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First Workshop on Biomass & Coal Conversion Programs of the USAID/GOI Alternative Energy Resources Development Project

Report on Trip to India

November 7-19, 1983

FIRST WORKSHOP

ON

BIOMASS AND COAL CONVERSION PROGRAMS

OF THE

USAID/GOI ALTERNATIVE ENERGY RESOURCES DEVELOPMENT PROJECT

REPORT ON
TRIP TO INDIA
NOVEMBER 7-19, 1983

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REPORT ON TRIP TO INDIA, NOVEMBER 7-19, 1983

FIRST WORKSHOP ON BIOMASS AND COAL CONVERSION PROGRAMS
OF THE
USAID/GOI ALTERNATIVE ENERGY RESOURCES DEVELOPMENT PROJECT

I. EXECUTIVE SUMMARY

The First Workshop on the USAID/Government of India Cooperative Program on Alternative Energy Resources Development - Coal/Biomass Conversion was held at the Taj Palace Hotel in New Delhi, India on November 7-11, 1983. The intent of the workshop was to provide a forum for a technical exchange between the U.S. and Indian specialists in specific areas of interest in coal/biomass conversion. The meeting also served the objective of acquainting each side with regard to the "State of the Art" and ongoing research and development activities in the U.S and India. Work plans were developed and modified for implementing the selected projects. At the end of the workshop site visits were made to assess the facilities and equipment and meet the technical personnel available to carry out the proposed projects.

There are six projects selected for collaboration in coal conversion and three in biomass conversion. The six coal projects are:

- Evaluation of Freeboard Performance in a Fluidized Bed Combustor
- AFB Boiler Scale-Up
- Hot Gas Cleanup
- Cold Gas Cleanup and Separation
- Rheology, Stability, and Combustion of Coal-Water Mixtures
- Coal Beneficiation.

The three major biomass conversion projects are:

- Development of a village-level gasifier (5 hp for irrigation pumps based on charred agricultural residue);
- Utilization of producer gas in small horsepower (3 to 5 hp) utility engines; and
- Development and field implementation of small wood-based gasifier-engine systems (5 to 30 hp).

The workshop sessions included presentations by Indian scientists/engineers and U.S. team members, followed by panel discussions. At the opening of the workshop, representatives from the Government of India, some of the participating laboratories, U.S. AID office in New Delhi, and U.S. DOE provided introductory remarks which emphasized the need and importance of technology development in meeting India's energy needs.

This trip report presents only the highlights of the techical discussions held during the workshop and the subsequent site visits. Project Plans on the specific projects selected are presented in a separate document. The detailed technical presentations are included in the Technical Proceedings of the workshop, to be released in February 1984.

II. PURPOSE OF VISIT

The purpose of the visit was to participate in the First Workshop held in New Delhi, under the auspices of the joint USAID/GOI Alternative Energy Resources Development Project. The intent of the workshop was three-fold:

1. To provide a forum for a technical exchange between U.S. and Indian specialists so as to achieve a better appreciation of the technology in each country in the specific areas of interest in coal and biomass conversion.

2. To acquaint each other with regard to present R&D activities and future plans in the U.S. and India, and

3. To develop detailed project outlines including project objectives, activities, and responsibilities and to formulate implementation plans for each of the selected collaborative projects.

Six projects were selected for collaboration in coal conversion and three in biomass conversion. The six coal projects are:

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- AFB Boiler Scale-Up
- Hot Gas Cleanup
- Cold Gas Cleaning and Separation
- Rheology, Stability, and Combustion of Coal-Water Mixtures
- Coal Beneficiation.

The three major biomass conversion projects are:

- Development of a village-level gasifier (5 hp for irrigation pumps based on charred agricultural residue);
- Utilization of producer gas in small horsepower (3-5 hp) utility engines; and
- Development and field implementation of small wood-based gasifier-engine systems (5-30 hp).

An additional objective of the program as a result of this workshop was the encouragement of commercial activity between the two countries.

The U.S. team traveling to India for the workshop was comprised of the following members:

- Daniel Bienstock, Pittsburgh Energy Technology Center, Program Manager
- John Byam, Morgantown Energy Technology Center
- Allen Deurbrouck, Pittsburgh Energy Technology Center
- Virgil Flanigan, University of Missouri, Rolla, Missouri
- Madhav Ghate, Morgantown Energy Technology Center
- John Goss, University of California, Davis, California
- R.P. Krishnan, Oak Ridge National Laboratory, Oak Ridge, Tennessee
- Jack Saluja, Viking Energy Corporation, Pittsburgh, Pennsylvania
- Abu Talib, Mitre Corporation

The U.S. commercial representatives who accepted the invitation to participate on their own were:

- K.S. Ahluwalia, Foster-Wheeler, New Jersey
- T.J. Loraine, Foster-Wheeler, London
- Fred Beierle, Pyrenco, Inc., Prosser, Washington
- Pramod Parikh, Marichi Co., Kirkland, Washington

III. INTRODUCTION

India imports crude oil to supplement its indigenous production which provides only 30 to 40% of its current requirements. To meet its annual oil needs, $5 billion is required, which is more than half of India's export earnings. The energy resources of the country comprise recoverable reserves of 114,000 million tons of coal, 180 million tons of oil, and 41,000 MW of hydropower. India ranks 10th in the world's coal reserves and 7th in the world's coal production. This abundance of coal emphasizes the necessity for assigning greater importance to coal and for developing efficient technologies for the production, beneficiation, and utilization of coal. The drawback to the use of Indian coals is its high-ash content. Coal available for the power sector contains 35 to 40% ash. Improved coal combustion and gasification plants should be put into service in India to use an increasing proportion of inferior quality coals.

The biomass conversion component of the U.S./India energy collaboration program can also play a very significant role in alleviating the Indian dependence on imported oil. India is a predominantly agricultural country which produces annually 200 million tons of agricultural residue such as wheat straw, rice hulls, nut shells, etc. India in general is facing deforestation problems; however, several states, particularly the State of Gujarat, have started active reforestation projects. It is expected that these man-made forests could also provide additional sources of biomass fuel. The dispersed nature of biomass resources restricts their use to small-scale conversion technologies. Therefore, the collaborative research, development, and demonstration projects in the biomass conversion area are based on small-scale technologies. It is estimated that there are approximately 25 million farms in India using 5 hp diesel engine sets to satisfy their irrigation requirements. A small producer gas generator (gasifier) is an ideal small-scale biomass conversion technology which holds great potential in fueling these diesel-operated irrigation pumps.

IV. WORKSHOP

During the two-week stay in India, the U.S. specialists participated in the technical deliberations of the first workshop on Alternative Energy Resource Development, held discussions specifically relating to the selected collaborative projects, and made site visits to assess the level of technical assistance (i.e., equipment and consulting) required for each of the related projects. This section documents the above-mentioned activities in a chronological order.

A. Technical Presentatiosn During the Workshop

The first three days (Monday, November 7, through Wednesday, November 9) of the workshop were devoted to technical presentations in coal and biomass conversion areas, and the last two days (Thursday and Friday, November 10 and 11) to the development and/or refinement of work plans in the selected collaborative projects. The agenda for the workshop appears in Table 1. The biomass session was expanded to provide an opportunity to additional Indian groups to present their work. The list of attendees and invited guests appears in Appendix A. During these technical sessions, Indian and U.S. specialists presented the ongoing research, development, and demonstration (RD&D) activities in the respective countries. The detailed documentation of the technical presentations, along with the related questions and answers, is being prepared as a Proceedings to be released February 1984.

The technical presentations provided an excellent forum for exchange of information on the state-of-the-art of selected coal and biomass conversion technologies. The active participation of the Indian specialists was largely responsible for the success of all the technical sessions.

B. November 7, 1983 - Morning Session

The workshop commenced with an introduction by Daniel Bienstock, PETC, U.S. Department of Energy. Following this, brief presentations were made by the panel members on the scope and objectives of the program in relation to the energy needs of the country. Mr. R. Nachtrieb, U.S.AID, New Delhi, Mr. B.N. Swarup, Director, Department of Non Conventional Energy Sources, New Delhi, Professor B.K. Mazumdar, Director, Central Fuel Research Institute, Dhanbad, and Mr. M.K. Sridhar, Director, Technical Services, BHEL, addressed the audience.

Mr. Swarup stated that in India 80% of the population lives in rural areas where the need is critical for services such as heat, light, and electric power. Provision of these services is the only way to guarantee health and quality of life for the rural poor. Because of this need, the public sector investment in agricultural development is budgeted at 11 Billion U.S. dollars in the sixth five-year plan. Development of a sustained and cheap energy supply on a decentralized basis is vital. Toward this end, the Indian Government is attacking the problem on three fronts. These are:

1. Biogas program for converting animal waste to useful energy. This program is being organized on a national scale.

2. Energy from wood - Use of wood-burning stoves. This program is also being launched on a national scale.

3. Conversion of crop residues to useful energy. This program has not made much headway. Are there technical or economic problems standing in the way?

