commissioned by Babcock & Wilcox in the US in 1953, India waited for another 60 years for the deployment of this technology (the first super-critical power plant of India was commissioned in 2012 at Sipat).

This absence of participation in the technology advancement journey was compensated to a certain extent by the Industrial sector owing to the peculiar energy resource constraints of the country (China is the only other country which had a similar situation). While the entire western world deployed electricity, oil & gas for their Industrial energy requirement (of heating, cooling and power), Indian industrial development was on the back of captive power and co-generation that was primed predominantly by coal and a good proportion of the heating and cooling requirement also met with coal and biomass as the input fuel. This unique situation has afforded the Indian steam generator industry an opportunity to bring in and further develop advanced coal combustion technologies right from the early nineties.

PECULIARITY OF INDIAN COAL

India has a wide variety of coal, most of which is inferior in overall quality when compared to the rest of the world.

	India	Indonesia	South Africa	USA
Calorific Value	3000 – 4750	4000 – 6500	6000	5000 – 7000
Ash Content	25 – 45%	6 – 12%	12 – 14%	8 – 15%
Moisture	8 – 12%	18 – 38%	8 – 10%	2 – 3%
FBN	0.5 – 1.15%	0.7 – 1.15%	1 – 2.5%	1.5%
Sulphur	0.3 – 0.8%	0.3 – 1.2%	1%	0.2 – 4%

Calorific Value: Indian coal on an average is 30 to 35 percent lower in its heating value in comparison to the rest of the world. This would translate into enhanced sizing of the entire coal transportation and handling system by a similar percentage, apart from over-sizing of the furnace and other heat transfer zones too.

Ash Content: Arguably Indian coal has the highest ash content among the commercially exploited sources in the world. There are technical limitations for most of the prevalent coal combustion technologies to handle ash content of this magnitude. In fact, this has prompted the Central Electricity Authority (CEA) to stipulate a ceiling of 35 percent ash content in coal for feeding into steam generators deployed in power plants. It is likely that as we go deeper and deeper for extracting the coal from mines, the ash content in coal will further enhance, making it even more difficult to combust. In order to overcome this difficulty, the power industry is left with no choice, but, to resort to deployment of large scale coal washeries to reclaim higher quality of coal with lower ash content. Consequently, the washeries produce mountains of middling and rejects that cannot be used in the conventional power plants deploying pulverized coal combustion technology.

Apart from a higher content of ash inherently present in Indian coal, the quality of ash and its content pose an added challenge while designing a power plant deploying Indian coal. Silica content in Indian ash is as high as 55 – 65percent. And the iron content varies between 4- 6 percent. Erosion characteristics, owing to these abrasive contents in the ash poses one more challenge while designing Indian power plants.

Fuel Bound Nitrogen: One of the major advantages of Indian coal is a comparatively lower presence of Fuel bound Nitrogen. The biggest challenge while limiting the NOx emission from a power plant is the FBN percentage, since almost 75 percentage of all the NOx created within the steam generator emanates from the fuel and the rest from the nitrogen carried into the furnace through the combustion air. Thus a lower FBN will certainly help in reducing the size of de-NOx plant deploying SCR technology. But this advantage will get partially negated by the higher ash content of the coal, which will have an adverse impact on the effectiveness of the impregnated catalyst in either form of the SCR design i.e. honey-comb as well as plate type.

Sulphur: Indian coal, with the exception of the one mined in the north-east, has relatively lower Sulphur content when compared with the rest of the world. This affords a positive advantage in bringing down the SOx emission while designing a power plant deploying Indian coal. Apart from reducing the overall size of the Flue Gas Desulphurization unit, the lower Sulphur content also brigs down the operating cost for meeting the emission norms, with a lower consumption of chemicals and power.

COAL COMBUSTION TECHNOLOGIES

The coal combustion technologies that are proven and in practice differs substantially between power plants and industrial captive and cogeneration plants in India.

Power plants: Indian power industry has successfully migrated from moving grates into Pulverized Fuel (PF) in its early days itself. This technology is today almost perfected by the Indian manufacturers as well as India based joint ventures of global leaders around the peculiarities of the domestic coal in all aspects.

Thanks to the seamless working of the academia, research institutions and the industry, considerable amount technological advancements were accomplished in the past few decades in this technology through indigenous research and development. PF technology in coal preparation, pulverizing, combustion, heat and mass transfer through radiation, conduction, convection, nucleate boiling, super-heating, re-heating, all allied hydraulics, material sciences, control and automation are totally a part of India's knowledge stream. In fact, today, the academic and research institutions of the country are producing sufficient (may be more than necessary) talent in combustion and power plant engineering and we will be able to provide this capability to the rest of the developing world too.

What we need to develop further is the next level of advanced ultra-critical thermal power plants that will work at 700+ degree C temperature and enhance the cycle efficiency beyond 50 percent. The main challenge we need to overcome for this is more to do with material science and metallurgy rather than combustion technology. We may also need to co-develop it along with global research institutions to accelerate the pace of this development, rather than totally depend on domestic capabilities alone. Since the developed world may not have a strong inclination towards coal based power generation any more and we, in India, will have to certainly depend upon coal for a considerable period of time for our economic development, it will be in our national interest to elicit global association/ partnerships to hasten the advanced ultra-critical technology development and deployment.

