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Bureau for Science and Technology
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ASSESSMENT OF INTEGRATED COAL GASIFICATION COMBINED CYCLE TECHNOLOGY FOR INDIA

Report of Mission to India
March 23, to April 10, 1988

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Any errors or omissions are the responsibility of the authors.

1.0 PROJECT BACKGROUND:

1.1 Project Background and Objectives:

The original objective of the Government of India (GOI), as stated in the January 1988 Report of the Expert Group, was to "evaluate coal gasification processes for power generation and to identify suitable technology for the setting up of a demonstration plant of 100-120 MWe, based on an Integrated Coal Gasification Combined Cycle (IGCC) system." The candidate coals will contain about 40 percent ash with ash fusion temperatures above 1400 degrees celsius. This decision was taken by the Minister of Energy, Shri Vasant Sathe, on March 11th, 1987.

The Indian Department of Coal has nominated the Council of Scientific and Industrial Research (CSIR) as the nodal agency for conducting this evaluation. The National Planning Commission has concurred with this decision. The evaluation will be performed by a group of experts drawn from CSIR, the Departments of Coal and Power, Bharat Heavy Electricals Limited (BHEL), and Projects and Development India Limited (PDIL), a public sector engineering company.

Dr. Ram K. Iyengar, Additional Director-General of CSIR and Additional Secretary of the Department of Scientific and Industrial Research (DSIR) has been designated the leader of the expert group. Dr. G.S. Sidhu, former Director-General, CSIR, and Secretary to the Government of India, has been nominated as a "Member-Advisor".

The expert group will:

a. Evaluate potential coal gasification processes for power generation and will identify the technology appropriate for a commercial plant in India.

b. Prepare a techno-economic package for the setting up of a 100-120 MWe power plant based on IGCC technology. The plant will be a joint venture involving the GOI and foreign technology vendors/equipment manufacturers.

As a result of extensive discussions held in New Delhi with the U.S. Definitional Mission in March/April 1988, the original project objective has been enlarged. The expert group will examine the feasibility of deploying a fully commercial 400-500 MWe plant in the eighth five year plan (1990-1995), assuming that further analysis and testing confirms the economic feasibility of IGCC technology compared with pulverized coal-fired power plants. Since an IGCC plant can be built in modular units of approximately 225 MWe, consisting of 150 MWe of gas turbines and 75 MWe of steam turbines, the first module of a commercial unit used with high-ash Indian coals will serve the function of an IGCC demonstration plant.

An effective approach to constructing a 400-500 MWe commercial plant in India could be to conduct large-scale testing for a period of two to three months in the United States at one of the existing demonstration units

(Coolwater, Shell or Dow). This procedure would cost perhaps $10-$20 million compared with about $300 million for a 100-120 MWe demonstration unit in India. Since the building of such a demonstration unit would also require large-scale testing, there is a compelling economic and technical case for leapfrogging directly to a commercial plant after conducting extensive, large-scale tests in the United States.

During the visit to New Delhi, the Definitional Mission held several meetings with key individuals in the Planning, Power and Coal Sectors of the Government of India to discuss the IGCC project. The general philosophy and basic requirements for the adoption of IGCC technology in India were outlined by Mr. Hiten Bhaya, Member of the Planning Commission with principal responsibility for the energy and power budget. He stressed the need for an objective examination of the economic viability of IGCC plants compared with pulverized coal-fired plants at the minemouth. He was aware of the U.S. commercial interests and strong competitive position in IGCC technology, but was emphatic about the need for an unbiased economic analysis to justify the inclusion of an IGCC plant in the eighth five year plan.

Mr. Bhaya felt that investment in new coal technology should be commercially replicable, and not restricted to "one-of-a-kind" projects focused primarily on demonstrating technical viability. He also stated that India's power grid needed economic peaking units, and indicated the need to examine the load-following capabilities of IGCC units.

1.2 The Energy/Power Sector in India:

Sustained economic growth in India depends critically on the quantity and quality of delivered electric power and on the financial and operational performance of the power sector. Power generation capacity has increased 27 fold since 1952, with a growth rate of 8.3 percent over the period 1973-1987. In spite of this rapid expansion, Indian electricity use is constrained by the availability of capital for new generation capacity, and the quantity, quality, and reliability of delivered power is inadequate to meet burgeoning industrial, agricultural, commercial and residential needs.

The projected capital requirements for expanding power generation, transmission and distribution systems far exceed the financial resources available. In the current (seventh) five year plan, the energy sector accounts for one-third of the total plan allocation of $150 billion, with the power sector accounting for $28 billion, or one-fifth of total seventh plan budget.

India had 51,000 MWe of installed generation capacity as of December 31, 1987. The Central Electricity Authority (CEA) estimates that 32,000 MWe of additional capacity will be required during the seventh five year plan to keep pace with rapid demand growth, at a capital cost of approximately $56 billion. However, only half of this amount has been allocated to the power sector during the seventh plan, resulting in a pruning of capacity addition to 22,000 MWe. The current shortfall between supply and demand is

therefore about 10,000 MWe.

During the period 1986-87, India experienced an average power deficit of 9.3 percent. Because of the drought situation, the national deficit is expected to climb to 12 percent, and peaking power shortages as high as 30 percent are expected in the Northern region. A study by the Federation of Indian Chambers of Industry (FICCI) estimated a $6 billion loss in annual industrial production arising from a 10 percent power shortage. To cope with these shortages, there has been substantial industrial investment in small, uneconomical diesel sets, from 2860 MWe in 1979-80 to 4190 MWe in 1984-5. A further increase to 7,056 MWe is projected for 1990.

Electricity use in India will continue to be severely constrained by capital availability. The CEA estimates that an additional 110,000 MWe will be required in the period 1990-2000, at a total investment cost of $170 billion. This represents an annual average investment of $17 billion between 1990 and 2000, compared with $5.6 billion between 1985 and 1990.

The poor power plant availability is of major concern to the GOI. A major impact on power delivery and capital investment requirements could result if the disappointing 50.1 % average plant load factors (PLF) of thermal power plants were increased to 55 percent or higher. The PLF can be improved through technological improvements and plant rehabilitation as well as through better operational and maintenance procedures. A 1% improvement in PLF will bring an additional capacity of 500 MWe on line at costs which are a fraction of new capacity additions. Short term measures to reduce transmission and distribution losses also appear very promising.

About 60 percent of the electricity generated in India occurs through the combustion of coals with very high ash content, ranging typically from 30 to 45 percent. The consumption of coal for the power sector is expected to increase from 120 million metric tons in 1989-90 to 250 million metric tons in the year 2000. The GOI expects the quality of coal to deteriorate further with increased opencast mining.

The high ash content has been a major cause of the poor plant load factor of thermal power stations. A study carried out by the Damodar Valley Corporation (DVC) indicated that plant availability decreases abruptly with increasing ash content. For coals with ash content between 28 and 38 percent, availability fell 2 percent for every 1 percent increase in ash content.

Changes in mining techniques have caused extraneous dirt and stones to be mixed in with the mined coal, leading to a sharp deterioration in coal quality and an increase in its variability. Although Indian coal is low in sulfur, both the poor quality of coal and its great variability have led to serious operational and maintenance problems at Indian power stations. Studies conducted by the National Productivity Council (NPC) for the National Thermal Power Corporation (NTPC) reveal that the use of beneficiated coal can result in considerable financial benefits for power station operators.

2.0 CURRENT PROJECT STATUS

2.1 GOI Expert Group Activities.

The Minister of Energy, in a meeting on the 11th March, 1987 decided to form a group of experts to evaluate coal gasification processes for power generation and to identify suitable technologies for the setting up of a demonstration plant of 100-120 MWe based on Integrated Gasification Combined Cycle technology.

This group visited the major IGCC technology licensors in the US, Europe and Japan during July/August 1987. The Expert Group made a preliminary comparison of the major gasification technologies and submitted a report to the Department of Coal in January 1988. In their report, the Expert Group presented several conclusions regarding the commercial readiness of IGCC technologies, and recommended several steps towards the realization of a commercial IGCC plant in India.

2.2 Current Opinions and Conclusions.

The data and information gathered during the visits was almost exclusively related to the low ash coals. The Expert group concluded that IGCC is an attractive alternative for generating power from low ash coal, and that IGCC plants are more efficient, are environmentally cleaner, and require less water than conventional pulverized coal power plants (PCPG).

Of the processes reviewed, Lurgi Dry Ash (LDA), British Gas Lurgi Slagger (BGSL), Dow, Texaco, High-temperature Winkler (HTW) and Shell were considered to be technologies that could be commercialized today.