TABLE 1. WORKSHOP AGENDA

Monday, November 7, 1983

Morning Session

10:00 a.m. - 12:00 noon	**Introduction - D. Bienstock, DOE (PETC)** Presentations by the following organizations o USAID - W. Nachtrieb o DNES - B.N. Swarup o CFRI - B.K. Mazumdar o BHEL - M.K. Sridhar
12:30 p.m. - 1:30 p.m.	**Lunch**

Afternoon Session: Fluidized Bed Combustion, Session Chairman, Y.P. Abbi (BHEL)

2:00 p.m. - 2:45 p.m.	**Indian Presentation**, K.M.V. Malarkkan - BHEL/M.M. Sen (CFRI)
3:00 p.m. - 3:20 p.m.	**Overview of U.S. DOE FBC Program** - J.W. Byam, DOE, (METC)
3:20 p.m. - 3:45 p.m.	**Evaluation of Free Board Performance in a Fluidized Bed Combustor** - R.P. Krishnan, ORNL
4:00 p.m. - 4:15 p.m.	**Break**
4:15 p.m.	**Panel Discussion**

Tuesday, November 8, 1983

Morning Session: Coal Water Mixtures, Session Chairman, M.K. Sarkar (IIT)

9:00 a.m. - 9:45 a.m.	**Indian Presentation**, M. Chakraborty - CFRI/ K.M.V. Malarkkan - BHEL
10:00 a.m. - 10:45 a.m.	**Status of Coal Water Mixture Technology** - D. Bienstock, DOE (PETC)
11:00 a.m. - 11:15 a.m.	**Break**
11:15 a.m.	**Panel Discussion**
12:30 p.m. - 1:30 p.m.	**Lunch**

TABLE 1. WORKSHOP AGENDA, (Continued)

Tuesday, November 8, 1983, (Continued)

Afternoon Session: Coal Cleaning, Session Chairman, B.K. Mazumdar (CFRI)

2:00 p.m. - 2:45 p.m.	**Indian Presentation,** A.K. Chakravarti (CFRI)
3:00 p.m. - 3:45 p.m.	**Status of Coal Cleaning Technology in U.S.** - A. Deurbrouck, DOE (PETC)
4:00 p.m.	**Break**
4:15 p.m.	**Panel Discussion**

Wednesday, November 9, 1983

Morning Session: Biomass Conversion, Session Chairman, O.P. Vimal (DNES)

8:30 a.m. - 8:55 a.m.	**Indian Experience in Gasifying Agricultural Residues** - P.D. Grover, IIT, Delhi
8:55 a.m. - 9:20 a.m.	**Small Internal Combustion Engines for Producer Gas Application** - H.D. Mathur, IIT, Delhi
9:20 a.m. - 9:45 a.m.	**Wood Gasifier Program** - Surendra Kumar, Jyoti Solar Energy Institute, Vallabh Vidjanagar
9:45 a.m. - 10:00 a.m.	**Technology Development Through Biomass Conversion** - M.K. Sarkar, IIT, Delhi
10:00 a.m. - 10:15 a.m.	**On the Combustion of Corncobs in Fluidized-Bed** - A.K. Drona, G.B. Pant, University of Agriculture and Technology, Nanital
10:15 a.m. - 10:30 a.m.	**Break**
10:30 a.m. - 10:55 a.m.	**Gasification and Pyrolysis of Biomass Fuels** - Virgil Flanigan, University of Missouri, Rolla, Missouri
10:55 a.m. - 11:20 a.m.	**State-of-the-Art of Agricultural Residue Gasifiers in the U.S.** - John Goss, University of California, Davis, California

TABLE 1. WORKSHOP AGENDA, (Continued)

Wednesday, November 9, 1983, (Continued)

Morning Session, (Continued)

11:20 a.m. - 11:45 a.m.	**Implementation of Wood/Biomass Energy Projects in Developing Countries -** Abu Talib, The MITRE Corporation, McLean, Virginia
11:45 a.m. - 12:00 M.	**Brief Review of Wood/Biomass Development Work by Pyrenco, Inc. -** Frederick Beierle, Prossor, Washington
12:00 M. - 12:15 p.m.	**Comments** by G.S. Sidhu, Director General, CSIR
12:15 p.m. - 12:30 p.m.	**Indian Biomass Conversion Experience -** R.C. Maheshwari, Head, Electromechanical Engineering Division, Central Institute of Agricultural Engineering, Bhopal
12:30 p.m. - 12:45 p.m.	**Development of Small (3-5 kW) Producer Gas Plant Running on Locally Available Waste -** Anil K. Rajvansni, Director, Energy Division Nimbkar, Agricultural Research Institute
12:45 p.m. - 1:00 p.m.	**Concluding Remarks -** O.P. Vimal, DNES
1:00 p.m. - 2:00 p.m.	**Lunch**

Afternoon Session: Gas Separation and Gas Cleanup, Session Chairman, M.K. Sarkar (IIT)

2:30 p.m. - 3:00 p.m.	**Indian Presentation,** R. Rangan (BHEL)
3:00 p.m. - 3:30 p.m.	**Status of Gas Separation and Gas Cleanup Technology in the U.S. -** M. Ghate, DOE (METC)
3:30 p.m. - 3:45 p.m.	**Break**
3:45 p.m. - 4:15 p.m.	**Panel Discussion**

Concluding Session

4:30 - 5:15 p.m.	**Panel Discussion** M.K. Sridhar, BHEL

TABLE 1. WORKSHOP AGENDA, (Continued)

Wednesday, November 9, 1983, (Continued)	
Concluding Session, (Continued)	
	Don Masters, USAID D. Bienstock, DOE, Moderator
7:30 p.m.	**Reception and Diner**
Thursday and Friday, November 10 and 11, 1983	
Development of Work Plans-Refine, modify and finalize work plans where required, including initiation of projects.	
9:00 a.m. - 12:30 p.m.	Project Managers will continue to develop work plans.
2:00 p.m. - 5:30 p.m.	Project Managers will continue to develop work plans.
Monday, November 14, Saturday, November 19, 1983	
Individual Site Visits.	

Mr. Swarup emphasized that in the deliberations we should address whether the technological, economic, and sociological parameters are satisfactory for the conversion of crop residue to useful energy.

Professor Mazumdar presented a scenario on coal mining, coal beneficiation, and coal-water slurry technology. He indicated that the workshop was of key importance in developing efficient methods for coal utilization in India. Coal beneficiation is, and will continue to be, a high-priority area in the coal technology development program in India. Significant breakthroughs are needed in this area to reduce the ash content to levels suitable for coking coal production. This in turn can reduce the dependence on foreign coking coal for steel production.

Mr. Sridhar noted that the major portion of power generation in India is based on coal firing and therefore the real opportunity for increasing the use of coal in India involves getting the small industrial users to switch from boilers using oil to boilers using coal. Mr. Sridhar also focused on the goals of the fluidized-bed combustion technology. BHEL has the lead role in the development of this technology in India and their target is to commission boilers in the 30 MW(e) range for utility application. The customer response to this technology has been rather slow. Customers still prefer stoker-fired boilers. However, the situation is gradually changing because of the inherent problems and low reliability of the stoker-fired boilers, particularly for high-ash coals and pulverized mill rejects. FBC is considered the best available technology for burning these low-grade fuels. There are several projects in progress on FBC boilers for industrial and utility applications at BHEL, Trichy.

The scaleup problems in FBC as summarized by Mr. Sridhar are in the coal/ash handling system, fly ash separation, optimization of design and operating parameters in the larger size units, minimizing the unburnt carbon loss (improved combustion efficiency), and mechanical and component design. Some of these are being investigated in-house at Trichy, but there is need for collaborative work and/or information exchange in these areas. It was also pointed out that the transfer of FBC technology to Indian coals poses additional problems in India because of the high-ash and poor quality of Indian coals. Mr. Sridhar emphasized that the U.S.AID/BHEL FBC program should take into account these differences in coal quality.

C. November 7, 1983 - Afternoon Session

1. Fluidized-Bed Combustion

In an overview of the Indian activities in fluidized-bed combustion, Mr. Malarkkan stated that the 45-ton-per-hour atmospheric fluidized-bed boiler, which has been under construction by BHEL over the last two years, recently began operation and is expected to begin producing steam in mid-November, 1983. Their next large project is the design and operation of a 20- to 30-MW atmospheric fluid-bed boiler. These units will be competing with existing stoker-fired boilers for application in the industrial sector.

One key application for fluidized-bed combustion in the power generation sector would be to burn beneficiation rejects from the power station rather than to dispose of these rejects in landfills. It was noted that, while coal-water mixtures might be a viable alternative in the United States and some European countries for feeding fluidized-bed combustors, a restriction in India would be a critical lack of water for producing coal-water mixtures. Typical coals in India contain 30 to 40 percent ash and this poses an additional problem for the making of coal-water mixtures. Additional details on the Indian presentations can be obtained from the Workshop Proceedings.

The current work in combustion research and development by BHEL includes testing different fuels in the fluidized-bed combustion, design of a small fire tube boiler for rural application, and some investigations in PFB technologies. Additional future work is needed in the area of solid fuel feeding and scaleup, data on performance using low-grade fuels, and improved instrumentation for the test units. Alternative applications for fluidized-bed combustion, as pointed out by Dr. M.M. Sen of CFRI, are in the areas of developing hot air dryers to produce a 200°C gas for drying agricultural products such as tea and paddy.

Dr. R. Krishnan of ORNL presented a paper on the current design of the experimental apparatus in the freeboard combustion zone. The initial goals and objectives of this facility will be to develop data on the erosion/corrosion rates in the freeboard zone, to develop gas-sampling and solid-sampling capability, and to improve on cycle design as it applies specifically to the Indian coals. The unit will be operated with relatively shallow beds in the 175- to 1500-mm range.

Mr. J. Ryam of METC presented an overview of the DOE fluidized-bed combustion program, its current status, and where the program is going. Details are available in the Workshop Proceedings.

D. November 8, 1983 - Morning Session

1. Coal-Water Mixtures

The presentations of the morning session was on coal-water slurries. The Indian status of work on coal-water mixtures was presented by Dr. M. Chakraborty of CFRI and Mr. Malarkkan of BHEL. According to them, this technology holds significant potential for replacing oil and gas used in boilers and furnaces with minimum modification and investment. General characteristics of Indian coals were reviewed and it was stated that demineralization would be necessary to make the coal-water slurry fuel comparable with residual oil. CFRI and BHEL have already initiated work in slurry preparation and combustion studies, respectively, and that the preliminary results are very encouraging.