Industrial Power Generation: Captive and co-generation in India, though started off with different varieties of moving grate technologies, had to migrate to fluidized bed technology as the ash content in the domestic coal crossed the 30 percentage barrier, way back in the eighties. Starting with a Bubbling bed, the industry quickly advanced into Atmospheric Fluidized Bed Combustion (AFBC) technology at very quick pace. By late eighties the country created total indigenous capability and capacity to design, manufacture, construct, operate and maintain AFBC technology, with a well-oiled domestic supply chain too.

Industrialization of India took a vertical path, post the liberalization and opening up of the economy in the nineties. As the scale of manufacturing multiplied, industrial captive power generation capacity got elevated to 40 – 60 MW in steel, cement, non-ferrous metallurgy and heavy chemical segments. Apart from this, advent of global completion compelled the Indian industry to opt for cheaper versions of solid fuels like Low grade Indian coal, pet coke, Lignite, and washery rejects. This duel challenge of fuel complexity and elevated capacity could not be addressed by the AFBC technology. This paved the way for a selected, innovative and technically savvy Indian manufactures to upgrade to the Circulating Fluidized Bed Combustion (CFBC) technology. All of them struggled in the initial days with this highly advanced technology but has perfected it by the early days of the new millennium. On the back of an unprecedented economic growth and industrial development of the country in the past decade, CFBC technology has matured in the country and has today entered also the core Power Industry in the sub-critical range with single plants of up to 250 MW.

INDIA’S PRIORITY FOR ADVANCED COMBUSTION TECHNOLOGY

C F B C Technology : CFBC technology with its innate ability to combust coal with even a 60 percent ash content is far more suited for dealing with the already inferior and further deteriorating Indian coal. Since the CFBC furnaces are designed to operate at temperatures ranging between 850-950 degree C, generation of NOx will be lower too when compared with PF furnaces that operates at much higher temperatures. Apart from these two distinct advantages, CFBC technology also has the ability to capture predominant part of the Sulphur within the furnace itself through the usage of crushed lime as the fluidizing media.

Poland was the first country in the world to deploy the CFBC technology in the super-critical range with a 400 MW power plant. Korea Power Corporation is currently building a 4 x 600 MW CFBC based super-critical thermal power plant. China will be ready with their CFBC super-critical plants in the near future.

India is ideally the most needy and deserving market for super-critical thermal power plants with CFBC technology. The ongoing joint development program supported by the government for the development of ultra- super critical technology should certainly incorporate CFBC as one of or even the primary option for our country.

Clean Coal Technology: Emission reduction commitment in line with the Paris agreement will necessitate development of clean coal technologies to restrict the per capita CO_2 emissions. There are two distinctive possibilities for India, that needs closer evaluation for further development.

1. **Oxy-fuel Combustion and Carbon Sequestration:** Carbon capture and sequestration combined with oxy-fuel combustion is theoretically the best solution available to contain or even negate the ill effects of coal based thermal power generation. But, despite the support given by the wealthiest of global economies and engagement of the most brilliant technical intellects of the world, no tangible and commercially viable solutions are created nor in sight at this juncture. Even if a technically viable and universally acceptable solution is developed in the near to medium term, it is going to be an unviable solution for a financially constrained economy like India. Unless a major and disruptive technology development happens in this arena, India should keep away from this imaginative solution.

2. **Coal Gasification and Combined Cycle:** Gasification of coal and further conversion of it for petrochemicals was developed as a viable technology and part deployed by the Oil and Gas sector, quite some time back. But the globally manipulated oil and gas pricing has kept the further development and commercialization of this technology at bay. The current glut in crude prices and the expectation of it remaining range bound between \$ 40 – 65 per barrel will further dampen its deployment in the near future.

   With sufficiently large enough coal reserves, that will remain the mainstay and backbone of our economic development in the medium term, India will have to develop coal gasification technology at a faster pace. This technology route will offer a two dimensional advantage for the country by way of enhancing the power generation efficiency to over 60 percentage (as against the dream of a maximum of 50 percentage with ultra-super critical) as well as bringing down the entire emission worries (both technical and financial) to a manageable level.

CONCLUSION

India has already created a robust platform in advanced coal combustion technologies. This was sufficient to support the size and pace of development of our economy in the past. As the countries embarking upon the path of becoming the manufacturing and technology giant of the ongoing century, we need to change the strategy, path of technology and its pace of development. This will need policy and financial support from the government along with active participation from the academia, research institutions and the industry.

Proposal on Clean coal technology - Coal to gaseous fuel for power generation or syngas

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ABSTRACT

This proposal aims at conducting studies on fluid bed gasification of small-size coal (3 to 8 mm) with air-steam and oxy-steam as reactants. The needed preliminary study with reverse downdraft gasification approach very successful in biomass was extended to small-size coal to obtain insight and also determine parameters for fluid bed gasification system design with air and air-steam mixtures at different reactant flow rates (or superficial velocity). Limited studies on coal in fluid bed with air-steam mixture indicated the parameter range that can affect the performance – bed temperature from 650 to 900 °C, superficial velocity (0.2 to 0.5 m/s) and ash fraction (less than 30 %). It is first intended to conduct gasification studies in a lined reactor (about 200 mm dia)to establish the feasibility of steady gasification process in the fluid bed with coal of higher ash content. Nominal coal consumption rate is set at values between 5 - 10 kg/h. Addition of limestone will be explored to eliminate the sulfur related issues. Issues of gas quality in terms of particulates and tar as well as ash extraction process will all be studied aimed at producing reliable and affordable strategies for the process to be commercially significant at lower throughputs.