Due to the absence of experience with high ash coals, it was not possible to select a single technology for Indian coals, which have an ash content of approximately 40%. However, an analysis was made extrapolating the low (10%) ash coals data to allow for a 40% ash content. It was found that the IGCC technology appeared to still be economically attractive relative to pulverized coal fired power stations.

The analysis showed that for low ash levels the most efficient coal based power plants generate 2.3 kwh/kg of coal with flue gas desulfurization (FGD) and approximately 2.5 kwh/kg without FGD. The estimated IGCC generation rate with sulfur and nitrogen oxides removal is estimated to be 2.5 to 3.0 kwh/kg of low ash coal.

For high ash coals the energy yield for conventional pulverized coal fired plants is of the order of 1.5 kwh/kg without FGD. For high ash coals, IGCC yields were estimated to be 1.3 to 2.0 kwh/kg with sulfur and nitrogen oxides removal, an attractive result justifying further work.

A comparative analysis was made of the commercial and near commercial technologies at 10% and 40% ash levels. The commercial processes included were BGSL, LDA, Texaco, HTW and Dow. The specific power production rates for these processes were estimated to be as follows:

Table 2.1

Specific Power Production Comparison Between IGCC Technologies

Ash Content	BGL	LDA	Texaco	HTW	DOW	PC	Shell
	- - - - - Available IGCC Technologies- - - - -						
	(kwh/kg Dry Coal)						
10%	3.1	2.5	2.8	2.6	2.7	2.3-2.5	3.0
40%	1.9	1.6	1.4	1.3	1.5	1.5	1.6

Discussions with the Definitional Mission highlighted some minor technical inconsistencies in calculating the overall efficiency, but these are not likely to significantly alter the conclusions of this analysis.

Based on the work carried out at this stage, the Expert Group recommended that:

1. Two coals be selected for testing and sent to the nine process licensors - BGL, Dow, HTW, KRW, Lurgi, Prenflo, Shell, Texaco and U-Gas, for laboratory scale tests.

2. Based on the laboratory scale evaluations, the processes be short listed for carrying out pilot/commercial plant scale studies.

3. Based on the results from the pilot/commercial scale trials, a techno-economic feasibility report (TEFR) be prepared jointly by experienced Indian and foreign consultants to identify a suitable technology.

4. The GOI appoint a National Project Team to evaluate the various tests and analyze the TEFR.

5. That the 25 ton/day dry ash moving bed process plant at the Regional Research Laboratory at Hyderabad (RRL-H) and the BHEL 150 ton/day plant at Tiruchirapally, be run on 40% ash coals to generate data for inclusion in the TEFR.

6. A national programme be undertaken on Pressurized Fluidised Bed Gasification (PFBG) suitable for high ash (40-45%) Indian coals.

7. An intensive, urgent, time bound R&D programme be carried out in India on the washing of coals to reduce the ash content from 40% to about 25% to establish the recovery and economics of washing.

8. Qualified domestic and foreign consultants be selected to advise the NPT.

2.3 Position of Participants

The current work on IGCC technology assessment has been carried out by the CSIR as the nodal agency, under sponsorship of the Department of Coal in the Ministry of Energy. A National Project Team is likely to be constituted shortly to coordinate and analyze the ongoing work in this area, and to prepare the TEFR. This report will be submitted for the review and approval of the Standing Scientific Research Committee in the Department of Coal. At that stage, the recommendations to proceed with a commercial venture would be presented by the Department of Coal to a Committee of the Secretaries for approval and inclusion in the Eighth Five Year Plan. The members comprising this Committee are from the Planning Commission and the Departments of Power, Scientific and Industrial Research, Fertilizer, Environment, Labor, and Finance.

The Definitional Mission met with the Secretaries of the Departments of Power and Coal, a Member of the Planning Commission, and the Member (Thermal) of the CEA to ascertain the importance that these organizations place on the IGCC proposal. These organizations are supporting the efforts of the Department of Coal in its project development work, but are waiting for the results of the TEFR before making any judgement on the commercial viability of the project.

The senior government officials interviewed were unanimous in their belief that the funding for a commercial plant would be made available if IGCC were shown to be economically attractive under Indian conditions. They also stressed the need for an unbiased and realistic economic evaluation of IGCC Technology.

3.0 FUTURE APPROACH AND OPTIONS

3.1 General Considerations

In the United States IGCC and coal gasification technology has reached the stage where the first commercial units are in the engineering stages and are expected to be on stream in the mid 1990's. To reach this stage, the technology development has passed through scale up from initial pilot plant operations to the construction of three demonstration units in the 1000 ton/day range. Further technology development and demonstration at the different plant size levels is continuing.

The justification for the commercialization of IGCC technology in the US has been based on the improved efficiency of the IGCC plant over conventional power generation technology, and on the distinct improvement in environmental emissions. Other factors such as improved reliability and onstream factors, and modular expansion potential, are secondary justifications.

Faced with one of the world's largest electrical capacity expansion requirements, India has a vital interest in determining whether the IGCC technology will be an attractive option under local conditions. However, as with almost all developing technologies, the decision is seldom clear cut. The evolving nature of the technology suggests a delay in commercialization while conversely the timely adoption of the technology invariably accelerates its development.

Considering the current state of IGCC development in the US and Europe, the major questions from the Indian perspective are:

a) Can the currently demonstrated technologies be applied economically to gasify high ash Indian coals and/or what modifications will be needed to do this?

b) What further developments are needed in IGCC technology to improve power generation capabilities in India?

c) What are the costs, risks and rewards of various courses of action?

d) What are the commercial and contractual arrangements under which joint technology development of high ash coals can occur?

e) Is IGCC technology widely replicable in the Indian context?

f) What should be the nature and structure of a testing program to generate data to justify a 400-500 MWe plant?

3.1.1 Technology Choice

In considering the application of IGCC technology the gas turbine and power cycle part are well developed and demonstrated. Even though further improvements are anticipated, no specific problems in commercialization are expected. The major questions surround the gasification of high ash Indian coals.

A major conclusion that emerged from the Indo-U.S. discussion was that the only technologies that could be considered as ready for commercialization were: the Texaco, Shell and Dow Entrained Gasification processes, the Lurgi Dry ash and the British Gas/Lurgi Slagging Gasifier. All of these have now been tested at sufficient scale to be considered commercially viable candidates. From the current stage of development, a commercial plant could conceivably be placed into operation in India by the mid 1990's, contingent on demonstration of operability with Indian coals.

Other processes and/or major modifications of existing processes could become more attractive in the future. Technologies under development include the KRW process, the high temperature Winkler process, and the two gasifiers under development in India today. It is possible that with the current pilot plant facilities and experience in India, a moving bed dry ash IGCC plant could be designed and built in India by the mid 1990's.

For this reason a two pronged approach is suggested:

a) the analysis of the application of currently available technologies,

b) the evaluation of potential future technologies in the context of the time frame for commercial application.

3.1.2 Comparative Basis

The justification of an IGCC plant in comparison with the alternative routes for power generation requires some major assumptions about the future, since it will take at least seven years to bring such a plant on stream, followed by a 20 to 30 year operational life.

Apart from the economic and financial developments, two major areas that will influence the future viability of IGCC technology are the quality of future coals, and the environmental constraints placed on plant emissions. The IGCC process has a distinct advantage of lower emissions (NOX, Sulfur and particulates) than conventional power generation technologies.

Another factor is the maturity of the technology. Conventional pulverized coal firing technology is a relatively mature technology with little further improvement potential. IGCC on the other hand is at the bottom of the learning curve and can be expected to further improve in efficiency and cost reduction.

These and other factors complicate the comparison of power generation technologies. The final analysis will require some subjective decisions

which cannot be easily quantified.

3.2 Decision-making Methodology and Criteria

The objective of the present analytical work is to ascertain whether IGCC technology is a technically viable, cost effective option of generating electrical power from low grade (high ash) coals in India. Based on discussions held during the Definitional Mission visit, the following criteria were established for determining the commercial viability of IGCC technology:

1. The comparison of IGCC versus pulverized coal firing will be made at the level of 400-500 MWe.

2. IGCC will be compared with conventional pulverized coal fired power stations located at the mine mouth.

3. IGCC performance will be evaluated according to existing environmental control requirements which do not require stack gas scrubbing on conventional units.

4. While a comparative economic evaluation should encompass all aspects of the fuel cycle from pithead to final electricity consumer, the present comparison will be limited to IGCC and PC generation facilities.

5. The comparison will be carried out based on one coal. The various alternatives and options for optimizing the ash level through beneficiation will be considered as a separate issue.