Mr. D. Bienstock of the Pittsburgh Energy Technology Center covered the status of the coal-water mixture technology in the

U.S. and the activities in this area in various countries. During the presentation he emphasized that coal-water mixture has emerged as a viable alternative to displace scarce fuel oil or gas in both utility and industrial sectors. Although fuel oil costs are presently low with oil supplies abundant, the concern for depending on a fuel with an uncertain future in price and availability, especially for importing countries such as India, makes the coal liquid mixture technology very attractive. He also discussed the various pulverizing processes, such as dry grinding, wet grinding, ultrafine grinding, and coal beneficiation to prepare coal-water mixtures.

E. November 8, 1983 - Afternoon Session

1. Coal Cleaning

Mr. A.K. Chakravarti, of the Central Fuel Research Institute (CFRI) at Dhanbad, reviewed the status of coal preparation in India. The coals of India normally contain fine mineral matter disseminated throughout the coal substance. Thus, beneficiation of these coals is quite difficult. During the period 1951 through 1983, seventeen coal washeries were built in India with an aggregrate throughput capacity of about 29 million long tons per year. Thirteen of the washeries in India contain dense-medium cyclones having a combined throughput capacity of about 3,500 tons per hour. All of the coal washeries in India excpet one produce coal for the coking coal market. The one exception is a small plant producing washed coal for a cement plant. A good Indian coking coal is cleaned to 17% ash. Unfortunately, the quality of the coals being mined has deteriorated significantly in the last few years. This, along with inefficient operation of the coal washery plants, has resulted in an increased ash content of the coking coals reaching as high as 20 to 22%.

The U.S. presentation was made by Mr. A. Deurbrouck of the Pittsburgh Energy Technology Center. He gave an overview of the current coal preparation practices in the U.S. He emphasized that if our use of coal is to grow, we must make it a more acceptable fuel by removing the impurities that provide a serious drawback because of environmental concerns. To do this we must wash more coal There is no quicker, less expensive way to reduce significantly the ash and sulfur content from coal than to wash it. This is true in the United States and also with the coal industry in India. Coal preparation provides a means for providing custom feedstocks of desired quality to meet end use specifications.

In the United States about 50% of all coal washed is processed in jigs; however, the utilization of dense-medium processes, in particular cyclones, is growing at a very rapid pace owing to the fact that dense-medium proceses provide the sharpest separations attainable, especially for fine-size coal. The cleaning of fine coal by froth flotation is also increasing substantially. Although only a small percentage of clean coal is produced by dry separation processes, there is renewed interest in upgrading lower

rank coals by dry techniques, particularly in the arid regions of the western United States.

A typical coal preparation plant in the U.S. is operated approximately 13 hours a day, 5 days a week, 220 days a year; however, new plants going on-line are being designed for a minimum of two shifts and the capability of operating three shifts per day. Plants of one or two thousand tons per hour capacity are being developed with parallel circuits. An interesting example is the Paradise plant recently built by the Tennessee Valley Authority (TVA) which has four independent 500 ton per hour circuits. Thus, one circuit can be down for maintenance and the other three can be processing coal at full capacity.

An interesting trend is the small modular coal preparation plant of from 50 to 200 ton per hour capacity. Such facilities can be built and brought on-line in a very short time.

An interesting example of a new flowsheet configuration designed specifically to reduce pyritic sulfur content is provided by the Homer City Coal Preparation Plant in Pennsylvania. The Homer City facility provides an ultraclean low-sulfur product to feed a 650 megawatt generator that is subject to strict SO_2 emission standards.

F. November 9, 1983 - Morning Session

1. Biomass Conversion

The biomass session began at 8:30 a.m. and continued through 1:00 p.m. Three Indian presentations were originally scheduled for this session; however, considering the high interest shown by other Indian biomass specialists to present their work, it was decided to expand the number of Indian presentations from three to seven. During the biomass session, Dr. G.S. Sidhu, Director General, CSIR, expressed his comments on the U.S./India alternative energy collaboration program. His comments, as well as the highlights of the discussions of the workshop, are included here.

Professor P.D. Grover of the Indian Institute of Technology started the session by focusing on the need for gasifying agricultural residues and then reviewing the Indian experience. He reiterated what Mr. Swarup had said that almost 80% of the population in India lives in 500,000 villages. By the year 2000 the population is expected to reach one billion, and it is likely that most of the people will continue to inhabit the rural sector. To sustain such a vast population and develop the rural and agricultural economy, a considerable increase in energy production will be essential.

To meet this growing energy demand, one of the major approaches is to utilize agricultural residues efficiently. Over 200 million tons of these residues are being produced annually. Gasification of agro-wastes has great potential provided that an appropriate

gasifier capable of operating under a village environment is developed. The gasifier is then used to power an engine-pump set for irrigation. The objective of this development is to have a decentralized system for irrigation for which the farmer does not depend upon the availability of diesel fuel and grid power, and the only fuel available to him, agro-waste, is utilized. Most of the agro-wastes cannot be used directly for gasification in small-scale gasifiers. These have to be modified in accordance with the requirements of feed stock for such gasifiers. For gasification, most of the experience in India is based on gasification either of coal or of charcoal made from wood. Experience in gasification of wood is also very recent and limited, and has yet to be utilized in the field.

For gasification of agro-wastes for motive power, three technologies are being stressed such as pyrolysis, direct gasification of raw biomass, and gasification of charred and briquetted biomass with emphasis on the last. Technology to make briquetted fuel "Paru Fuel" has already been developed, but its suitability for gasification, extent of charring, and other fuel characteristics still needs to be studied.

The next paper was that of Dr. H.B. Mathur on Small Internal Combustion Engines for producer gas application. He stated that the use of producer gas in existing spark ignition engines results in substantial loss of power and also in the reduction of the thermal efficiency of the engine. At higher loads, however, the thermal efficiency is close to that attainable with gasoline. He believes that the producer gas engines offer a promising alternative in meeting the agricultural sector energy needs of India.

The third paper of the morning was by S. Kumar of Jyoti Solar, who reviewed the Wood Gasifier Program of his Institute. They have developed a 5-hp wood-based gasifier which saves them 70 to 80% of diesel oil. They envision that this collaboration will result in the field demonstration of this technology and the development of the infrastructure in the rural areas of the country for subsequent wide-scale implementation.

The next paper was that by Professor M.K. Sarkar of IIT, Delhi. He reviewed the biomass conversion and utilization activities in the country. Some of these activities are:

- Generation of biogas by fermentation where the gas could be used for rural energy supply
- Direct gasification with air for generation of low calorific gas for engines for water pumping application, refrigeration, and power generation
- Partial charring of biomass for conversion to briquetted fuels, and
- Improvement of burning appliances for direct combustion of biomass.

Dr. Sarkar indicated that a small pilot plant consisting of fluidized-bed gasifier, Fischer-Tropsch reactor, and a methanator is under construction.

The fifth paper, by A.K. Drona, examined the potential of corncob as a commercial fuel and the development of a highly efficient fluidized-bed combustor, whereas the last two Indian papers, by A.K. Rajvanshi and R.C. Maheshwari, discussed projects similar to those already presented.

The first U.S. presentation was that of Dr. Virgil Flanigan on Gasification and Pyrolysis of Biomass Fuels. He reviewed several processes of interest in converting biomass fuels into useful energy, with special emphasis in fluidized-bed gasification and charring systems.

The next presentation was that of Professor John Goss on the state-of-the-art of agricultural residue gasifiers in the U.S. He reviewed some of the past and present biomass gasification activities. Specifically he presented to experience of the Agricultural Engineering Department of the University of California at Davis in designing, fabricating, and operating several agricultural residue and wood-based, down-draft, gas producer engine systems.

The last formal U.S. presentation was made by Abu Talib of Mitre Corporation, who focused on the implementation of Wood/Biomass gasifiers in the developing countries. He reviewed the potential wood energy projects and suggested a phased implementation strategy for successfully implementing a wood/biomass gasifier.

2. Address by Dr. G.S. Sidhu, Director General, Council of Scientific and Industrial Research and Secretary to the Government of India

I am indeed very happy to be here. When I received the program I found that I am one of the panelists this afternoon but, due to some breakdown in communications, this notice came a little bit late and I am committed for the whole of the afternoon with the Federation of Indian Chamber of Commerce and Industries, so I will miss the opportunity of taking part in the panel discussion this afternoon. So Dr. Bienstock was kind enough to ask if I could come at this time.

All I can say is that the development of alternate sources of energy for India is very important and the importance is realized from the fact that the Government of India has a separate department for this purpose. We in the CSIR have several research institutions which are involved in the development and conservation of energy. We were, for example, yesterday reviewing what CSIR as a whole has done and can do for the utilization of solar energy. We intend to have this review of our own work and the part it can play in an internationally integrated development plan for the use and the conservation of energy. So this workshop is very opportune in that a number of my colleagues are participating

and we are sure that we will benefit by the deliberations that are taking place in this seminar.

In many cases when one discusses these things the question of cost crops up. Whenever one thinks of an alternative, let us say the utilization of coal, then the question of cost must come in. On the utilization of solar energy through photovoltaics, the subject is raised that it is so many times more costly than petroleum or power generated by conventional means. Looking at it from a research and development angle, we have come to the conclusion that any cost calculations are premature until a substantially large demonstration unit has been built. And, after all, one of the purposes of research and development is not only to make a thing work but, after making a thing work, look at the cost reductions, and cost reductions always come. To rule out a development program on the basis of paper calculations has proved to be the wrong decision in many a case.

