Report on the

WORKSHOP ON COMMERCIALIZATION OF BLACK LIQUOR AND BIOMASS GASIFICATION FOR GAS TURBINE APPLICATIONS IN THE PULP AND PAPER INDUSTRY

hosted by
The Center for Energy and Environmental Studies
School of Engineering and Applied Science
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1. EXECUTIVE SUMMARY

A unique opportunity now exists for commercializing black liquor gasifier/ combined cycle (BLGCC) and biomass-gasifier/combined cycle (BGCC) technologies for pulp and paper industry applications in the United States. Four factors have helped create this opportunity:

- The competitive position of the U.S. industry is threatened by a diverse set of pressures, including high and perennially-growing capital investment requirements, continuing demand for improved environmental performance, and uncertainty about future purchased-energy prices due to utility deregulation and possible greenhouse gas emissions mitigation measures. Some of these pressures would be relieved or even converted into economic opportunities through the implementation of BLGCC and BGCC technologies.

- Together with large investments that have been made in the development of coal integrated gasification/combined cycle technology, sufficient research, development, and demonstration has been done relating specifically to BLGCC and BGCC that these technologies can likely be brought to commercial readiness relatively rapidly.

Key ideas from the workshop...

Technology suppliers have not seen convincing evidence of market opportunity or industry commitment to the development of gasification systems. It will be important that different paper companies work together to facilitate commercialization despite the challenge in doing so. Early opportunities to help catalyze commercialization will most likely arise where there are unique and compelling needs for technology change. For paper companies, the task of comparing a mature (existing) technology with an emerging (gasification) technology is difficult. The tendency is to value the near-term more heavily, while having to live with the consequences of a choice for the 30- or 40-year life of the technology.

- Denny Hunter
Weyerhaeuser Company
(from page 12)

- Agenda 2020, the forest and paper industry's technology visioning process catalyzed and supported by the the U.S. Department of Energy, provides an opportunity for enabling industry cooperation in commercializing BGCC and BLGCC technology.

- Existing powerhouse equipment at a large number of U.S. pulp and paper mills are approaching the age (30-40 years) at which they will need to be replaced or have major rebuild work. The next 5 to 15 years represent a rare window of opportunity for introducing BLGCC and BGCC technology within the natural capital equipment turnover cycle of the industry. The total replacement market alone for BLGCC capacity through 2030 is some 8 GW_e. The market for BGCC capacity could be up to 30 GW_e.

This unique set of circumstances provided the motivation behind the Workshop on Commercialization of Black Liquor and Biomass Gasification for Gas Turbine Applications in the Pulp and Paper Industry. Specific objectives were to illuminate opportunities for gasification-based cogeneration in the pulp and paper industry, to review the status of black liquor and biomass integrated-gasifier/gas turbine technologies and remaining uncertainties to be

addressed before commercial application, and to identify steps to insure timely commercialization of the technologies. The workshop was hosted by Princeton University's Center for Energy and Environmental Studies as part of its research program on advanced technologies for biomass energy utilization in the pulp and paper industry. Paper companies, gasifier and gas turbine suppliers, engineering firms serving the paper industry, universities, national labs, and the Department of Energy were represented among the 50 participants.

The first day of the workshop was devoted to illuminating some of the opportunities for gasification-based cogeneration in the industry and to understanding technical hurdles to be overcome to reach commercial readiness. Leading gasifier vendors offered perspectives on what steps would help advance gasification technologies toward timely commercialization.

Morning presentations highlighted what will be the most apparent feature of gasification-based powerhouses compared to today's pulp mill powerhouses: much higher electricity production. Analyses at Princeton and elsewhere have shown that power production at a pulp mill could be doubled or tripled with BLGCC technology. A detailed study by Weyehaeuser of one of its facilities found that combined BLGCC/BGCC technology would permit some 100 MW_e of electricity to be generated in excess of mill demands. In a similar BGCC-only study, Weyerhaeuser found that an electricity sale price in excess of 3.5 ¢/kWh would be sufficient for a positive project net present value.

During the day, workshop participants heard from companies actively pursuing commercialization of the BLGCC concept. Two of these, ABB and MTCI, have low-temperature gasifier designs. Kvaerner-Chemrec and Noell have high-temperature gasifier designs. Babcock & Wilcox, Texaco, and others are evaluating entering the black liquor gasifier market. Black liquor gasifier suppliers at the workshop indicated that while there do not appear to be any insurmountable technical hurdles, convincing evidence of market opportunity and industry commitment are essential to the commercialization of BLGCC systems. They suggested that it will be important for the industry to work collectively to facilitate timely commercialization.