6. Technical and economic viability of each of the IGCC technologies will be assessed according to the following:

   - Overall energy efficiency - kwh/kg of coal,

   - Cost of power generated - rps/kw,

   - Investment cost - rps/MWe,

   - Environmental emissions,

   - Reliability,

   - Complexity,

   - Indianization potential, and degree of involvement of Indian manufacturing and engineering firms,

   - Need for coal beneficiation, and

   - Financing/Commercial packages.

3.3 Commercial Approach

The initial anticipation was that the commercialization of any of the four technologies under consideration - Texaco, Dow, Shell and BGL, would require the construction of a large sized demonstration plant in India comparable to the Coolwater plant in the US, to prove out the operability on high ash Indian coals. This would entail an investment in excess of $300 million and a time frame of six to ten years for construction and testing. At the size level considered (120 Mwe) it is doubtful that the power generated from such a unit would be economically attractive.

An alternative suggestion was made to test Indian coals in large quantities at one or more of the existing US Demonstration plant facilities. This would eliminate the need for building a Demonstration plant in India, and would save several years in the commercialization of IGCC technology in India.

3.4 Level of Effort needed for next Stage

The Definitional Mission discussed various options and approaches to assess the viability of IGCC technology for power generation based on high ash coals. These ranged from an indepth analysis of a single technology on a specific site basis to a broad scoping study on all pertinent technologies, including combinations of coal beneficiation and alternative coal firing technologies.

Various levels of coal testing, engineering and cost estimating were considered. The level of confidence in the operability of the processes, and the accuracy of economic estimates for various levels of effort were discussed in considerable detail. As was the cost of going to different levels of detail.

The various levels of effort discussed by the Indian and US Teams are briefly outlined in Table 3.1.

Table 3.1

Levels of Technical and Economic Analyses

1. Scoping Analysis

Yields:	Based on computer simulation correlations, published data and first principles by engineering company experienced in IGCC technology.
Engineering:	Heat and material balances by engineering contractor. Definitions of plant sections and some major equipment.
Cost estimate:	Prorated by sector from prior experience. (40%)
Reliability:	Laboratory tests for refractory life, abrasion and erosion.

2. Prefeasibility Study

Yields:	Based on 1 censor process package.
Engineering:	Definition of major equipment and overall details based on licensors package, by an engineering contractor experienced in IGCC technology.
Cost Estimate:	Costs based on major equipment estimates and factored construction costs. (25-30%)
Reliability:	Same as Level 1.

3. Definitive Project

Yields:	Based on pilot plant tests by licensors.
Engineering:	Detailed engineering of major plant and equipment based on process package by process licensor.
Cost Estimate:	Based on equipment vendor bids. (20%)
Reliability:	Same as level 1.
Licensing:	Preliminary Discussions.

Table 3.1 (cont.)

4. Detailed Engineering

Yields:	Based on demonstration plant tests.
Engineering:	Detailed engineering based on results of demonstration tests.
Reliability:	Confidence level set by demonstration plant tests and other equipment development programs.
Licensing:	Commercial arrangements set prior to testing program.
Financing:	Project financing discussions.

5. Engineering and Construction

Detailed engineering and construction of a 400-500 Mwe unit in India.

4.0 RECOMMENDATIONS

The following recommendations were agreed upon by the Indian and US teams:

1) The immediate objective is to establish a level of technical and economic confidence to evaluate a 400-500 MWe IGCC commercial plant. To establish this, a coal test run at least at the bench scale level will be needed.

2) One specific site was selected for the evaluation. This site is the Piparwar/Ashok site in the N.Karanpura Coal field in Bihar. (Figure 4.1)

3) While some preliminary economic analysis has been carried out on the four gasification processes, further data and analysis are required to select the appropriate process for Indian conditions.

4) The next step will be carried out in two phases.

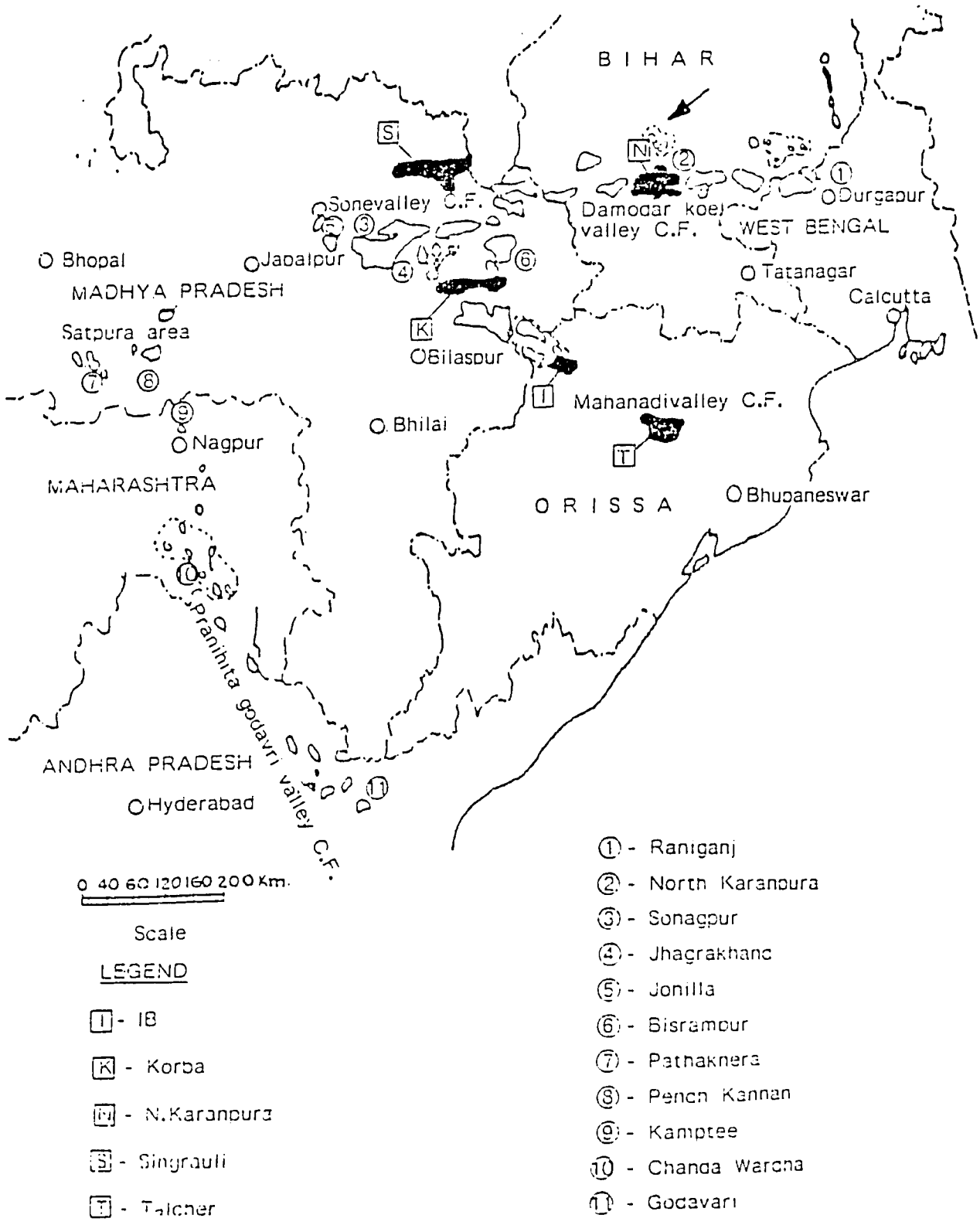
   Phase 1: A preliminary scoping analysis (Level 1) will be carried out in three to four months.

   Phase 2: A prefeasibility study (Level 2) which will take approximately six months to a year to complete.

5) The work on the project will be carried out jointly by the Indian and U.S. participants. An Indo-U.S. Steering Committee will be established to coordinate the efforts.

Figure 4.1

NON-CAKING COAL FIELDS IN INDIA



5.0 SCOPE OF WORK

5.1 Phase 1

5.1.1 Objectives

The objective of Phase 1 is to compare IGCC technology with conventional pulverized coal firing power generation running on high ash Indian coals. Four gasification technologies will be considered - Texaco, Shell, Dow, and BGSL. Preliminary technical and economic assessments of the four processes will be carried out at a level of accuracy required to determine whether IGCC warrants further evaluation and coal testing.

In parallel with this effort, preliminary estimates will be made of the viability of deashing high ash Indian coals. The effect of lower ash levels on IGCC economics will be assessed before proceeding to Phase 2.

The level of accuracy expected in Phase 1 should be sufficient to indicate the economic viability of the four gasification technologies and any specific technical advantages/disadvantages of each technology. The analysis is not likely to be sufficiently accurate to allow the selection of a single process.