Moving away from the energy area, let us remember the cost of penicillin when it was first discovered and the way it was made and refrigerated and could be given to only a few patients. If one looks at the literature at that time one would come across arugments that yes, these things will only remain a laboratory curiosity. And look at what research and development did -- today it is one of the cheapest antibiotics and it has opened up an era of antibiotics, and medicine has completely changed. So today we will look at solar energy and say that, unless the cost factor of photovoltaics is brought to 10% of what it is, it is not going to be competitive. I think that these developments will come if we realize their importance. That would be true of any other R&D in the field of energy. We in India have, in most of the regions, plenty of sunshine so we should be making a major effort to utilize and harness its energy. We have plenty of agricultural wastes so we should also find out what are the optimal methods of utilizing these. And in that we must be benefited by the advice of people in commerce, economics, sociology -- because, especially with regard to the by-products of agriculture, the bottleneck is not going to be in the development of technology, it will be in the collection and transport of material. The plant material which we will use -- let us say a hundred tons a day -- will have to be transported. Then one will have to look at the radius from the point where we put such a plant and the collection point, and the cost of transport of this lighweight material to a central plant. Therefore it is germane to think of what should be the optimum size which will meet the requirements of a given community and which could be put where the transport of this very light raw material will not be uneconomic in itself.

The second thing which occurs to me in this particular field is that, when we take the cost of raw material which is available today and is not being put to any organized industrial use, the moment you start doing that you have to put a cost which is many times more than when it is freely available. This will be true of rice husks, true of garden stalks, and true of anything you can

think of. Therefore we must have a realistic picture during the development work in order to put some reasonable cost of that raw material which we do not always do in our calculations.

Another point I would like to make is that when we consider alternatives -- actually the word "alternative" itself means you have a choice, that you are choosing between two alternates -- that is why we will use the term "additional" sources of energy, not alternative sources of energy. You are not ruling out one and taking the other. If you are thinking of development, you do utilize every source of energy available and which can be optimally utilized in a given location. It may cost us say ten times more to generate a megawatt of power through photovoltaics but, if you put this at a location where we may have to take a transmission line a few hundred kilometers, and taken into account also the transmission losses and the maintenance of this line and the staff that is engaged, maybe then it is more cost effective. So that is why we say, not alternative, but additional sources of energy, which will be utilized at a given time to the maximum possible. Another thing -- unfortunately there is a tendency to associate some of these technologies with a low level of development of technology. But I think the development that will be useful is the one that utilizes these additional sources at the highest level of technology and innovation and scientific thinking. Only then will we find solutions which are worthwhile and which can take us many steps forward in this direction.

So I thank you once again for giving me this opportunity of being here and I wish the delegations all success. We look forward to the recommendations of the various groups and seeing how far we can incorporate these in our own R&D programs. Thank You.

G. November 9, 1983 - Afternoon Session

1. Gas Separation and Gas Cleanup

The Indian presentation was given by Mr. R. Rangan of BHEL. He reviewed the status of hot gas cleanup at BHEL, specifically addressing the particulate removal aspects. Indian coals have very low (~0.5 percent) sulfur content and, as such, there is less need to develop technologies to remove sulfur. However, due to high-ash content, particulate removal is of prime importance.

The U.S. presentation was made by Dr. M. Ghate, who gave an overview of various techniques used to clean hot and cold products from coal gasification and combustion processes. Details are available in the Proceedings.

H. November 10 and 11, 1983

1. Development of Workplans and Biomass Gasifier Demonstration

These two days were set aside for the development, refinement, and modification of workplans, so that all the projects selected were

finalized prior to the end of the workshop. Additionally, a small demonstration of a skid-mounted biomass gasifier developed by Pyrenco, Inc., of Prossor, Washington was exhibited during the lunch hour each day.

2. Development of Project Workplans

The project workplans in each of the specific areas appear in a separate document. Project titles and names of principal investigators are provided below:

a. Coal Conversion Projects

(1) Evaluation of Freeboard Performance in a Fluidized Bed Combustor

Principal Investigators:
Dr. R.P. Krishnan, ORNL, USA
Mr. K.M.V. Malarkkan, BHEL, Trichy, India
Mr. S. Chandrasekaran, BHEL, Trichy, India

U.S. Project Manager:
Mr. John Byam, Morgantown Energy Technology Center

(2) AFB Boiler Scaleup

Principal Investigator:
Mr. K.M.V. Malarkkan, BHEL, Trichy, India

U.S. Project Manager
Mr. John Byam, Morgantown Energy Technology Center

(3) Hot Gas Cleanup

Principal Investigator:
Dr. R. Vaidyeswaran, RRL, Hyderabad, India

U.S. Project Manager:
Dr. Madhav Ghate, Morgantown Energy Technology Center

(4) Cold Gas Cleanup and Separation

Principal Investigator:
Dr. R. Vaidyeswaran, RRL, Hyderabad, India

U.S. Project Manager:
Dr. Madhav Ghate, Morgantown Energy Technology Center

(5) Rheology, Stability, and Combustion of Coal-Water Mixtures

Principal Investigator:
Dr. M. Chakraborty, CFRI, Dhanbad, India

U.S. Project Manager:
Mr. Daniel Bienstock, Pittsburgh Energy Technology Center

(6) Coal Beneficiation

Principal Investigator:
Mr. A.K. Chakravarti, CFRI, Dhanbad, India

U.S. Project Manager:
Mr. A.W. Deurbrouck, Pittsburgh Energy Technology Center

b. Biomass Conversion Projects

(1) Development of a Village Level Gasifier for Irrigation Pumps Based on Charred Agricultural Residue

Principal Investigator:
Dr. P.D. Grover, IIT, Delhi, India

U.S. Advisor: Professor John Goss, University of California, Davis

(2) Utilization of Producer Gas in a Small Horsepower Utility Engine

Principal Investigator:
Dr. H.B. Mathur, IIT, Delhi, India

U.S. Advisors: Professor John Goss, University of California, Davis
Dr. Virgil Flanigan, University of Missouri, Rolla

(3) Development and Field Implementation of Small Wood-Based Gasifier Engine System

Principal Investigator:
Dr. Surendra Kumar, Jyoti Solar Energy Institute

U.S. Advisor: Dr. Virgil Flanigan, University of Missouri, Rolla

The project manager for the three biomass projects is Mr. Abu Talib of Mitre Croporation, McLean, Virginia.

c. Equipment/Hardware Demonstrations of a Biomass Gasifier

An interesting aspect of the workshop was a demonstration of a small biomass-based gasifier, engine-generator system by Pryenco, Inc., Prossor, Washington, a U.S. gasifier manufacturing firm. The gasifier, engine-generator system, net output of less than 1 kW, was especially fabricated and shipped to India for the workshop. A picture of the gasifier engine-generator system is shown in Figure 1. The load on

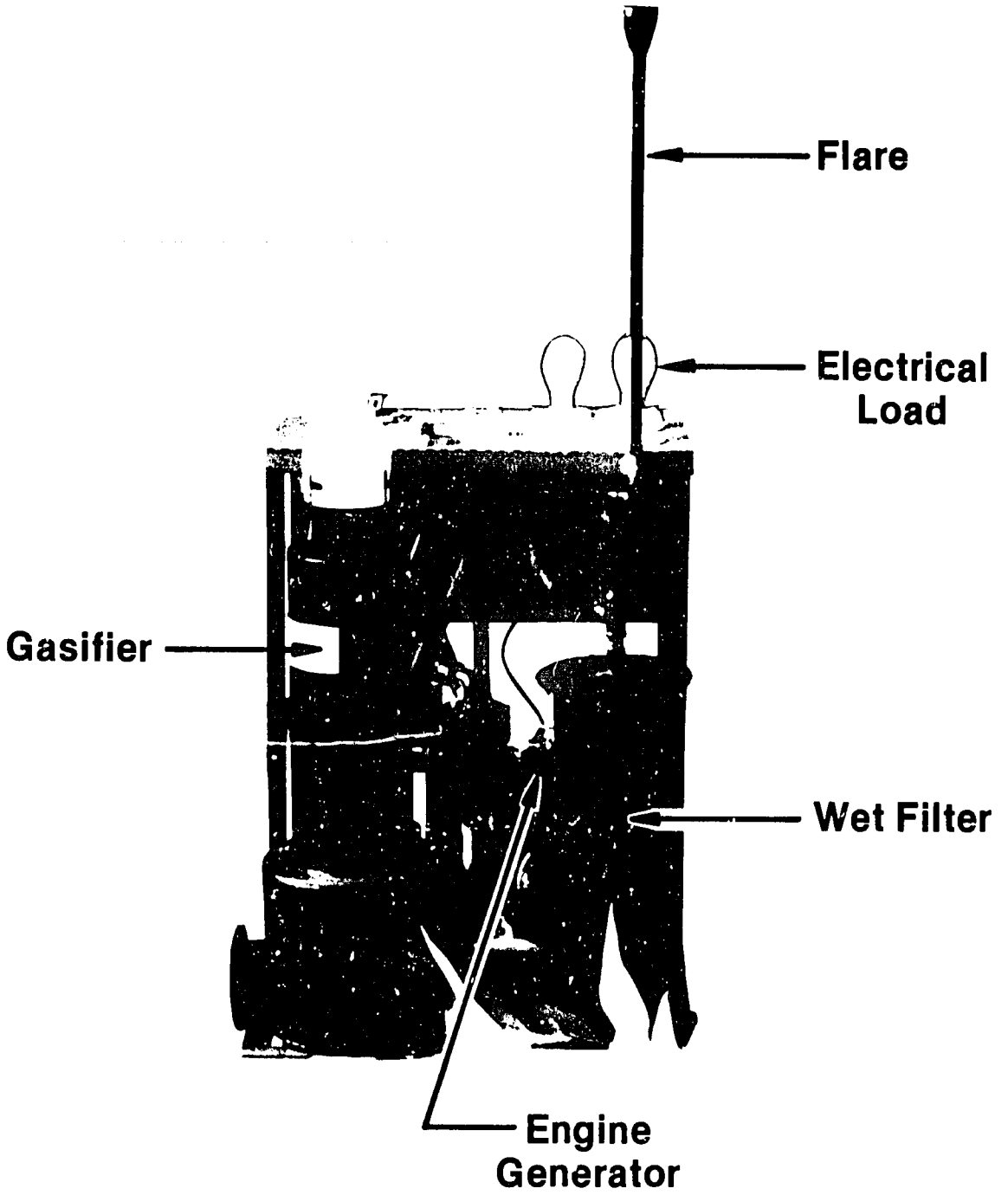

FIGURE 1

PYRENCO INC. SMALL (0.8-kWe) BIOMASS-BASED GASIFIER-ENGINE SYSTEM

this system consists of four 200 watt electric bulbs. The gasifier ran on pelletized biomass fuel, specifically pelletized sawdust, for several one-hour demonstration runs.