After the establishment of the air-steam gasification process in which the aim is to use the available heat in the system to heat coal, air and generate steam, the study will be extended to oxygen-steam gasification process.

The air-steam gasification process leads to *producer gas* that would help power generation at power levels of 5 - 10 kWe. The demonstration can be scaled up after review to commercially significant levels – 200 kWe upwards.

Oxygen-steam gasification process leads to *syngas* (nitrogen free) that would be a feedstock for Fischer-Tropsch (FT) process to produce oil crude. Experience gained at IISc on catalyst development will be spooled in appropriately in a new generation catalyst-slurry based reactors.

The project is envisaged to be implemented in stages:

1. Fluid bed air-steam gasification of coal - gas quality measurements and system integration. Duration – 24 months – project finances – Instrumentation including gas composition measurements Rs. 18 lakhs, fabricated hardware – 15 lakhs, Blower and related equipment – 5 lakhs, Staff salaries (2) 14 lakhs, coal and other consumables – 10 lakhs, JU overheads (at 15 %) 9.3lakhs – Total Rs. 71.3 lakhs.

2. After this segment is reviewed and its status provides further encouragement, the second phase involving oxygen-steam gasification process can be undertaken. Duration 18 months. Cost ~ about 40 lakhs (will be estimated more precisely later).

Other aspects of the project like engine operation can be contemplated during the annual review of the project.

BACKGROUND AND EARLIER LITERATURE

This proposal has arisen because of interest shown at INAE in examining new technologies for clean conversion of coal to energy – electricity or liquid fuels apart from addressing issues of the current use in other segments - metallurgical applications and others that is beyond the scope of this study.

The essential features of coal utilization in India are that the coal has higher ash content, but the Government has ruled that for power generation purposes, the coal beneficiation process should produce coal at ash fractions less than 30 %. It is recognized that sulfur fraction is small in Indian coals, but for gasification process to be meaningful, even this sulfur needs to be dealt with. Coal combustion as practiced today in power plants of significance deals with coal by pulverizing it to around 70 microns. The energy going into pulverizing the coal is significant and this is also one of the reasons for limiting the inorganic (ash) fraction of coal by the beneficiation process. As discussed at the earlier meeting at INAE and as can also be inferred, there is a limit to beneficiation and the energy and cost going into beneficiation will not necessarily paid back in the use of the "cleaner" coal. While it is also true that the optimal point at which utilization at the given inorganic fraction overtakes the beneficiation process can vary with time and other economic compulsions, it appears appropriate to deal with coal at ash fractions less than 30 %. The reason for pulverizing the coal is to reduce the combustion time and use a more convenient feed option of high density fuel carry-through system.

Othmann et al (2007) have studied air-steam gasification of various Malaysian coals (~ 1 – 1.2 mm size) that have ash fraction less than 10 % in a sand medium (0.35 to 0.5 mm). The approach is atmospheric fluidized treatment of the gasification process in a reactor of 250 mm dia and reactor height of 1 to 1.2 m with temperatures controlled by electric heating of the system at 600 °C but the bed temperatures maintained at 750 to 1000 °C. The principal defect of this experimental study is that autonomous gasification process is not created.

In an interesting recent paper by Toporov and Abraham (2015), a description of the famous Winkler process also termed HTW^{TM} fluidized-bed gasification process is set out. It is very useful to quote from this paper: "….It was based on the Winkler generator, which was developed in the 1920s in Germany by IndustrieGewerkschaft (IG). From 1920 to 1930 IG investigated the possibility of using low-rank local coals, such as brown coal, instead of expensive coke, for synthesis gas production and subsequent production of ammonia and methanol. Dr. Winkler in 1921 conceived the idea of using a 'boiling' bed, *i.e.* using particles of fuel small enough to be almost gas-borne and hence comparatively mobile. Under such conditions the fuel bed behaves very much like a liquid; the gas passing through the fuel gives an appearance as if the bed were boiling, the bed finds its own level, as does a liquid, and circulation of particles within the bed is such as to give substantially equal temperatures throughout the bed. This is what we nowadays call a fluidized bed.The first Winkler generator was put into operation at Leuna, Germany in 1926, making power gas and having a capacity of 40 000 Nm^3/h. In 1930 the production of nitrogen-free water gas began, which was obtained by continuous blast of pure oxygen with steam…… Commercial-scale Winkler gasifiers were operated at atmospheric pressure in over 40 applications around the world. Since 2000 more than 40 new atmospheric units have been built in China alone. Thus, the Winkler gasification process became a widely used technology, characterized by the following advantages:

1. Low oxygen consumption due to moderate temperatures
2. Optional use of air or pure oxygen as an oxidant
3. Simple coal preparation
4. Good partial load behavior over a wide range of operating conditions
5. Simple start-up and shut-down procedure
6. High operational reliability
7. No by-products in the raw gas, such as tars, phenols, and liquid hydrocarbons…."