5.1.2 Project Management and Coordination

The project is a collaborative development and commercialization effort involving the Governments of India and the United States. The nodal or coordinating entities are the Indian Council for Scientific and Industrial Research and the U.S. Agency for International Development.

To provide proper coordination and cooperation during Phase 1, and to ensure continuity during subsequent phases, a Joint Indo-U.S. Steering Committee will be established. This committee will be responsible for preparing all final reports. The project management coordination relationship of the steering committee is shown in Figure 5.1.

5.1.3 Timing

The work on Phase 1 will start in May 1988. Initial conclusions will be available for review by September 30th. A final draft report will be completed by December 15th.

The timing of individual tasks is shown in Figure 5.2

Figure 5.1

Project Management and Coordination

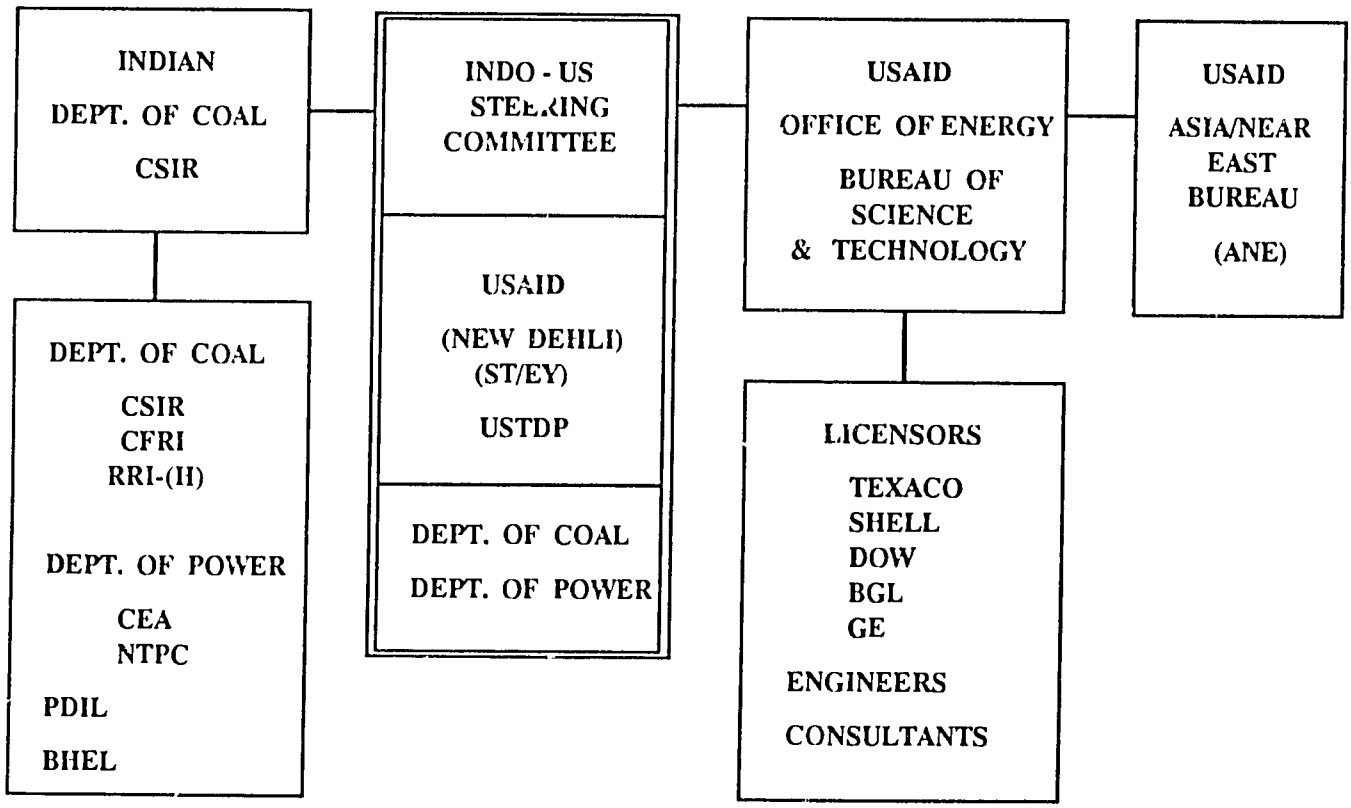


Figure 5.2

Project Schedule - Phase 1

TASKS	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A. Basic Information								
1. Coal Data	------							
2. Pipewar Site Data	------							
3. Coal Analysis Protocol	--							
4. Coal Lab. Tests	----------							
5. Enviromental Specs.	------							
6. Economic Criteria		--------						
B. IGCC Tech Evaluation								
1. Licensor Discussions	----							
2. Process Design		----------						
3. Economics				----------				
4. Indian Investments						----------		
5. Risk Analysis					----------			
C. PC Power Generation								
1. Actual Costs		----------						
2. Planned Costs		----------						
3. Enviromental Analysis		----------						
D. Deashing Technology								
1. Technical. Analysis	----------							
2. Economic Analysis		----------						
E . Techno-Economic Analysis								
1. IGCC versus PCPG								
2. Alternatives					----------			
3. Enviromental Impact					----------			
4. Phase 2 Plan								----
F. Coordination and Management								
1. Coordination Activities	----------							
2. Preliminary Review								----------
3. Final Report						X		X

5.1.4 Scope of Work for Phase 1

The major tasks in Phase 1 are as follows:

A. Prepare Basic Information.

B. Evaluation of IGCC Technologies.

C. Evaluation of Pulverized Coal Power Generation Economics.

D. Investigation of Deashing Technology and Economics.

E. Techno-Economic Evaluation of IGCC and Pulverized Coal power systems.

F. Coordination and Management.

Specific tasks and the primary responsibility for their execution are as follows:

A. Basic Information.

1. Prepare detailed analytical data for Piparwar coal in accordance with the outline in Appendix III of the "Report of the Expert Group" (see Appendix). (I)

2. Prepare Site specific data for the Piparwar site. (I)

3. Prepare details of specific coal analysis or protocols required by licensors. (US)

4. Carry out laboratory tests on the candidate coal to establish fluxing requirements and properties. (I)

5. Prepare detailed environmental specifications and restrictions to be used for the evaluation. (I)

6. Prepare financial and economic criteria for evaluation. (I/US)

B. Evaluation of IGCC Technology.

1. Preliminary discussions with gasification technology licensors and gas turbine manufacturers. (US)

2. Prepare heat and material balances for a 500 Mwe IGCC unit for each gasification technology, based on prior experience, licensors information and first principles. (US)

3. Prepare overall investment and operating cost estimates for each process based on US conditions. (US)

4. Translate investment and operating costs into Indian conditions and define any specific requirements and/or restrictions dictated by Indian conditions. (I/US)

5. Identify the factors that will contribute to minimization of risk, improved reliability and improved efficiency of the IGCC installations. (I/US)

C. Evaluation of PC Power Generation Economics.

1. Assemble and analyze actual capital and operating costs of recently constructed power generation facilities. (I)

2. Assemble and review projected costs for current and planned power generation facilities. (I)

3. Review and analyze current environmental emissions from coal fired power stations, including particulate emissions. (I)

D. Investigation of Deashing Technology and Economics.

1. Assemble and analyze information on the past experience on coal washing and beneficiation of non-coking coals in India and the U.S. (I/US)

2. Prepare preliminary economic analysis of coal beneficiation as a function of final ash content for Piparwar coals. (I)

E. Techno-Economic Evaluation of Alternatives.

1. Using the results of B, C and D, prepare a comparison of IGCC and PC power generation for a 500 Mwe plant located at Piparwar, using 40-45% ash coal. (I/US)

2. Analyze the economic and technical alternatives, risk factors and other considerations that will influence the IGCC route. (I/US)

3. Conduct a comprehensive environmental impact analysis for both IGCC and PC power plants in the Piparwar area. (I/US)

4. Identify and recommend the next steps in the commercialization of IGCC technology in India. (US/I)

F. Coordination and Management.

1. Coordinate activities outlined in A through E. (I/US)

2. Preliminary review of evaluation and conclusions.

3. Prepare detailed scope of work for Phase 2. (I/US)

5.2 Scope of Work - Phase 2

5.2.1 Objectives

The objectives of Phase 2 will be to prepare a technical and economic evaluation of IGCC technology in sufficient detail to allow the Committee of Secretaries to make a decision to proceed with a full scale commercial (400-500 Mwe) facility during the Eighth Five Year Plan.

The results of Phase 2 should permit the choice of a commercially viable IGCC technology. Phase 2 will require some testing of coals at the bench scale level.