The first demonstration run was initiated on Thursday morning, November 10, and lasted for about one hour of uninterrupted operation. During this demonstration, Mr. Prafull H. Bhatt, Chairman of Gujarat Dairy Development Corporation, and his technical staff were present. Several demonstrations were held on Friday, November 11, for Indian and U.S. biomass specialists, DNES, and the National Dairy Development Board (NDDB) technical staff.

The demonstrations were very effective in illustrating the operation of small biomass-based gasifier-engine systems. The U.S./Indian biomass specialists, along with the technical staff of DNES and NDDB, were impressed by the compact size and ease of operation of the Pyrenco, Inc., gasifier-engine system. The Pyrenco demonstration resulted in several inquires from Indian firms interested in future collaboration to manufacture the gasifier-engine systems in India. This development was very encouraging since promotion of commercial activity is also one of the objectives of this joint USAID/India program.

V. SITE VISITS BY COAL CONVERSION AND BIOMASS CONVERSION TEAMS

November 14-18, 1983

A. Visits by Coal Team

1. Visit to CFRI - Dhanbad

On November 14, Al Deurbrouck and Jack Saluja visited the Central Fuel Research Institute at Dhanbad. They were greeted by the Director of CFRI, Professor B.K. Mazumdar, whom Deurbrouck has known for quite some time as he was intimately involved with the 9th International Coal Preparation Congress held in New Delhi. Professor Mazumdar described the organization and the research efforts of his Institute. CFRI is the consummate coal research organization in India, their research activities extending from basic coal science to coal preparation and utilization. Special emphasis in utilization research is directed toward coke making. They also have programs in direct coal combustion, liquefaction, and gasification. The combustion programs are quite varied from pulverized fuel combustion through fluidized-bed boilers to the utilization of coal slurries, both oil and water, as fuels.

After completion of the talks with the Director, Deurbrouck and Saluja were given a tour of the facility by the three Deputy Directors, Dr. P.N. Mukherjee, Mr. S.K. Rao, and Mr. A.K. Chakravarti. Mr. Chakravarti is also the chief coordinator of the Coal Washing Division and the Principal Investigator on the Indian side of the USAID/India program in coal preparation.

The CFRI coal preparation facilities are extensive. They have a pilot plant of 40-ton per hour capacity, which includes a 20-ton per hour Baum jig and a 20-ton per hour heavy-medium drum separator of Soviet design. This pilot plant includes no fine coal cleaning circuits; however, they do plan to put in such facilities in the future because of the need to produce high-quality coking coal to meet the demands of the growing Indian steel industry.

Mr. Chakravarti showed a high-bay area in which he plans to put the heavy media cyclone circuit required in the program. This space appeared to be most satisfactory. The Institute has adequate analytical facilities for the needs of the collaborative program. However, they have limited capabilities to produce the large quantities of narrow-size fractions of coal required for the program as now contemplated. Similar difficulties were noted in their fine-size, float-sink facilities. They have a very small centrifuge capable of swinging four cups of approximately 1-1/2 inch diameter. The extensive number of float-sink separations required to develop the distribution curves necessary for evaluation of dense-medium cyclone performance will mandate the acquisition of additional small centrifuges of the type they are now using or the acquisition of a larger centrifuge, perhaps of the size used at Pittsburgh Energy Technology Center.

An area of concern that must be addressed is CFRI's desire to grind and classify the magnetite medium that will be used for these tests. We were shown a free-swinging hammer mill integrated with an air classification system that they felt would allow them to produce any size magnetite desired. We have serious reservations about their ability to maintain the type of quality control on size distribution of magnetite that is desired, the obvious problem being control of the amounts of minus 5 and minus 10 micron particles. Alternatives to their system should be considered, including transport from the U.S. of the magnetite presized to the program specifications.

The staff of the Coal Washing Division of CFRI includes:

6	Seniors Engineers
14	Scientists/Chemists
6	Junior Scientists/Laboratory Assistants (These have college degrees).
8	Technicians
6	Laborers

Mr. Chakravarti assured me that adequate personnel would be available from his staff for the collaborative program.

In summary, it was found that the people at CFRI are quite knowledgeable and obviously enthusiastic about coal and its future role in the energy needs of India. The work done here in coal preparation by people such as Dr. G.G. Sarkar and Mr. A.K. Chakravarti is well-known and respected throughout the

coal preparation fraternity. However, in general, the equipment and instrumentation available here is quite limited and, by U.S. standards, antiquated. We must be certain that the project is kept at a level that reliability can be maintained. A few duplication (verification) runs will be advisable. We must be very careful in allowing acquisition of equipment such as the requested Microtrac unless we are confident it is a reliable instrument that will require only limited inventory of spare parts and could be repaired locally by the trained technicians. All power here is 220 volt 50 cycles, and this must be kept in mind when ordering equipment. Through the use of a little ingenuity, we must try to keep this study sufficiently clean to avoid long downtimes due to equipment malfunctions or spare parts shortages.

2. Site Visit to BHEL - Trichy

On November 14, Daniel Bienstock, PETC, Madhav Ghate and John Byam, METC, and R.P. Krishnan, ORNL, visited the combustion test facilities at BHEL - Trichy. Persons contacted included Mr. K.M. Malarkkan and Mr. S. Chandrasekaran. Mr. Malarkkan is in charge of the combustion work at BHEL Trichy, and is the project manager for the overall fluidized-bed program. Mr. Chandrasekaran is a senior development engineer in charge of the atmospheric fluidized-bed test rig at Trichy. At the meetings, questions concerning the work statement were reviewed and the subject of travel by the Indian engineers to the U.S. was again discussed. It was indicated by the U.S. team that we would discuss with TVA the possibility of TVA's involvement in the design review as well as obtaining from TVA information on its instrumentation school. It is the desire of the Indians to send one of their instrumentation engineers to this instrumentation school. During the discussion of the scaleup design work, DOE offered to send to Mr. Malarkkan a copy of Dr. Zenz's scaleup manual. Upon conclusion of the meeting the U.S. delegation visited the fluidized-bed combustion site and observed a startup of the 10 ton/hr FBC boiler. Mr. R.T. Arasu of BHEL accompanied the group. The following test facilities are located in the fossil energy development complex at Trichy:

- A 10 t/h steam prototype FBC Boiler
- A 0.5 m x 0.5 m FBC test unit
- A firetube FBC shell boiler
- A liquid fuel burning test facility
- A solid fuel burning test facility

- 10 t/h Steam Prototype FBC Boiler

The prototype boiler is a forced circulation, balanced draft system. Steam conditions are 10 atmosphere pressure and 180°C (saturated steam). Coal feed rate is 2 t/h of 30% ash coal and and 3.5 t/h, 70% ash washery rejects. Coal is fed to the combustor from the bottom and is metered by rotary air locks.

The combustor is octagonal in shape in the bed zone and square-shaped in the freeboard. The distributor floor area is 3 m^2. A perforated plate air distributor is fitted to the combustor. The bed is refractory lined in the in-bed section and the furnace is of water-wall construction. Provision for in-bed tube bundles is available in the combustor. Presently the tubes have been removed to permit testing of low-calorific, high-ash coals.

It was interesting to note that they are able to start up the unit in 30 minutes using charcoal soaked in kerosene as the only ignition source. The bed is separated into four sections and, by starting the two sections initially, they are able to bring the bed on-line and up to temperature within one-half hour. BHEL has tested many fuels including wastes from a sugar cane refinery factory, from rice husks, and from wood processing. They have achieved many successes in demonstrating that their fluidized-bed design can burn these indigenous fuels; however, their one shortcoming is the lack of instrumentation to adequately address the performance of the unit on these various fuels. The possibility of providing instrumentation from DOE's and GSA's excess equipment list meeting the Indian's specifications will be investigated.

Coal handling and preparation, ash disposal and water treatment are done at the site itself. Measurements of the basic fluidization parameters, air, water and steam, are possible in the system.

The boiler has been in operation since 1977 and has logged over 2500 hours. It is primarily being used as a demonstration facility for prospective customers. The experience from this unit has helped BHEL to sell two commercial boilers. The first unit (26400 lb/h) steam is operating at a local distillary in Trichy. The second unit (100,000 lb/h) was recently commissioned at a chemical plant (Hindustan Polymers Limited) at Vizagapatnam.