Similar indications of the quality of this design have been provided by Leckner (2016) and Berault (2010). What is clear is that Winkler technology which at its core is a fluid bed gasification process seems reliable. There is a whole literature of pyrolysis of coal that does not seem to have been used in the formal design of successful systems, partly because Winkler technology that preceded all these explorations seemed to have worked over a wide range of conditions – though initially intended for lignite that is more reactive, hard coals have been used. Of course the European coals that were explored have had ash fraction less than 10 % in most cases. Even though Toporov and Abraham (2015) discuss low-rank coals, no specific indication of the composition with inorganic fraction is indicated in their paper. In any case, lignite that qualifies for low-rank coal is not the most significant fuel of choice in India.

It is interesting and useful to note that a very recent articlein Science Mann (2014) examined the developments in China on clean coal technologies re-emphasizedfacts that have been understood in India for a long time.

THE CURRENT EFFORT

The study was partly motivated by a view that studying coal chemistry is vital for evolving coal conversion technologies, a fact that was found favor with due to large number of publications in this area in journals of significance, like Fuel. Indian coal whose composition depends (at a certain level of detail) on the mining area and the depth of mine allows for wide spread studies of this nature. A somewhat similar feature was present in the area of biomass. Select scientific groups in India and elsewhere have done very significant work on low temperature conversion techniques like pyrolysis of biomass and its chemistry. The extent of this work is argued as important by the fact that even the same biomass grown in different areas has many inorganic elements – potassium, sodium, magnesium, manganese embedded in the structure to a total content between 1 to 10 % (only rice husk and straws have up to 20 % of inorganic content). It is known that these inorganic elements in whatever form they are embedded in the solid matrix cause varying degrees of catalytic function for higher temperature conversion processes.

In an earlier meeting of INAE, a presentation was made of a new approach (by this author) to dealing with clean coal technology based on relatively simple but insightful experiments. The essential basis for these experiments came from reverse downdraft gasification systems for biomass that appeared a very important technology as well as tool to investigate reactivity. A key finding of the effort on biomass was that the entire conversion process, from solid to gas can be treated as "diffusion controlled" rather than reaction controlled. This could be affirmed because the study allowed the description of the consumption rate or flame propagation rate through the packed bed for a wide range of biomass and different particle sizes could all be condensed into a single curve (Varunkumar et al, 2013) with the propagation rate depending only on a quantity called superficial velocity (it is the mean flow velocity inside the empty reactor). The advantage that this provides even for exploring coal is that if we can create conditions so that the rate is dependent on oxygen transport to the surface of the fuel that itself is controlled by the superficial velocity, we could get a process that is weakly dependent on the coal properties. As long as a minimum heat release is assured (that occurs because of the heating value which is dependent on the ash content largely), one can construct a conversion process that is robust ensuring that variations in coal quality and size do not affect the reactor performance significantly.

REDS (REVERSE DOWNDRAFT REACTOR) EXPERIMENTS (2014 – 2015)

Several experiments were performed between August 2014 and Jan 2015 (with the support of Mr. Suri Suresh who conducted the experiments) on two kinds of geometries. In the first set of experiments typical reverse downdraft configurations were used. It was aimed that the size of the coal pieces must neither be too small (like hundred microns) because the energy going into pulverizing would be significant. The size could be made as large as the residence time would permit. If the residence time was large, ash fusion would be a sure possibility. Based on some preliminary experiments, it was decided that coal sized to 3 to 8 mm should be satisfactory and initial experiments were conducted with coal and air at ambient conditions. It was found that there were three segments of conversion process. The first part related to the ignition, the second to conversion of coal to coal char and final part, coal char to ash. Unless the mass flux of air was kept very low (~ 10 cm/s or so), ash fusion was observed in most cases and conversion was reasonable, but needed improvement. It was then thought that if coal was heated to a temperature not far below the volatilization temperature and air was also heated to values close to this, the speed of volatilization process could be increased. This is because the heat required for the material to move from its condition to one where it would ignite and volatilize would be smaller. And if air was also preheated, this would aid the heat transfer to the raw coal; both ignition and volatilization would be expedited. A separate steam generation system and air heating system were added to the reactor. Hot air alone or with steam at desired fraction could be generated at temperatures of 120 - 160 C and would be introduced into the bottom of the reactor.

The reactor schematic is as shown in Figure 1. Air and steam generated outside of the reactor are metered and brought into the reactor bottom. Coal sized to 3 to 8 mm is poured into the reactor from the top.