5.2.2 Scope of Work

The major tasks in Phase 2 are as follows:

A. Basic Information and Project Definition.
B. Coal Testing.
C. Detailed Engineering.
D. Techno-Economic Analysis and Report.

The detailed tasks required under each of these tasks are as follows:

A. Basic Information and Project Definition.

1. Selection of US consultant/engineering contractor.

2. Short list of gasification technology licensors.

3. Development of site and coal specific data.

4. Definition of coal testing requirements.
   a) US licensors.
   b) Indian coal testing and process development.

B. Coal Testing.

1. Preparation and transportation of coal to the US.

2. Coal tests.

C. Detailed Engineering.

D. Techno-Economic Analysis and Report.

5.2.3 Timing

The schedule and details of the tasks in Phase 2 will be determined during Phase 1. The main factor that will determine the exact schedule will be the need for testing of coals. The level of testing will depend to a large extent on processes short listed and on other technical and

commercial discussions with the licensors.

A preliminary schedule for the commercial plant and the major milestones is shown in Figure 5.3. This schedule anticipates the completion of Phase 2 in mid 1989, with project approval in the fourth quarter of 1989.

Figure 5.3

Time Schedule For Demonstration/Commercial IGCC Plant

ACTIVITIES	1988	1989	1990	1991	1992	1993
Pre-Project Activities						
1) Appointment of NPT and selection of foreign and Indian consultants	---					
2) Lab scale/Pilot Plant test of candidate coal	------					
3) Preparation of TEFR and its Evaluation	------					
4) Negotiation with process licensors/foreign consultants	------					
5) Approval of project and license agreement by GOI		------				
Project Activities						
1) License/Know how by process licensor and basic design by foreign consultant		----------				
2) Detailed Engineering by Indian Consultant			----------			
3) Order and Delivery of Equipment			----------			
4) Civil Work and Construction			----------			
5) Testing and Commissioning					---------X	

6.0 MAJOR TECHNICAL ASPECTS

6.1 Requirement for Coal Testing.

The Definitional Mission concluded that licensor correlations were sufficiently accurate to preclude the need for any bench scale tests in Phase 1. Higher ash levels should not markedly affect predicted yields other than to act as an inert material than can be handled by basic engineering principles.

Flux requirements in the slagging gasifiers are not well defined and will require some experimental laboratory work to better define flux needs in each process.

Subsequent stages in the commercialization of gasification processes with Indian coals will require testing both at the pilot plant and/or demonstration plant level. The tests will be needed for operational reliability assessment and guarantee needs rather than for basic yield predictions. They will only be essential when a commercial project is contemplated.

6.2 Coal Beneficiation

The economics of IGCC process is very sensitive to ash content, especially for slagging gasifiers. The slagging gasifiers suffer from an efficiency penalty in having to melt and dispose of large volumes of solids. In addition, substantial quantities of limestone flux amounting to 20 to 30% of the ash content, must be added and subsequently disposed of.

The reduction of ash in the feed coal through coal cleaning will reduce both the quantity of ash to be processed and the flux requirements, and will significantly decrease gasification costs. Coal cleaning for non-coking coals has only found very limited use in India, though it is generally recognised that more attention will have to be paid to this in the future. The trade off between coal beneficiation and gasification costs is a critical factor in evaluating the viability of IGCC technology in India.

6.3 Environmental Emission Standards

Environmental emission standards are central to the comparison of IGCC technology with conventional pulverized coal-fired power plants in India.

Stack gas desulfurization represents about 25% of the capital investment and operating cost for a direct fired power plant, but only 5 to 7% in the case of IGCC. The advantages of IGCC are therefore considerably reduced when there are weak or non-existent sulfur emission standards.

The low sulfur content of Indian coals and current sulfur emission standards do not require the installation of FGD on conventional power plants today. No change to this is seen in the immediate future.

6.4 Onstream Factor

The major problem in power generation operations in India currently is the low capacity utilization factor which is reported to be around 50%. This is attributed to the abrasive nature of the high ash Indian coals which leads to mechanical failure of the pulverizing equipment, as well as to inconsistent coal quality .

Some claims have been made for the higher reliability of the IGCC technology relative to conventional facilities. This will need to be critically analyzed and substantiated.

7.0 APPENDIX

7.1 LIST OF KEY GOI OFFICIALS MET

1. Mr. M. M. Kohli
   Secretary
   Department of Power

2. Mr. S. Vardhan
   Secretary
   Department of Coal

3. Mr. Hiten Bhaya
   Member
   Planning Commission

4. Mr. R. N. Tiwari
   Member, Thermal
   Central Electricity Authority

5. Mr. S. Vardharajan
   Chief Consultant
   Planning Commission

6. Dr. Ram Iyengar
   Additional Director General
   CSIR

7.2 MEETING NOTES

The notes of meetings included in this report are the impressions obtained during the visits and represent the Definitional Mission's understanding at that stage. Some of these may have been subsequently changed, but are included here for completeness.

These notes have not been reviewed by the participants or the Indian Team.

7.2.1 Meeting 1: Coal Gasification based IGCC

Date: 23/24 March, 1988.

Location: CSIR International Science Center,
Lodhi Road, New Delhi.

Participants:

T.S.R. Anjaneyulu	RRL(H) CSIR
S.S. Raghavan	CFRI CSIR
K.K. Sinha	PDIL, Sindri
S.D. Garg	CSIR, New Delhi
G.S. Sidhu	Member - Advisor
R.K. Iyengar	CSIR, New Delhi
B. Dutkiewicz	IDEA/USAID
N. Holt	EPRI
D. Jhirad	USAID
S. Padmanabhan	USAID, New Delhi
B. Madhusudhan	RRL(H) CSIR
Y.P. Abbi	BHEL

The meeting was held to discuss the current status of the IGCC proposal and to define the possible avenues of cooperation between the GOI and the US Government. The discussions centered on the technical aspects of IGCC technology in general and on the evaluation of the different technologies by CSIR. These preliminary results are spelled out in a report of the Expert Group - Integrated Gasification Combined Cycle Power Generation Plant based on High Ash Indian Coals prepared for the GOI Department of Coal in January 1988.

The following notes summarize some of the details covered in the meeting.

General

1. The CSIR is the prime promoter of the IGCC technology and the current study work is being done under the sponsorship of the Department of Coal in the Ministry of Energy. If the demonstration plant goes ahead, it would be operated by the Department of Power. Neither NTPC nor CEA is currently participating in the study at

this stage, other than their membership in the Expert Group.

2. Funding for the Demonstration plant has been allocated in the 7th five year plan (1985-1990). It is felt however that if this project is not pushed aggressively in the next year or so, then the funds will disappear.

3. At this stage the work has centered on preparing a Technical and Economic Feasibility Report that addresses the feasibility and comparative economics of IGCC versus pulverized coal. This report is to be completed by April 1989 for submission to the Scientific Advisory Committee in the Department of Coal, and then to the Committee of Secretaries which will include the Departments of Power, Coal, Planning, Industry. Approval of these Committees are needed to go ahead with the Demonstration Unit.

4. Major concerns at this stage are that the technology must be economic and must work on Indian coals. Higher overall efficiency on high ash coals is the primary driving force. Environmental aspects are not a major concern.

5. The general guidelines on economic viability of a project in India would be a payback of 8 years. The feeling of CSIR is that this technology would be justified even if it came to within 10% of the current PC generation costs. The reason for this is that these costs are expected to go up in future as the ash content of the coals increases. IGCC on the other hand is in its technological infancy and has a large improvement potential.

Project Definition

1. Until now the project has centered on the analysis and choice of gasification technologies. No attempt has been made to analyze the integrated mining/transportation/generation system.

2. Coal choice: A number of different coal sources have been studied and the choice has been narrowed down to two: Dipka (Madhya Pradesh) and Piparwar (Bihar). Both would be grassroots open cast mines. The coal ash content for these two coals varies between 22 and 48%. The potential benefits of deashing prior to gasification is recognised though little work has been done in this area. Studies to date have not included coal cleaning.

3. The preliminary work carried out to date has narrowed the choice of technologies to the Dow, Texaco and Shell entrained bed gasification processes and the British Gas Lurgi Slagging gasifier. These technologies are considered to be sufficiently developed to become candidates for commercialization. The U-Gas and KRW fluidized bed processes are considered to show promise but are not sufficiently far advanced to warrant inclusion in the current evaluation.

4. The present thinking envisages the construction of a 100-120 MWe demonstration plant in the next five year plan. There is nothing sacrosanct about the size of the plant, which should be an optimum size to demonstrate the process(s) chosen. The alternative of demonstrating the technical viability of the process on high ash Indian Coals by running coal tests in existing demonstration plants in the US was discussed as an alternative to building a prototype plant in India.