- <u>0.5 m x 0.5 m FBC Test Rig</u>

This unit is square in cross section. The combustor is refractory lined in the active bed portion and water jacketed above the active bed. The coal is fed pneumatically under-bed. Bed material is generally crushed refractory. The tube bundles are horizontal and of conventional design. The unit is mainly used to test the combustion characteristics of various fuels. A list of the fuels tested so far includes bagasse, rice husks, spent liquor, bark, wood chips, paper sludge, and spent bagasse.

- Firetube FBC Shell Boiler

A 7.5 tons/hour saturated steam firetube, two-pass FBC shell boiler has recently been commissioned. Shakedown is in progress. This is the first firetube FBC shell boiler being developed in India with the purpose of providing smaller boiler manufacturers in India with a complete design package for coal-fired FBC shell boilers in the 15 t/h steam capacity range.

- Liquid Fuel Burning Test Facility

The liquid fuel burning test facility (LFBTF) at BHEL, Trichy has been in operation since 1978. The LFBTF has a water-cooled test furnace in which oil burners up to 20 million Kcal/h capacity can be tested. It has a fuel storage, pumping and heating system, ignition system, combustion-air system and atomizing media system. The facility is equipped with essential instruments to measure the combustion gases, oxygen, temperatures, etc. Portable instruments are used to monitor these parameters in the absence of on-line instrumentation.

In the test facility, the influence of various input parameters such as fuel pressure, fuel temperature, fuel viscosity, combustion air pressure and temperature, and other associated parameters (either individually or in any combination) on ignition and combustion behavior of fuels can be studied. In addition, evaluation of new products such as High Energy Arc Ignitors, Trifecta Valves, etc. can be done before application as a regular feature in commercial boilers.

The test facility has been used in the following projects:

1. Development of low-excess-air, oil burners for PRAI 120 MW and PASIRGUDONG 120 MW export boilers in Malaysia.

2. Establishment of the capability and limitations of HIGH ENERGY ARC IGNITORS for application in utility boilers.

3. Development of AIR COOLED OIL GUN which is presently being offered for all new contracts.

4. Evaluation of the suitability of TRIFECTA VALVES for application in boilers with high-energy arc ignitors.

5. Identification of optimum location of DISCRIMINATING FLAME SCANNERS for maximum flame signal strength.

6. Development of wide range of LOW-EXCESS-AIR/LOW-STEAM CONSUMING OIL BURNERS for front wall-fired boilers.

There are plans to use this test facility for coal/water and coal/oil slurry testing. However, the size of the unit appears too large for conducting basic experimental studies on coal/water and coal/oil slurries.

- Solid Fuel Burning Test Facility

The test facility consists of raw coal handling and feeding system, pulverizing and classifying system, separation and feeding system, air-handling and air-heating system and test furnace. The furnace is designed for a firing capacity of 2200 lb/hr coal. The walls of the furnace are lined with refractory and are water cooled. The purpose of this facility is to study flame stability with regular tangential burners and with riffled coal nozzle burners at part-load conditions. The implications of these tests are that new burner designs can be retrofitted in coal-fired operating units to reduce the oil consumption at part-load. In addition, these novel burner designs are expected to reduce the unburnt carbon losses in existing pulverized-fuel boilers.

BHEL has supplied coal burners, developed in this test facility, to customers who have had problems with high unburnt carbon in fly ash from pulverized-fuel burners.

3. Site Visit to Regional Research Laboratory (RRL) - Hyderabad

On November 15, Daniel Bienstock, PETC, John Byam and Madhav Ghate, METC, and R.P. Krishnan, ORNL, visited RRL, Hyderabad. The purpose of the trip was to discuss the work plans in the area of gas cleanup. The group met with Dr. Thyagarajan, Director of the Laboratory, and Dr. R. Vaidyeswaran, Associate Director. Dr. Ghate met separately with Dr. Vaidyeswaran to discuss specifics with respect to the USAID gas cleanup program. RRL is interested in cold gas cleanup systems as they are primarily interested in gas cleanup for Fischer-Tropsch synthesis. This will require removal of chemical constituents (particularly sulfur compounds) in the cold synthesis gas.

As the test facilities at RRL were visited in May 1983, no visits were made at this time. Discussions were held on the scope of work and work plans for the USAID project.

4. Visit to BHEL - Hyderabad

The corporate R&D center for BHEL is located at Hyderabad. On November 16, Bienstock, Byam, Ghate, and Krishnan, joined by Jack Saluja of Viking Energy Corporation, met with the fossil energy group of BHEL. Attendees at the meeting included Mr. M. Suresh Kumar, Mr. R.S. Rangan, Mr. A.K. Ghosh and Mr. K. Venkatramani.

The purpose of the visit was primarily to develop work plans in the area of hot gas clenaup. Dr. Ghate of METC, who is respons-

ible for this activity in the USAID program, met with the group separately to come up with the work plan. Dr. Krishnan met with Mr. Kumar, who is responsible for the PFBC activities, to discuss the instrumentation requirements for the PFBC. Mr. Kumar was interested in the instrument specifications for the USAID/BHEL AFBC test facility. He also suggested that thermocouples for the AFBC facility could be fabricated in India. BHEL Hyderabad has obtained custom-made thermocouples from Fabrika, Inc., in Bombay, and they are quite satisfied with them. Samples of the thermocouples procured from Fabrika were seen in the instrumentation shop. Fabrika, Inc., was contacted in Bombay on the return trip to Trichy. A site visit to their facilities is being arranged. The BHEL instrumentation engineer from Trichy will accompany Mr. Krishnan on the forthcoming trip.

Additional discussions included a co-generation project underway at BHEL, which involved pressurized fluid bed gasification and operation of a gas turbine with the gas produced. This proposed activity will generate 4 Mw of electricity from the gas turbine and 2 Mw from a supplementary steam turbine. The gasifier should produce 13,000 m^3 of gas per hour while burning 150 tons of coal per day. The facility is currently in the final design phases and is due to be operational in the first quarter of 1985. The gas turbine is being provided by Mitsui of Japan and is one of their standard industrial turbines. Wet scrubbers for hot gas cleanup will be used in this system.

Mr. John Byam, METC, gave a presentation on the current status of the IEA PFBC Grimethorpe facility at the request of the BHEL fossil energy group. The talk addressed the current operational experience as well as information on the mechanical and system problems which have occurred at the Grimethorpe facility. The floor was then opened for questions and information on such subjects as the distribution plate design changes and the causes for leakage, experience with the hot valves, experience with startup operations, and instrumentation of the facility. It was also agreed that John Byam would provide Mr. Kumar with copies of recent reports from IEA-Grimethorpe on these various subjects so as to provide more technical detail.

The following activities are being carried out at BHEL - Hyderabad in the coal area:

- Pressurized fluidized-bed gasification
- Pressurized fluidized-bed combustion
- Hot gas cleanup

- <u>Pressurized Fluidized-Bed Gasification</u>

  An 18 t/d coal process and equipment development unit is in the fabrication stage. Scheduled commissioning is planned for the end of 1984. The objective is to use the pilot plant to design larger gasification plants for power generation with coal input of around 150-200 t/day. The gasification

process is a BHEL in-house process and is not linked to any of the existing processes. Details on the BHEL gasification process are not available.

- Pressurized Fluidized-Bed Combustion

A 200 mm diameter, pressurized, fluidized-bed combustor, without cooling surfaces and capable of operating at 10 atmospheres pressure, and 900°C has been erected and is in the shakedown stage. Coal feed rate will range from 20-50 Kg/h. Bed material will be crushed refractory. The feed system consists of a pressurized lock hopper, a screw feeder, and a pneumatic transport line. Start-up is achieved with liquified petroleum gas. A larger combustor capable of burning 300 Kg/hr coal, and 420 mm in diameter with cooling surfaces with option of hot water or steam generation is under fabrication. The scheduled start-up date is end of 1984.

- Hot Gas Cleanup

BHEL has identified high-efficiency cyclone separators and granular bed filters as potential systems for hot-gas cleanup. The cold model studies are planned to be conducted at IIT, Madras. A test loop for the cyclone is being erected at IIT, Madras and initial studies are expected to start by March-April 1984. This will be followed by a similar test loop for the granular bed filter. A hot-model, scaled-up version will be installed at Hyderabad and would be linked with the PFBC.

The emphasis in hot-gas cleanup is particulate removal to meet gas turbine requirements.

5. Site Visit to Hindustan Polymers Limited (HPL) - Vizagapatnam

On November 17 and 18, Dr. M. Ghate, METC, and Dr. R.P. Krishnan, ORNL, visited Hindustan Polymers Limited (HPL). HPL purchased a 45 t/h steam fluidized-bed boiler from BHEL to replace the existing oil-fired boilers (three), each 10 t/h steam capacity. The process steam requirement at HPL is 22 t/h. The FBC boiler will be used to supply the process steam and also to generate electricity. A 3 MW steam turbine has been installed for this purpose. The total cost of the FBC boiler, including the coal and ash handling system, is $4 million US. Delivered cost of coal (containing up to 50% ash) is $60-80 per ton.

A tour of the facility was arranged by BHEL. Mr. S. Srinivasaraghavan, Mr. C. Bhaskaran and Mr. K. Krishna Rao from BHEL accompanied the U.S. team on the tour and provided the details on the FBC boiler. The facility is well laid-out and is impressive. Erection and commissioning of the boiler were completed in a one-year period, from November 1982 to October 1983.

The first hydrostatic test was completed in May of 1983 at 1.5 times the design pressure. The boiler was undergoing shakedown tests. It will supply process steam as well as cogenerate 1.1 MWe electricity. The company expects 3 years as a payback period. After stabilization of this boiler, the company will scrap the existing oil-fired boilers.