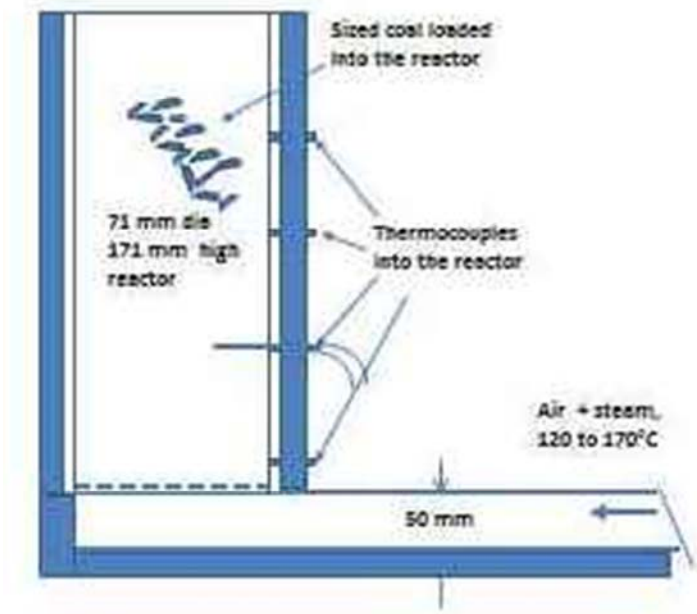

Fig. 1 : The schematic of the reverse downdraft gasifier

Fig. 2 : The actual system during the test. The faint flame is visible

In order to obtain a reference for measuring the flame propagation rate through the bed, experiments were also conducted with high density biomass. Wood and broken coconut shell were chosen at high densities as can be noted from Table 1 that contains other experimental details. Also experiments at densities about the same as coal were conducted using biomass pellets. The superficial velocity set out in the table refers to the gas stream (air or air + steam) in the empty cross section of the reactor (71 mm dia). While many experiments were conducted with air, several were conducted with a mixture of air and steam as well. Some additional experimental details are set out in Table 2.

Table 1 : Summary of the experiments

Item	Wood	Coconut shell	Pellet cylinder	Indian Coal with Air			Indian Coal Air+steam	
$\rho_{biomass}$, kg/m^3	850	850	1260	1250			1250	
Size, *mm*	4 - 5	6-8	8 d x 15 L	3 - 8			3 - 8	
Ash content, %	1	1	9	21			21	
Volatiles, %	87	-	81	27			27	
Sup. Vel, cm/s	19.4	19.4	20	5.7	19	28	43.89	68.03
Air temp (^oC)	28	155	28	145	150	155	170	170
Fuel flux, kg/m^{2}h	120	470	100	126	728	960	799	604
ρ_{char}, kg/m^3	406	327	406	800	736	729	777	711
X_{H2O}	-	-	-	-	-	-	0.29	0.31
Char size, *mm*	7 d,14L	5	7 d x 14 L	2 - 7	3-8	3-8	3-8	3-8
Steam-to-Air (w)		-	-	-	-	-	0.25	0.276

Table 2 : Additional details of the experiments conducted

Material	**Date**	**Ash, %**	**Size, mm**	ρ_p, kg/m^3	**Initial Fuel Temp.^{0}C**	**Hot Air Temp. ^{0}C**	**Initial fuel wt. g**
Wood, 1	20/08/'14	1	4-5	850	150	185	144
Coco-shell	20/08/'14	1	4-5	860	150	180	139
Coal, 21%	01/07/'14	21	3-8	1250	100	165	370
Coal, 21%	02/07/'14	21	3-8	1250	100	165	285
Coal, 21%	06/08/'14	21	3-8	1250	200	150	316
Coal, 21%	06/08/'14	21	3-8	1250	125	160	288
Coal, 21%	27/08/'14	21	3-8	1250	150	120	292

Fig. 3 : Pictures of the ash collected in various experiments

The experiments lasted about an hour. The ash collected at the end of the experiments were photographed and they are set out in Figure 3. The ash in some cases were weakly fused and they were fragile. Slight use of force would break them to pieces. As can be noted from the color and established with weight measurements, the carbon conversion is complete. These results are set out in Table 3. The ash weight indicated in Table 3 is less than the ash expected in the experiments. This is because some fine ash would get blown off in the hot gases coming out of the reactor and was widely dispersed preventing collection and measurement. The last three columns show the results in terms of propagation rate ($\acute{r}$) and the fuel mass flux ($\rho_p\acute{r}$). Clearly noticed is the fact that the propagation rate is strongly dependent on the superficial velocity.

Table 3 : Results of the experiments

Material	**Initial Fuel Temp.C**	**Ini. fuel wt. g**	**Final Fuel wt. g**	**Initial reactor Length mm**	**Final ash ht. mm**	**V_{sup}, m/s**	**$\dot{r}$, mm /s**	**$\rho_p\dot{r}$, kg/ m^2 s**
Wood, 1	150	144		95	-	19.4	0.35	300
Coco-shell	150	139		95	-	19.4	0.37	311
Coal, 21%	100	370	81	100	45	5.7	0.17	212
Coal, 21%	100	285	61	90	45	19.4	0.20	250
Coal, 21%	200	316	75	98	50	19.4	0.20	250
Coal, 21%	125	288	70	95	48	19.4	0.18	225
Coal, 21%	150	292	62	93	53	28.3	0.35	437