5. The milestones for the project currently are as follows:

   - TEFR for 4 processes to be completed by April 1989
   - Submission of TEFR to Committee of Secretaries April 1989.
   - Negotiation of commercial terms with licensors during the preparation of TEFR and remainder of 1989.
   - Decision on plant - December 1989.
   - Engineering design by licensor and Indian engineering company 18 months.
   - Construction - 45 months.

   - Operation of Pilot Plant - 2 years.

6. Project Structure - The GOI would like to see the process licensor become an equity participant in the demonstration plant. A participation level of 15 to 25% was suggested. Repatriation of dividends or capital would start after the technological success of the project (a minimum of one year of operation). The investment of US Government funds would not be included in the equity portion of the project, but could be recovered through future royalties or export of joint US/Indian technology. Procurement restrictions for the Pilot plant construction dictate that at least 70% must be from Indian sources, 30% can be from foreign sources.

7. The evaluation of the technologies presented in the Expert Report was based on the extrapolation of experience with coals having a maximum of 10% ash to 40% ash levels. The results of this evaluation are as follows:

   - Power generation from conventional pulverized coal plants firing 40% ash coals is of the order of 1.5 Kwh/Kg. In India it is about 1.66 KWh/kg without FGD but with precipitators. With FDG this would decrease to 1.2 Kwh/kg.

   - For IGCC with FGD the figures estimated are between 1.3 and 2.0 Kwh/kg with existing turbine inlet temperatures and potentially 1.6 to 2.5 Kwh/kg with higher inlet temperatures.

8. A review of the methodology used in the evaluation indicates that gas yields are probably not significantly effected by the higher ash levels, especially for the entrained gasifiers. The assumptions of flux requirements for the different processes is however

critical to the economic evaluation of the process. Some of the flux requirement rates assumed did not reflect the latest experience. Fluxing tests for Indian coals will be required to remedy this problem.

9. There is some divergence in opinion of what level of coal testing is needed to allow a more accurate estimate of IGCC economics to be made. It was recognised that coal testing at the demonstration plant level would be needed to make the decision to go ahead with a commercial plant. For the next stage of economic evaluation, licensor correlations would be sufficient to determine yields. Laboratory analysis of fluxing needs and slurry properties, where appropriate would still be needed.

7.2.2 Meeting 2

Date: 28th March,1988

Location: Ministry of Energy, Department of Coal, Delhi

Present:

Department of Coal	Dr. Vardhan, Secretary of Coal
CSIR	Dr. R. Iyengar
CSIR	Dr. S. Garg
USAID	S. Padmanabhan
USTDP	R. Bobel
EPRI	Dr. N. Holt
IDEA	B. Dutkiewicz

The meeting was arranged by CSIR to discuss the current status of Coal development in India in general, and to give the Definitional Mission insights into the Department of Coal's perception of the IGCC project. The discussions covered the broader aspects of coal development and utilization in India.

1. No indication of the size and nature of the current coal research budget was available. However the combined coal and power R&D 5 year budget is of the order of 500 crores rps. The work currently being done on coal slurry transportation was given as an example of the type and scale of projects currently being carried out. A 50 Km test pipeline is currently under construction.

2. The Department of Coal is primarily responsible for the work being carried out on IGCC, and it would be this Department that would be responsible for the execution and operation of the Demonstration Plant.

3. On several occasions Dr. Vardhan made the point that funding for the Demonstration Plants would not be a problem, provided that the technology was shown to be economic. The funding would come out of the Coal and/or Power Sectors which both come under the Department of Energy. The project and initial TEFR will have to be submitted to the Scientific Advisory Committee of the Department of Coal. Dr. Vardhan is the chairman of this Committee.

4. The current status of R&D in coal washing is rather unclear and it was not possible to ascertain to what extent the planned washing projects included in the 7th plan were being executed. Little work has apparently been done on the washing of non-coking coals. One test has been carried out indicating a washing cost of 70-75 rps per ton.

5. The feeling is that environmental restrictions will increase in the future especially for particulate emissions. Sulfur and NOX are not a problem at present and are not being closely monitored, but will come under closer scrutiny in the future.

6. There was no indication given that any thought had been given to any project development work beyond the stage of the preparation of the current TEFR. Nor was it possible to ascertain what quantitative criteria would be used to determine the viability of the IGCC technology.

7. An AFB prototype is currently running on 72% ash coal rejects.

7.2.3 Meeting 3

Date: 28th March,1988

Location: Ministry of Energy, Department of Power

Present:

Department of Power	Dr. Kohli, Secretary of Power.
CSIR	Dr. R. Iyengar
CSIR	Dr. S. Garg
USAID	S. Padmanabhan
USTDP	R. Bobel
EPRI	Dr. N. Holt
IDEA	B. Dutkiewicz

The meeting was setup by the CSIR to allow the Mission to obtain an idea of the current thinking of the Department of Power regarding the outlook for new generation technologies in general and the IGCC project in particular.

1. The major concern of the Department of Power is the expansion of generating capacity by whatever means to meet the expanding demand for power in the future. This year an additional 4500 Mwe of new capacity were added versus 5000 planned. In the 90's the need will be from 6000 to 7000 Mwe of new capacity annually.

2. The split of generating capacity is roughly 40/60 between hydro and thermal, and it is expected that the thermal portion will increase in future. Coal and natural gas will continue to play the major role. The future contribution of gas is an unknown quantity since it will depend on gas discovery rate. It will probably not be more than 1000 Mwe.

3. The environmental groups are becoming more vocal in their demands. It is recognised that it will no longer be possible to defer environmental clean up and more stringent regulations are expected. Sulfur is not considered as problem due to the low sulfur nature of the coal.

4. New technology - They are currently looking at putting up a supercritical powerplant, and may look to other technologies - such as Solar in the future. The viability of IGCC technology is being analyzed by the Department of Coal. If this proves positive, then IGCC will be used. The idea of testing in an existing US Demonstration plant, rather than reinventing the wheel in India was considered to have considerable appeal.

7.2.4 Meeting 4

Date: 28th March,1988

Location: Central Electricity Commission (CEA)
New Delhi

Present:

CEA	Dr. Tiwari - Member Thermal
CSIR	Dr.S. Garg
USAID	S. Padmanabhan
USTDP	R. Bobel
EPRI	Dr. N. Holt
IDEA	B. Dutkiewicz

The meeting was setup by the CSIR to allow the Mission to obtain an idea of the current thinking of the CEA regarding the outlook for new generation technologies in India.

1. The current thinking of CEA is that the overall efficiency of an IGCC unit is a primarily measure of the viability of the technology. Current pulverized coal power plants have an efficiency in the range of 32-35% and cost approximately i2500 rps/kw. Of major interest is the comparative efficiency of an IGCC unit fixed with Indian high ash coals.

2. A major problem with existing facilities is the reliability of crushing and grinding equipment which is a major source of down time. Any process that does not need significant size reduction would have an advantage. This is one advantage of fluid bed technology.

3. No analysis has yet been made of the overall potential for IGCC technology in the Indian Power Sector.

4. The question of beneficiation of coals, either current or future, has not been addressed to any large extent. The use of beneficiation, if included in the final proposal, should be clearly defined.

5. The relative merits of building a Demonstration plant in India, or the use of US Facilities to test Indian Coals was discussed at some length. While the financial savings were admittedly large, the use of a domestic technology and demonstration plants could have several important advantages. Both approaches merit consideration.

6. Discussion on the optimum commercial plant size hinged on the use of currently available technology, especially the size of the gas turbines. A 400 - 500 MWe multi train installation was considered to be appropriate.

7.2.5 Meeting 5

Date: 31 March, 1988

Meeting : Coal Gasification Seminar.
Presentation by Dr. Neville Holt, EPRI.