The design parameters of the FBC boiler are:

Steam generation rate	45 t/h at 18 atmospheres and 363°C superheat
Cross section area of the bed	19 m^2
Number of compartments	4 (only 2 active at this time)
Turndown capability in each compartment	Up to 70% of full load
Number of coal feedpoints	16 (one per 1.3 m^2 of bed area)
Freeboard height	2.5 m
Furnace configuration	Bare water walls
Outside diameter of tube bundles	380 mm
Bed material	Crushed refractory
Air distributor type	Perforated plate
Superficial velocity	2.8 m/s
Particle size	1/4" x 0
Feeding mode	Underbed pneumatic
Feed line size	10.2 cms (4")
Static bed height	400 mm (1.3 ft.)
Bed temperature	700-800°C
Excess air, %	10 - 15
Thermal expansion	Provision has been made on sides
Tubes	Suspended from the top
Response time	2 to 3 minutes
Cold startup	10 minutes

Feed pipes	Carbon steel
Unstream factor	88%
Combustion efficiency	90-91%

Coal Analysis:

C	44.30	VM	28.80
H	3.47	Ash	39.47
N	0.74	Moisture	3.7
S	0.47	Higher Heating Value	4470 Kcal/g
O	7.89		

On-line instrumentation and data acquisition capabilities are lacking. However, the important performance parameters (pressure, temperatures, flue gas composition, coal/air feed rates, etc.) can be measured. The successful operation of the HPL boiler should give a significant thrust to the commercilization of FBC technology in India.

B. Visits by Biomass Team

At the end of the first week in New Delhi, the U.S. biomass specialists, Mr. Abu Talib, Professor John Goss and Dr. Virgil Flanigan, visited the laboratory and equipment facilities of the proposed biomass conversion projects to assess their adequacy to successfully carry out the proposed program. During the site visits, the list of equipment to be procured from the U.S. for the individual projects was also reviewed. In addition, an agricultural residue-based, charcoal-pellets production plant was also visited. The site visits are described in chronological order below.

1. Site Visit to Jyoti Solar Energy Institute (JSEI) - Vadodara

The JSEI facilities are located in Vallabh-Vidyanager, about 60 miles from Vadodara. Dr. O.P. Vimal of DNES accompanied the team to JSEI on November 14. The team was met by Dr. Vyarawalla, Group Leader, Jyoti Ltd. Enroute to the facilities, the team stopped briefly to see a small wood gasifier-engine installation at Mughar. This is a field demonstration unit fabricated and installed by Jyoti Ltd. The gasifier-engine system is rated at 8.5 Kw power output. The engine is a commercial, dual fuel, diesel engine designed for biogas firing. The gasifier-engine system is running an irrigation pump which is lifting water (static head of approximately 3 meters) from a nearby canal.

The gasifier was fed with waste wood collected from a sawmill. The gas cleaning system was a combination of wet scrubber and dry charcoal filter. The gasifier-engine system has displaced up to 85% of the diesel fuel with producer gas. In normal operation, an average of 76% displacement is consistently achieved. The gasifier-engine has accumulated more than 1,000 hours of operation. After 1,000 hours of operation, the dual fuel engine was taken apart to determine any unusual wear of engine parts. Except for slight erosion of one of the injector tips, no abnormal wear was detected.

In addition to this small gasifier-engine system, demonstration site, the team also visited a 100-KW gasifier-engine plant which is currently in the final phase of construction. This plant is scheduled for startup during the first quarter of 1984. The gasifier and gas cleanup train was designed by Jyoti Ltd., and fabricated locally. An existing 100 hp diesel fuel engine will be retrofitted to burn the producer gas in a dual fuel mode. The existing diesel engine runs an electric generator to provide backup power to Jyoti Ltd.'s switchgear plant in Mughar.

At JSEI the team was met by Dr. Date, Acting Director of JSEI, and later joined by Dr. Surendra Kumar, Deputy Director, JSEI. JSEI is a not-for-profit institution which was established in 1979 to develop and demonstrate renewable energy technologies. In the past four years, JSEI has been instrumental in developing solar energy technologies and eventually transferring them to the private sector for commercialization.

The objectives of the JSEI biomass gasifier program are to design, develop, and field-implement projects in the range of 3- to 30-kW rated output.

Under a Ford Foundation grant, JSEI has developed a small wood gasifier, dual-fuel, diesel-engine system to run a small irrigation pump. At present, they have three gasifier systems; the prototype unit has accumulated over 1,000 hours running on raw wood blocks and chipped fuel. During our site visit, the prototype unit operated continuously over a period of eight hours with minimum operator attention. The Jyoti wood gasifier engine system is ready for field demonstration trials.

Dr. Kumar introduced the U.S. members to the JSEI project team involved in gasifier development and test work. The project team consists of enthusiastic young Indian and French engineers. Two French engineers, Mr. Farcy and Mr. Butin, are assigned to work at JSEI under a French government-sponsored program for a period of about one year. These two engineers have replaced the earlier engineer couple, Vincent Damour and Marie-Sabine Damour, who were instrumental in initiating wood gasifier development work at JSEI. It is expected that two French engineers will be available full-time to work on the proposed project.

JSEI engineers and technicians have considerable experience in the implementation and field monitoring of various renewable energy conversion technologies. The Institute's technical personnel are also experienced in training the rural population in the use of various energy technologies. This particular aspect of their experience will be very useful in carrying out the field trials and training of local personnel of the proposed gasifier demonstration project.

In the afternoon the U.S. team visited Jyoti's laboratory and test facilities. JSEI has adequate gasifier/engine test facilities currently being used to test the operation of a 5-hp, wood-based gasifier-engine, irrigation pump system. However, JSEI has very modest instrumentation and analytical equipment in its laboratory. Existing equipment/instruments were effectively utilized to develop a working wood-gasifier, engine system.

JSEI can use some instrumentation and analytical equipment to assist and enhance the ongoing R&D work. JSEI has prepared a list of special analytical equipment/instruments which are to be procured from the United States. The U.S. biomass specialists discussed the equipment list with the JSEI technical personnel to prioritize the list so that procurement of essential equipment can be initiated soon. The prioritized list for Jyoti's project appears in the Biomass Project Plans.

The JSEI visit was concluded after Dr. B.C. Jain, General Manager, Energy Systems, Jyoti Ltd., gave the team a brief rundown on their current R&D work in developing, field testing, and eventually commercializing biomass gasification technology in India.

2. Site Visit to Agricultural Residue-Based Charcoal Production Plant - Madras

The U.S. team visited this facility on November 16. The team was met by Mr. S. Kalyana Sundaram, Chief Executive Farm Implements, a private Indian firm which is involved in the fabrication and installation of agricultural residue-based charcoal production technology. This technology was developed by Dr. P.D. Grover of IIT, New Delhi.

Mr. Sundaram told us that there are three operating plants in Madras and they will install five more plants in other parts of India. The charcoal production plant can handle a variety of low-moisture (about 10% on a wet basis) agricultural residue. The capacity of the single plant is about 6 tons of raw biomass per day. A plant of this size will produce approximately 4 tons per day of charcoal pellets. The green pellets are produced in a mechanical extruder. The pellets are roughly 1 to 2 inches in diameter and about 3 to 6 inches in length. The extruder uses mild steel dies which are replaced every other month. Starch and/or sodium silicate are commonly used as binders.

The existing charcoal production plants use agricultural residue such as rice husks, coffee husks, and bamboo waste. The plant needs electric power to run the various electric motors, particularly those running the extruder and I.D. fan. It is estimated that the total connected load is approximately 25 kW per ton of charcoal production capacity. The installed cost of a charcoal 4-ton per day capacity plant is approximately Rs. 300,000 (about 30,000 U.S. dollars). The cost includes plant erection, commissioning, startup, and operator training.

After the meeting at the Farm Implements Office, the U.S. team was taken to the plant site. The charcoal production plant is located adjacent to their fabrication shop. The capacity of this demonstration plant is approximately 2 tons of charcoal per day. Recently, this plant was put into commercial operation. It has successfully pyrolyzed biomass feedstocks such as sawdust, rice husks, coffee husks, peanut husks, etc. The plant ran with very little operator attention. The charcoal leaving the pyrolysis reactor is cooled in a water-jacketed screw auger. The cooled charcoal product is dumped on a paved storage area from where it is manually transferred to the blending and extrusion area.

The blender is an ordinary impeller mixer. During the blending operation, the charcoal product turns into fine powder-like consistency. The blended material is then manually transferred to the extruder which is also manually fed to produce the green pellets. The green pellets, after atmospheric pre-drying, are put into a tray dryer where the hot fuel gas will drive the moisture off. The dried pellets are bagged and marketed as cooking fuel for homes and resturants.

The charcoal pellets produced at this plant are burned in cooking stoves. A clean smokeless burn was observed. During the burning process it was important to note that the charcoal pellets did not crumble; they staved in individual pieces and held their shape, thus indicating that the pellets had excellent physical strength. Based on these observations, it can be safely predicted that the charcoal pellets produced at this plant will be a good fuel for the small gasifier/engine system development project at IIT, New Delhi.

During the site visit the team was consulted on several minor operation problems at the plant. The U.S. specialists offered some potential solutions to these problems. Based on our on-site observation of the plant operation, the following remarks can be made:

- The "paru-fuel" technology has successfully demonstrated the production of charcoal pellets from commonly found agricultural residues in India.

- The successful demonstration of the technology had led to several existing commercial applications.

- The plant maintained a clean operating environment and produced a consistent quality product.

- Alternative tar collection and utilization techniques will further enhance the economics and environmental acceptability of the process.

- Charcoal produced from the plant, depending on the raw material used, will be a desirable fuel for small 5- to 10-hp gasifier-engine systems.