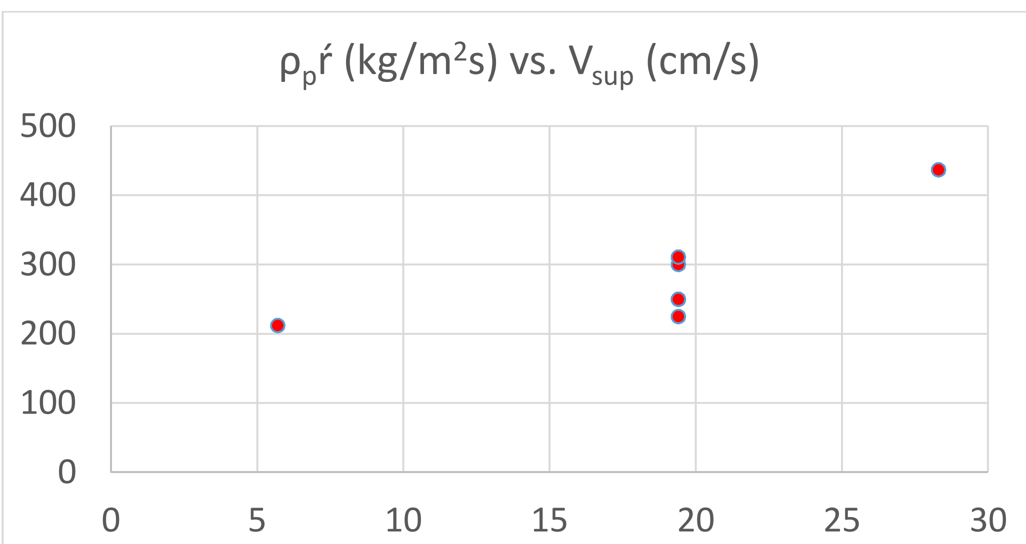

Fig. 4 : The mass consumption rate vs. superficial velocity

One important result with air and steam is set out in Figure 5.

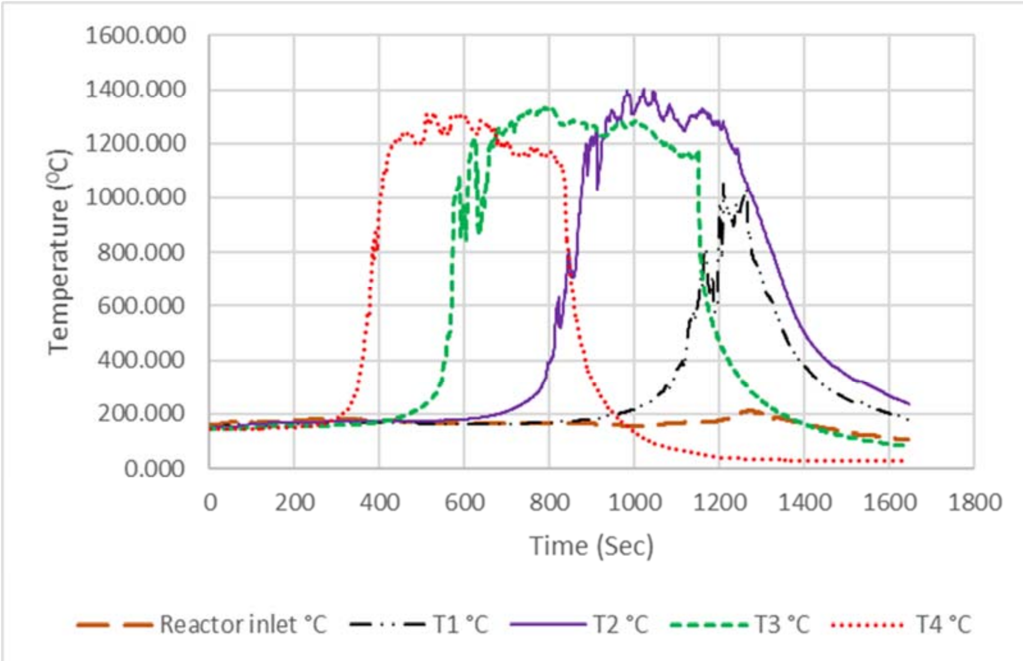

Fig. 5 : The temperature profiles at four stations, left most at the top (red dotted) and others spaced 40 mm each with the last one 120 mm below the top thermocouple; air flow 75 lpm, superficial velocity 28.3 cm/s and steam flow rate 22.3 g/min

In the experiment described by Fig. 5, the amount of coal loaded was 550 g and the final ash collected was 117 g. At an ash fraction of 21 %, the expected ash is 110 g.

An examination of Fig. 4 shows some interesting features. Between the thermocouples, the rise begins in 200 to 300 s intervals. This implies the propagation rate is 0.13 to 0.2 mm/s. The total consumption occurs in about 1000 s. If we take that the mean particle has dimensions of 3 mm x 4 mm x 8 mm, then the volume of each particle is 96 mm^3. At a density of 1250 kg/m^3, each particle will weigh 120 mg. Thus the number of particles consumed is 550/0.12 = 4600. Thus the average time of consumption of each particle is 1000s /4600 = 0.22 s. This is the order of magnitude of the time that has to be provided in any bed for each of the particles to be consumed. Under these conditions, the conversion was nearly complete without significant ash fusion. Other experiments revealed that if the temperatures were maintained at around 700°C, no ash fusion would result. Hence, it was thought appropriate to choose a fluidized bed design so that the temperature of the bed can be maintained at a desired value that could be between 650 to 750 °C, the precise value depending on the coal characteristics.