Location: CSIR International Science Center,
Lodhi Road, New Delhi

Participants:

Dr. Y.P. Abbi	BHEL, New Delhi
A. Ahuja	Industrial Consultant
R.W. Beckman	USAID, New Delhi
J.R. Bentjercdt	World Bank, New Delhi
C. Bhattacharya	C.E.A., New Delhi
D.K. Biscon	Scientist - CFRI, Dhanbad
R. Bobel	USTDP.
Bronek Dutkiewicz	IDEA/USAID
S.D. Garg	Senior Advisor - CSIR, New Delhi
Dr. Neville Holt	EPRI, Palo Alto, Calif.
Dr. Ram K. Iyengar	Add. Director General - CSIR, New Delhi
Dr. David J. Jhirad	USAID/S&T/EY
M.A. Khan	Chief Engineer - PDIL
R.C. Nakul	C.E.A.
Aditya Nehru	Vice President - Sandoz (India) Ltd.
S. Padmanaban	USAID, New Delhi
V. Raghuraman	National Productivity Council
A. Raman	C.E.A., New Delhi
C.H.V. Ramanamurty	C.E.A., New Delhi
M.A. Ramanan	C.E.A., New Delhi
O.P. Rau	Scientist - CSIR
P.R. Srinivasan	Dy. Dir. Gen. - National Prod. Council, New Delhi
Dr. S. Vardharajan	Planning Commission, New Delhi
C.R. Varughese	NTPC, New Delhi
V. Venkatejan	C.E.A., New Delhi

A general presentation of IGCC technology was made by Dr. N. Holt, followed by a discussion period during which the participants presented their impressions and concerns regarding IGCC applications to high ash India coals.

7.2.6 Meeting 6

Date: 4/6 April, 1988

Meeting: Coal Gasification for IGCC.

Location: CSIR International Science Center
Lodhi Road, New Delhi

Participants:

Dr. David J. Jhirad	USAID
Ronald Bobel	TDP
Bronek Dutkiewicz	IDEA/USAID
K.K. Sinha	PDIL
S.D. Garg	CSIR, New Delhi
S.S. Raghavan	CFRI, Ranchi
K.K. Raychaudhuri	CFRI, Dhanbad
A. Majumbar	CFRI, Dhanbad
R.K. Chakrabarky	CMPDI, Ranchi
O.P. Rao	CSIR, New Delhi
B. Madhusudhan	RRL(H) Hyderabad
C.H.V. Ramanamurty	C.E.A., New Delhi
N.N. Ramakrishnan	BHEL R&D, Hyderabad
T.S.R. Anjaneyulu	RRL(H)
G.S. Sidhu	

The meeting was held to lay out the capabilities of the various Indian entities that will contribute to the execution of the TEFR. The longer range plans for IGCC research and development in India were also addressed. The major points were as follows:

1. The goal of the present work is the construction of a full scale commercial IGCC power generation facility. The steps to be taken to arrive at that stage will be as follows:

   Step 1. Development of Proposal by USAID/TDP
   Division of Labor, India/US

   Step 2. Obtain licensor data
   Laboratory test data
   Definition of cost of next stage
   Short list of most probable gasification technology
   Coal Washing Tests and Analysis in India

   Step 3. Develop TEFR
   Define need for Beneficiation
   Define IGCC Plant based on 40% ash coals
   Obtain Accurate performance data
   Division of Labor - India/US

   Step 4. Construction of 500 megawatt IGCC unit

2. The Central Fuels Research Institute headquartered in Ranchi, Bihar has approximately 1200 employees, of which 400 are scientists, 400 technicians and 400 support personnel. They have four regional research laboratories.

   Their laboratory capabilities in the coal research area allow them to all the coal tests outlined in Appendix III of the Report of the Expert Group. (Page 173)

3. PDIL is the engineering arm of the National Fertilizer Commission, and has been responsible for the design and construction of 35 fertilizer plants in India. They also have a catalyst manufacturing capability. Approximately 3500 people are located in four engineering offices, with headquarters located in Sindi, Bihar.

   PDIL says it could do the Techno Economic Feasibility study from the basic engineering package, in India.

4. BHEL has been involved in the Combined Cycle technology through its manufacture of gas turbines under GE and Brown Boveri licenses. They have installed 1000 MWe of capacity to date.

   They have also studied eight gasification processes in detail and felt that they have a good understanding of the moving bed technologies.

   They have just started up a 6 MWe IGCC pilot plant leased on a moving bed gasifier, and would like to see this technology included in the TEFR.

5. General Project Considerations

   The following criteria were put forward by Dr.Iyengar as a basis for selection of the gasification technologies:

   1. Capital cost - rps/kw
   2. Levelized cost of Electricity - rps/kwh
   3. Indianization of Investment
   4. Reliability of Plant
   5. Mechanical Complexity
   6. Need to Beneficiate or Not
   7. Effluents
   8. Licensing arrangements and participation
   9. Financing

7.2.7 Selective Information From CSIR Notes On March 23, 1988 Meeting

The information provided below is a rendition of notes and materials excerpted from CSIR Meeting Notes.

Date: March 24, 1988

Participants:

T.S.R. Anjaneyula	RRL(Hyd)
Bronek Dutkiewicz	IDEA/USAID
S.D. Garg	CSIR, New Delhi
Neville Holt	EPRI
Ram K. Iyengar	CSIR
David Jhirad	USAID
B. Madhusudhan	RRL Hyderabad
S. Pakmanabhan	USAID, New Delhi
S.S. Raghavan	CFRI, (CSIR)
O.P. Rao	CSIR
K.K. Sinha	PDIL, New Delhi
G.S. Sidhu	
Dr. Y.P. Abbi	Dy. Gen. Manager, BHEL

Need For IGCC

- Coal for power 250 million tons by year 2000 AD
- Ash content 40 to 45%
- Better environmental performance
- Higher overall efficiency

Basis For Calculation

i) 71.0 MWe Thro G.T. and 50.7 Mwe Thro S.T.
According to EPRI-AP-3084 (33.8) (Texaco bases IGCC) 197.7 Million Kilo calories of chemical energy in crude gas is required.

ii) The (G.T. + H.R.S.G.) Set-up for each process is considered same.

iii) Additional S.T. power using the H.P. by-product steam is at 37.5% efficiency for S.T.

iv) Auxilliary power proportionate to coal feed rate.

v) Enthalpies of tar and oil (if any) are considered at 90% efficiency for conversion to steam.

vi) Fluxant addition based on EPRI data.

vii) L.P. steam given no credit.

viii) Latent heat of water vapor in gas not considered. S.T. power split - HRSG-33.8

Effect Of Ash In Coal

10% ASH COAL
- 2.3 KWH/kg from conventional plant without FGD.
- 2.5 to 3.0 KWH/kg from IGCC plant with build-in FGD.

40% ASH COAL
- 1.5 KWH/kg from conventional plant without FGD.
- 1.3 to 2.0 KWG/kg from IGCC plant with built-in FGD.

Assumptions Made During Extrapolation From 10% Ash-Case To 40% Ash Case:

i) Synthetic coal mixture of same quality with increased ash content is used.

ii) Extra ash does not take part directly or indirectly in the reactions - and passes through the reactor unchanged.

iii) Energy balance is used to arrive at material balance.

iv) Q-losses (as a percentage on total thermal input) are considered constant.

v) Oxygen and steam requirements are based on carbon content of coal.

vi) Lower calorific value resulting from higher ash content increases the coal requirement for same chemical energy output in crudegas.

Bore Hole Samples From Piparware

	Upper De KRA	Lower De KRA
SiO_2	59.8	56.7-58.1
$Al_2 2O_3$	28.0	29.7-30.0
Fl_2O_3	4.7	5.7-6.2
TiO_2	2.2	2.0-2.2
P_2O_5	0.8	0.9-1.0
CaO	1.5	1.3-1.4
MgO	1.0	0.9-1.0
SO_3	0.1	Traces-0.2

	Upper De KRA	Lower De KRA
Alkalies	0.1	0.9-1.8
	100.0	100.0
Ash Fusion		
IDT	1200-1360 °C	1300-1400+°C
Hemispherc	> 1400	> 1400

1. Proximate (at 60%-RH and 40°C)					
Moisture, Wt%	5.0 - 8.0	6.0 - 8.0	6.0 - 8.0	6.0 - 8.0	5.0 - 9.0
Ash, Wt.%	40.0 - 50.0	33.0 - 43.0	40.0 - 50.0	40.0 - 45.0	22.0 - 48.0 *
VM, Wt.%	22.0 - 26.0	25.0 - 28.0	22.0 - 26.0	25.0 - 28.0	23.0 - 29.0
2. Ultimate (DMF basis)					
C%	79.0 - 82.0	80.0 - 82.0	79.0 - 82.0	78.0 - 81.0	81.0 - 82.0
H%	4.7 - 5.2	5.0 - 5.2	5.2 - 5.6	4.6 - 5.1	4.8 - 5.0
N%	-	1.5 - 1.6	1.8 - 1.9	1.6 - 1.8	1.6 - 1.7
S%	-	0.6 - 0.7	0.7 - 0.9	0.4 - 0.7	0.6 - 0.7
3. Ash fusion temperature °C					
Softening temp.	1030-1200	1180-1210	1100-1260	1120-1220	1190-1230
Hemispherical	> 1400	>1400	>1400	>1400	>1400
4. Hardgrove Grindability Index	45-55	52-60	50-60	50-60	52-58
5. Gross calorific value Kcal/kg	2900-3700	3500-4300	2900-3700	3300-3700	3000-5700 **

* Bulk coal will be having more than 40% ash
** Largely below 4500

Conclusions

1. It is not possible to have coals with less than 40% ash for power generation in future in India.

2. Experience on 40% ash-coals is not available.

3. Washing of this coal to around 20-25% ash content is expected to improve the performance significantly. But the techno-economics are to be carried out.