- The availability of consistent quality charcoal feed from this centralized facility will help in the implementation and successful operation of small gasifier-engine systems in India and other developing countries.

- The proposed gasifier development projects at IIT, New Delhi should use charcoal produced in a "paru-fuel" plant to carry out their developmental and field testing work.

3. Site Visit to the Mechanical Engineering Department, IIT, New Delhi

On November 17, the U.S. team visited Dr. H.D. Mathur, Professor, Mechanical Engineering, IIT, New Delhi. Dr. Mathur, is the Principal Investigator for the Producer Gas-Powered Small Horsepower Utility Engines project. Dr. Mathur has been actively involved in the development and standardization of design modifications for existing spark-ignition and compression-ignition engines, so that non-conventional fuels such as ethanol, hydrogen, biogas, and producer-gas can be successfully burned in these engines. He has participated in several projects sponsored by Indian industries to provide design criteria and exhaust emission analysis for internal combustion engines burning non-conventional fuels. He also routinely tests engines for their performance on these fuels.

The U.S. team was taken to Dr. Mathur's engine test facility. The engine test facility is neat and well maintained, occupying space in two separate buildings. The proposed project will be carried out in the Unconventional Fuels Section of the test facility. The engine test facility is adequately equipped with test equipment and associated instrumentation.

At present, the test facility has two engine test rigs of approximately 110- and 300-hp rated capacity. Four test rigs of smaller rated capacity, about 11-hp, are also available for conducting tests on non-conventional fuels. In addition, a small charcoal-based gasifier-engine system is being used to test S.I. engine performance on producer gas. This charcoal-based, gasifier-engine system was put into operation for us and ran without any operating problems. Properly sized charcoal was being used as a fuel for this unit.

Adequate space, support equipment and qualified technicians are available to successfully carry out the proposed work. However, certain special instruments and analytical equipment will be procured from the U.S. for this project.

A list of equipment to be procured from the U.S. was originally prepared by Dr. Mathur. The U.S. biomass specialists discussed this list with Dr. Mathur to prioritize the requested items so that essential equipment could be procured and delivered soon. The prioritized list of equipment for Dr. Mathur's project is presented in the Biomass Project Plans.

The team also discussed the selection of a site for installing the first field demonstration unit. Dr. Mathur indicated that Masoodpure would be an ideal site for the first field demonstration unit. Masoodpure, we were told, is not only in close proximity to IIT but also has prior experience in hosting several renewable energy projects. Dr. Mathur has also indicated that his modified engine will be ready for integrated gasifier engine testing within six months from the start of the project.

At the conclusion of the meeting the team met Dr. K.L. Chopra, head of the Centre of Energy Studies, IIT, over lunch.

4. Site Visit to the Chemical Engineering Department, IIT, New Delhi

In the afternoon of November 17, the team visited the Chemical Engineering Department of IIT, New Delhi. The team was taken to the various laboratories and test facilities within the department by Dr. Raveja, Assistant Professor.

Dr. Raveja indicated that new laboratory space had been allocated to carry out the proposed project. The allocated laboratory space was visited and found to be adequate with respect to setting up the proposed small gasifier test facility with its associated analytical equipment and instruments. Specifically, sufficient space is available directly adjacent to the laboratory building so that the gasifier can be set up outdoors to operate under proper environmental conditions, while the associated instrumentation and microprocessors can be kept inside the building under controlled environment to obtain reliable data.

The existing machine shop in the Chemical Engineering Department seems to be adequate for carrying out most of the equipment fabrication needs under the proposed project. However, the team was told that a larger, well-equipped machine shop exists on the IIT campus which, depending on the need, will also be available for the proposed project.

Dr. Grover is the Principal Investigator of the project (Development of a village level gasifier based on charred agricultural residues). Dr. Grover has extensive experience in the gasification and pyrolysis of biomass, particularly agricultural residue. He has developed Paru-Fuel, an agricultural residue-based char

pellet production technology, which has been successfully commercialized in India. There are at least three plants currently producing charcoal briquettes or pellets in India, based on Dr. Grover's Paru-fuel technology. A visit to one of these existing plants was described earlier in this report.

Dr. Grover is presently experimenting with several drum type pyrolysis units to produce charcoal from agricultural waste. He has also developed a simple cooking stove which primarily uses charcoal as the fuel. The charcoal fuel, however, is supplemented with the pyrolysis gases produced from rice husks. This simple cooking stove looked very impressive.

After seeing the successful operation of a paru-fuel plant in Madras the U.S. biomass specialists were convinced that the charcoal produced from one of the existing paru-fuel plants should be used for the gasifier development work at IIT. This point was discussed with Dr. Grover and it was mutually agreed that he would procure a sufficient quantity of charcoal pellets from one of the existing paru-fuel plants to sustain the laboratory and field testing activities proposed under the two projects at IIT. Instead of spending a significant amount of time during Phase 1 on developing a simple drum-type charcoal production device, Dr. Grover will immediately initiate the proposed gasifier design, fabrication, and laboratory test tasks. Thus the gasifier, gas cleanup, and modified engine systems will be simultaneously ready for integrated testing within the first six months of Phase 1.

The team also discussed the list of equipment which is to be procured from the United States for this project. Based on the discussions, the original equipment list was prioritized and is presented in the Biomass Project Plans.

VI. CONCLUDING MEETINGS WITH DNES, NEW DELHI

On Friday, November 18, Daniel Bienstock and Abu Talib met with Mr. S.R. Faruqi, Joint Secretary, Department of Non-Conventional Energy Sources (DNES), Government of India. Dr. O.P. Vimal and Mr. Meena of DNES were also present during the meeting. Mr. Faruqi talked briefly about the major non-conventional energy resource development projects within his department. He indicated that the three proposed biomass conversion projects under the U.S./India energy collaboration program are very important to the DNES energy program and will receive maximum attention. The Secretary was very supportive of these three projects and assured us that the requested Indian funds will be shortly released to the individual Principal Investigators.

The U.S. members were told that these three biomass projects have already been approved by the administrative branch of DNES. However, the fiscal branch of DNES would like to see a formal peer review done on these proposals before releasing the requested funds. Mr. Faruqi suggested that, in lieu of a formal peer review, an independent review of these proposals by the U.S. biomass specialists may satisfy the fiscal branch. In this way, the lead time for the formal peer review process could be reduced

considerably and will enable the fiscal branch to release the requested funds before March 31, 1984, which is the end of the fiscal year in India. Mr. Talib, U.S. biomass specialist, agreed with Secretary's suggestion and promised to mail him a formal copy of the proposal review report as soon as possible.

Mr. Faruqi mentioned that DNES received a proposal from the Gujarat Energy Development Administration (GEDA) to support a 190-kW biomass gasifier-engine system to be installed at a selected dairy farm in the State of Gujarat. This proposed project will use the Pyrenco (a U.S. gasifier vendor) biomass gasifier and gas-cleanup system. The primary feedstock for this proposed facility will be pelletized cotton stalks and gin trash. The Joint Secretary mentioned that DNES is seriously considering funding the proposed project. He also indicated that a formal request will be made to the USAID mission in New Delhi to include the proposed project under the ongoing U.S./India alternative energy collaboration program.

After the meeting with Mr. Faruqi, Mr. Bienstock and Mr. Talib went to see Mr. Ram Berry, USAID Office of project Development at the U.S. Embassy. Mr. Berry was pleased to learn that both the workshop and the site visits went well. He discussed certain administrative matters with Mr. Bienstock. During the meeting Ms. Diana L. Swain, Assistant Project Development Officer, was introduced. She is expected to be involved in the ongoing U.S./India energy collaboration project.

VII. OBSERVATIONS AND RECOMMENDATIONS

Some general observations and recommendations resulting from the technical discussions held during the workshop and site visits with Indian specialists are:

A. Coal Conversion

It is believed that this USAID program is an attractive vehicle for the transfer of coal conversion technology to India. The greatest return may occur in the area of coal cleaning, where India has little advanced technology for the removal of high amounts of ash from their coal. The gasification, fluidized-bed combustion, and coal-water mixture portions of the USAID program will provide the Indian organizations with advanced instrumentation to enable them to take more accurate data and will expose the operating laboratories to the advanced technology in the U.S. This will assist them to further develop these technologies and their manufacturing capabilities within the country. The technical caliber and enthusiasm of the professional staff in the coal conversion projects are high.

B. Biomass Conversion

1. Observations

- Active support and commitment was expressed by the Department of Non-Conventional Energy Sources.

- Excellent professional capability is available to carry out selected projects.

- The primary candidates for initial implementation of a biomass gasifier-based energy program are the small diesel engine pump sets. A wider implementation will require establishment of a commercial fuel supply system.

- For charcoal-based gasifier-engine systems, the Paru-fuel technology can provide an excellent source of commercial fuel supply, whereas wood-based systems may require to be linked to the existing reforestation projects.

- Widespread implementation will be enhanced by a Government program supporting the financial requirements of the new and retrofit equipment.

2. Recommendations

- The Indian financial commitment must be made available to the principal investigators as soon as possible.

- High priority equipment items (i.e., test gasifiers) from the U.S. should be provided as soon as possible to the principal investigators.

- The field demonstration component must be given the highest priority to achieve project objectives.

- The focus should be the retrofitting of existing diesel engine pumps systems for dual fueling with producer gas.

- Future work should be directed at large gasifier engine systems for

  (a) Rural electrification
  (b) Powering agro-industries
  (c) Large dairy farms
  (d) Co-generation

- The long-term goal is the development of producer gas systems fueled with raw agricultural waste.

- The long-term goal is for complete substitution of petroleum fuels by developing spark ignition engines fueled by producer gas.

APPENDIX A

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