These studies allowed the determination of some essential parameters of the design: the particle size should be between 3 to 8 mm (odd shapes would not matter), the initial temperature of fuel and air be around 150 °C, the air-to-steam ratio of 20 to 25 %, this value also depending on the coal characteristics. The fluid bed gasifier could be operated at a fuel throughput of 450 to 500 kg/m^2h (the area is the cross sectional area of the reactor) with superficial velocities of 0.28 m/s. If it is noted that the peak specific consumption rate of a fixed bed in biomass is about 350 kg/m^2h, these values appear consistent in view of the fact that what is being considered is a fluid bed.

The same reactor was operated as a fluid bed system with periodic loading of the fuel and the flow behavior was examined. Clearly, the flame was seen over the lip of the reactor whereas the bed was deeper inside, this feature chowing that the gases did not find any air to burn inside and therefore were v=burning over the lip of the reactor. After the proof-of-concept was obtained, further experiments with well-defined features for extracting the ash and producing hot air and steam from the reactor heat itself need to be conducted.

OBSERVATIONS ON THE CHOICE OF PRESSURE

The current design is an atmospheric pressure design. Winkler design has also options for higher pressure operations. In fact, many overseas designs are high pressure designs. There are pluses and minuses with high pressure design. It is very ideal when being used with gas turbines because with the use of hot gas clean-up, the gas can enter into the combustion chamber of the gas turbine directly. For this, the throughput has to be high and the operating pressure around 6 to 8 atm. There is already some experience on this at BHEL. This approach has not been considered satisfactory, for otherwise the plant would have been functional. System designs should be attempted only after the gas turbine power level and operating pressure are identified. Otherwise, it would be far more expensive.

We have had experience on operating a 5 atm high pressure biomass gasifier at IISc in 1998 – 2000 as a part of an MNRE project on advanced gasifiers. While great struggle was made to get the matching gas turbine, it was found that it would highly uneconomical to operate the system. The fuel feed system as well as ash extraction systems need to have lock-hopper arrangement, clearly an over load on the infrastructure in terms of feed system and maintenance costs. It is only larger power generation systems that can absorb this overload, but then investment system costs will be far too high with the attached uncertainties on handling high ash Indian coals.

The current effort is atmospheric pressure design as there is much that can be learnt from it at small scale with very modest financial inputs. Once the reactor functioning has been established, the gasifier will be structured around this reactor to determine the cold gas quality with adequate instrumentation to understand the behavior under different operating conditions of air-to-steam ratio and coal bed loading. The ash extraction approach through a cyclone should be established. While the first efforts may use independent fuel heating, air heating and steam generation systems, the second phase will involve integration of these from the excess heats of the gasification system. It is intended that the gasifier operates around 700 to 800 °C, but tests will show how this influences the performance of the system.

Project time lines and costs

The project is envisaged to be implemented in stages:

1. Fluid bed air-steam gasification of coal - gas quality measurements and system integration.

2. After this segment is reviewed and its status provides encouragement, the second phase involving oxygen-steam gasification process can be undertaken. Duration 18 months. Cost ~ about 40 lakhs (will be estimated more precisely later).

Other aspects of the project like engine operation can be contemplated during the annual review of the project.

Item	**Ist year, lakh Rs**	**2nd year, Rs lakhs**	**Total, Rs lakhs**
Equipment: Gas analyzer, blower, steam generator	23	-	23
Instrumented gasification system hardware	15		15
Coal and other consumables + discussion meeting (1)	5	5	10
Staff (2) atRs. 30,000 per person per month	7	7	14
Overheads (at 15 %)	7.5	1.8	9.3
Total	57.5	13.8	71.3

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List of Suggested Areas of Focus for Technology Development in High Efficiency Low Emission (HELE) Technologies/Energy Efficiency & Emission Control measures

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Coal based

- Advanced Ultra Super Critical Technology cycle involving Boilers and its auxiliaries, Turbine, Blading and Turbine auxiliaries, Generator and its auxiliaries.(Auxiliaries include all the sub-systems and their parts to support the main equipment including Automation & control Systems)
- Air-cooled condensers for large rating Turbines.
- Re-Engineering the BoP systems suiting to Thermodynamic cycles of the above
- Combined CSP with Supercritical Coal Cycle
- Integration of Coal gasification with Combined cycle.
- Prototypes already developed need to be scaled up
- Emission control Technologies- Several technologies available both for Sox and Nox. Seems no movement after the regulation has been put in place almost a year ago excepting in a few new projects. There is a huge installed base and retrofitting of emission control systems needs to hasten.
- Carbon sequestration and use

R&M

- It is recommended to scrap old Power plants(>25 years) of Sub critical technology rather than going for Retrofitting (renovation) and modernization.
- Old Plants need be replaced with High Efficiency and Low Emission (HELE) Technologies to derive the advantages of Energy Efficiency and lower emissions.
- The Power Plants that have come up in the recent past need to be retrofitted with Nox, Sox and Particulate matter control(ESPs of improved parameters)systems.
- There is a need to adopt better O&M practices (like ensuring complete combustion in the boiler, maintaining proper vacuum in the condenser, on time cleaning of the electrodes of ESPs, evacuating Ash at desired intervals, cleaning Bag Filters, Implementation of PADO Systems etc.) to achieve the designed parameters for the plants, as often it is found that the coal based plants in India have lower efficiencies (Avg 31%)compared to other countries for similar plants.(World Avg 34%)