4. High ash coals perform better in IGCC compared to conventional plants.

5. Testing of coals needed to establish improvement quantitatively.
   - Moving bed process - in India
   - Fluid bed entrained bed processes abroad

7.3 IGCC BASED ON INDIAN COAL
COMMENTARY BY NEVILLE HOLT

The current IGCC investigation effort for India, as undertaken by the Expert Group, has oriented itself towards evaluation of the various gasification technologies as they might be used in a 100-120 MW demonstration plant in India.

As an alternative I suggest that the evaluation be reoriented at 500 MW units. Major reasons for this recommendation are:

1. A 100-120 MW demon. plant would be costly on a $/KW capital investment and unecomomic to operate.

   An investment of 200-250 M$ would be required and the cost of electricity would probably be 1.5-2.0 times that of a commercial coal fired unit.

2. The 100-120 MW unit is based on currently available gas turbines. I believe the orientation should be shifted to the higher temperature, higher efficiency gas turbines such as the GE 7001F.

   Coal gasification, particularly the advanced processes operating in the slagging region will suffer some extra economic penalties due to the necessity of flux addition, both from the efficiency point of view (due to the melting and subsequent rejection of a large volume of solids) and from the cost of limestone flux and subsequent disposal.

   With these debits IGCC will probably need the more efficient combined cycle to be able to compete.

3. The current evaluation is oriented at comparing IGCC with direct coal firing without desulfurization.

   Since desulfurization probably represents about 25% of the capital costs for direct coal fired plant but only 5-7% of the costs for an IGCC, this basis of comparison is severe debit for IGCC.

4. Building and operating a 100-120 MW demo. will result in an expenditure of $300-400M and no ongoing economic generation capacity.

5. If alternatively the effort was oriented at the testing of Indian coals in the larger units abroad e.g., Texaco, Shell, Dow, and BGL then a data base for the design of a commercial economically viable IGCC plant probably of 500 MW capacity could be ready much sooner, which would result in a generation resource base for India.

   This course of action would require expenditures of perhaps only 10-20% of the funds required for a new demo.

6. The above comments are particularly relevant to the potential utilization of coals from Bihar, Madhya Pradesh, Orissa and West Bengal with their high ash and low sulfur contents. If however, it was ever considered relevant to utilize the higher sulfur lower ash coals from Assam then sulfur emission controls would almost certainly be needed and IGCC would become much more economically attractive.

More Specific Suggestions for Modifications to the Current Evaluation

1. Modify approach in current report of expert group to a nominal 500 MW basis;

   a) Suggest a gas production rate sufficient to fuel two GE 7001F machines i.e., about 2 x 10^9 Btu/hr of HHV medium Btu gas (raw gas after particulate removal).

   b) Use a single coal for the evaluation of all processes e.g., Dipka or Piparwar at 40% ash.

   c) As a first approximation use the same amount of flux for all the slagging processes about 25-35% of the coal ash.

   d) Reduce the number of processes evaluated for the sake of this screening study to BGL, Texaco, Shell, and Dow oxygen blown. These are the processes at the most advanced state of development all having large scale facilities.

   e) Relegate the fluid bed processes to a side study probably air blown hot gas clean up with low Btu gas to GT.

   f) All performance data estimates should be updated from the latest published information on the BGL, Texaco, Shell, and Dow processes.

   g) Select design air conditions 90°F or 59°F?

   h) Select steam cycle conditions -- 1500psi/1000°F/1000°F ?

   i) The emissions standards basis for the IGCC schemes needs to be established. The current basis seems to be comparison with a direct coal fired plant without FGD and without NO_x control.

If the latter is really the case, then perhaps the IGCC cases should be based on no sulfur removal. Since in this latter case there would be no need to cool the gas, to the sulfur removal temperature and the raw gas after particulate removal could go straight to the gas turbine. This would mean that the NH_3 in the raw gas would go to the GT and NO_x emissions would rise, however from an efficiency point of view this would be preferred. It will also restrict the waste water treatment to the blowdown from the particulate scrubber.

Suggestions for Parallel Evaluation

Given the nature of Indian coals (high ash and high ash fusion) there are some reasons to expect that gasification processes that do not operate in the slagging region may have advantages for Indian coals,

i.e.
- no flux required
- no extra solids for disposal
- less thermal penalty

Unfortunately the candidate fluid bed processes HT Winkler, KRW and U Gas are at earlier stages of development.

HT Winkler has an 800 TPD unit in Germany but experience is currently limited to brown coal. However, they are recommissioning a pilot plant and tests on other coals including sub bituminous and caking coals and possibly air blowing are planned to be undertaken.

RBK (who operate the HT Winkler in Germany) have conducted IGCC evaluations for O_2 and air blown schemes, and the flow sheet described in their October 1987 paper (which includes a CFBC for ash residue combustion) could be of interest for Indian coals.

The KRW and U Gas gasifiers only exist currently at the 10-25 tpd pilot plant scale and should not yet be considered for commercial deployment. Their development should be monitored and if larger units are built could be of interest.

The concept of hot gas clean-up has been the subject of much speculation as to its potential advantages and some small scale work in underway in US, Japan, and Europe. These developments should be monitored.

I believe that of all the gasifiers, the HT Winkler or the Lurgi CFB (used as a gasifier) have the best chance of working with hot particulate removal, so that the gas could go directly to the gas turbine. (However, NO_x emissions will go up.)

BHEL is currently conducting a development program on a 150 tpd air or O_2 blown dry ash moving bed (Lurgi). This process does have the potential to handle the high ash, high ash fusion Indian coals, but of course does require a sized (lump coal) 2 x 1/8" coal as top feed. Again as in the HT Winkler, a hybrid scheme with a CFBC, in this case taking the fine coal as feed would probably look quite attractive since this CFBC, would provide the steam (and start up) for the gasifier. The Lurgi byproduct tars and oils could also be fed to the same CFBC.

Any air blown IGCC scheme must incorporate studies and developments with regard to the gas turbine. GE currently states that their 7001 F needs a gas of minimum, 180 Btu/SCF (HHV), and as currently engineered is thus unsuitable for air blown low Btu gas.

One particular scheme which would probably have an attractive efficiency for Indian coals would include an oxygen blown BGL gasifier operating on sized coal equipped with the usual quench at the gasifier outlet. The tars, oils and liquor together with fine coal would go to a CFBC. This CFBC would be used for start up and supply process steam to the BGL gasifier.

7.4 LIST OF INFORMATION OBTAINED ON MISSION

(Table of Contents of Info Binder)

1. Report of the Expert Group - January 1988.
   Integrated Gasification Combined Cycle Power Generation
   100-120 MWe Demonstration Plant based on high ash Indian coals.

2. EPRI Technology Seminars.
   Coal Gasification Process Technology.

3. Emission Regulations (July 1984) Part 1
   Central Board for the Prevention and Control of Water Pollution.

4. The Seventh Five Year Plan.
   Government of India
   Chapter 6 - Energy

5. Beneficiation of Non-coking coals for Power Generation in India.
   IX International Coal Preparation Congress, New Delhi. 1982

6. Issues in Coal - K.S.R. Chari

7. Report of the Expert Group on Conversion of Coal to Gaseous and Liquid Fuels. - May 1984.

7.5 LIST OF ABBREVIATIONS

AFB	Atmospheric Fluidized Bed
BGSL	British Gas Lurgi Slagger
BHEL	Bharat Heavy Electricals Limited
CEA	The Central Electricity Authority
CSIR	Council of Scientific and Industrial Research
FGD	Flue Gas Desulverization
GOI	Government of India
HTW	High - Temperature Winkler
IGCC	Integrated Coal Gasification Combined Cycle System
KRW	Kellogg Rust - Westinghouse
LDA	Lurgi Dry Ash
MWe	Megawatts
NPC	National Productivity Council
NPT	National Project Team
NTPC	National Thermal Power Corporation (India)
PCPG	Pulverized Coal Power Plants
PDIL	Projects and Development India Limited
PFBG	Pressurized Fluidized Bed Gasification
PLF	Plant Load Factor
rps	rupees
RRL(H)	Regional Research Laboratory (Hydrabad)
TEFR	Techno - Economic Feasibility Study