Solar PV Systems

- ❖ Solar Cells of higher efficiency (Re-Engineering of Space grade Solar cells of higher efficiencies of (of26% &above) to bring down the costs.
- ❖ Solar PV Modules of higher wattage per Module
- ❖ Inverters and Power conditioning equipment of higher ratings of 1 MW and above
- ❖ Innovative Mounting of PV Panels to reduce the foot print (Land area per MW.)
- ❖ Hybrid Solar Systems involving CSP and PV Systems to increase efficiencies and reduce the Foot print.

Concluding Remarks

India has vast reserves of coal and shall be dependent on coal as a source of energy for some time to come. With the growing concern of global warming and climate change due to emission of greenhouse gases, there is an urgent need to develop clean coal technologies so as to mitigate the negative effects in the environment due to the option of deployment of coal as a source of energy. Clean Coal technologies is also a thrust area of the Government. DST planned to invite research proposals in the area of clean coal technologies to overcome the existing gaps in technologies. DST requested INAE to convene a meeting of experts from INAE, R&D, industry and Academia and assist in identifying the thrust areas of research in Clean Coal technologies for inviting of proposals by DST. Accordingly, INAE identified suitable experts and conducted a Round Table meeting on the topic **"Clean Coal Technologies in India: Current Status, Demands and Aspirations – Pathways to Achievements"** on June 10, 2016 at New Delhi under the chairmanship of Dr. Baldev Raj, Immediate Past President, INAE wherein about 35 domain experts from INAE, Industry, Academia and R&D participated. Prior to the meeting, a Base Paper covering the pertinent issues in the area of Clean Coal technologies was prepared which was circulated to the participants for discussion in the first-Round Table meeting. The objective of the round table was to examine **the current status of clean coal technologies nationally and internationally and identify the areas where research can be initiated to develop the technologies to overcome the gaps.**

During the first meeting, the experts deliberated on the current status of the technologies available in India vis a vis the current international status of Clean Coal technologies; so as to assist in identifying the gaps/voids which need to be addressed on priority. During the deliberations in the first Round Table it was decided that the technical papers in areas requiring technical interventions so as to prepare a comprehensive report highlighting the specific areas of Clean Coal technologies be compiled. Accordingly, the experts were identified for authoring the technical papers on the areas identified. The experts were also requested to identify the areas of immediate concern where research proposals could be initiated by DST to overcome the gaps in the existing technologies.

During the second Round Table meeting on "**Clean Coal Technologies in India: Current Status, Demands and Aspirations – Pathways to Achievements"** held on Oct 26, 2016 at New Delhi; the papers submitted by the authors identified earlier were discussed and suggestions were invited for suitable research proposals emanating from the inputs; for submission to DST for consideration for funding of projects. The meeting was attended by 25 experts in the area of Clean Coal technologies. During this meeting a total of about 12 proposals were also discussed and approved for submitting to DST. The authors were requested to submit the details of the proposals covering **Background; Timeframe; Ball Park Cost and Participating Agencies** for onward submission. Subsequently, 11 research proposals received covering various aspects of Clean Coal technologies were submitted to DST for consideration during a meeting on Nov 19, 2016.

The titles of the research proposals received and submitted to DST are as under:

- Coal Beneficiation and Coke from Non-coking Coal

- Preparation of Data Bank for characterisation, Grading and Classification of Indian Coal resources for their effective utilisation
- Energy Use and Greenhouse Gas (GHG) Emissions Management in Coal Mining
- Methane Drainage Prior to Mining
- Investigation Into The Planning And Design Aspects Governing The Selective Coal Cutting Technology Using Surface Miner For Various Rock Conditions For Clean Coal Production
- Enhancement of Gas Production from CBM Wells
- Oxy fuel circulating bed combustion/ gasification test bed(s) at 10 MW scale for high ash and low quality coal for meeting the efficiency and emission norms and capturing CO_2 for end use applications
- An Integrated Approach to Mining and Environment for India's Surface Coal Mines
- Coal to gaseous fuel for power generation and syngas
- Clean Coal Technologies: Hybridization: Green Steam Initiative
- Development of Smelting Technology for Indian Raw Materials and Steel Plant Waste

DST subsequently requested INAE to prioritize the 11 proposals submitted to assist in phasing out the call for proposals to be undertaken. Accordingly, the third meeting of a Committee under the Chairmanship of Dr Baldev Raj comprising of Dr BN Suresh, President, INAE; Shri B Prasada Rao, FNAE, Dr Sanjay Bajpai, Adviser/ Scientist 'G', DST and Shri DP Misra, FNAE as Members was held on Dec 29, 2016 at NIAS, Bangalore to prioritize the research proposals. During this meeting, it was decided that all 11 proposals are important and should be considered for funding simultaneously in a phased manner by DST. DST had agreed to invite the call for proposals on all the 11 selected topics submitted, during the first Quarter of 2017.

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