Workshop participants also heard from biomass gasifier companies. Biomass gasification may be closer to commercial readiness for gas turbine applications than black liquor gasification. A number of air-blown, atmospheric-pressure gasifiers (20-40 MW_{th}) are commercially operating to provide fuel to pulp mill lime kilns. Several pressurized and other gasifier/gas cleanup demonstration projects are ongoing. One fully-integrated BGCC cogeneration system (8 MW_e equivalent) has been undergoing testing since 1993 and is scheduled for commercial operation beginning in 1997. Several additional BGCC demonstrations are well underway, including a 30-MW_e facility in Brazil, construction of which is scheduled to begin at the end of 1997. Today, low-

pressure biomass gasifiers are being readied for gas turbine applications by TPS, Lurgi, and FERCO. Pressurized designs are available from Foster-Wheeler, Carbona, and HTW/Lurgi.

A common theme in presentations from biomass gasifier companies was that the next few BGCC plants (regardless of gasifier design) will have relatively high capital costs--in the $1500-$2500/kW range. Because of these high costs, some mechanism of syndicating the financial risk will likely need to be found for the first few plants. Pulp and paper mills with low or negative feedstock costs, high costs for competing fossil fuels, and/or access to low-cost capital (through creative financing arrangements) should be attractive sites for these first facilities. Together with some additional technology development work in key areas (e.g., biomass drying and feeding), these few demonstration plants will allow capital costs for BGCC technology to be reduced--perhaps as much as 40% by the 5th unit. Systems based on pressurized gasification will likely be preferred in the 60 to 80 MW_e size range, while atmospheric-pressure systems will likely be preferred at 30 MW_e or smaller.

The second day of the workshop consisted of a round-table discussion to identify steps the paper industry might take to accelerate commercialization. By the end of the discussion, there was general agreement among the participants that commercializing both black liquor and biomass gasifier/gas turbine technology was, indeed, desireable. It was noted that gas turbines account for the majority of new generating capacity being installed worldwide, and that they will continue to do so for the foreseeable future as a result of ongoing advances in the technology. Leading the development of biomass and black liquor gasification for gas turbine applications will provide the opportunity for the industry to use this historic shift in power generation technology to advantage in dealing with competitive pressures it faces.

There was also general agreement among the workshop participants that no single paper company would be able to take on the task of commercializing gasification technology on its own and that a consortium of companies in partnership with the government was an approach that should be pursued. There was concensus that commercialization should be pursued in a manner that promotes healthy competition between technology suppliers, while allowing data and demonstration experience to be documented to permit more informed choices about gasification technology on the part of paper companies and to demonstrate clearly the market demand to technology suppliers.

It was suggested that early opportunities to help catalyze commercialization will most likely arise where there are unique and compelling needs for technology change. It was also noted that comparing mature (existing) technology with emerging (gasification) technology is difficult for industry business and facility managers. The tendency is to value the near-term more

heavily, even though a company must live with the consequences of a choice for the 30- or 40-year life of the asset.

It was agreed that additional work is needed at this stage to quantify the full range of potential benefits of gasification technology. An approach that allows individual companies to insert their own beliefs (regarding future energy prices, the value of process-related benefits of gasification, etc.) would be desireable. Because capital costs for BGCC and BLGCC systems are high at present, it was agreed that there would be benefits to defining and pursuing major pre-competitive leverage points for reducing capital costs. With respect to this effort, the problem should be divided between cost reductions for near-term commercial demonstrations and much more major reductions (50-60% from present levels) that might result from significant technical breakthroughs in the longer term. Facilities such as those at Värnamo (Sweden) and Burlington (Vermont) might be made available for such research and demonstration efforts.

A final recommendation was made that serious consideration be given to forming a consortium of pulp and paper producers to work with the government to fund the demonstration program needed to commercialize BGCC and BLGCC technology. As a first step toward a consortium, the suggestion was made that a task force within Agenda 2020 be created and charged with better defining the benefits of BGCC and BLGCC technology to allow more informed choices by paper companies relating to participation in the consortium (and to GCC technologies more generally) and to provide a better understanding of the potential GCC market to equipment suppliers.

2. WORKSHOP AGENDA

DAY 1 -- TECHNOLOGY ISSUES

8:45 **Welcome** -- James Wei, Dean, Princeton School of Engineering/Applied Science
Objectives and agenda for the workshop -- Eric Larson
Antitrust Statement -- David Cooper

9:00 **Context**
A window of opportunity for gasification in the pulp and paper industry -- Del Raymond
A DOE perspective -- Tom Foust

10:00 **Technology overviews**
Biomass and black liquor gasification/gas turbine systems -- Eric Larson
Gas turbine issues -- Stefano Consonni

10:50 **Break**

11:15 **Breakout sessions: Technology developer perspectives on steps needed to commercialize gasifier/gas turbine systems.**

1. *Black-liquor Systems*
   - **Chair: Denny Hunter, Weyerhaeuser**
   ABB -- Andy Jones
   Babcock & Wilcox -- Chris Verrill
   Noell -- Vic White
   Stonechem/MTCI -- Momtaz Mansour
   Kvaerner/Chemrec -- Stefan Jonssön

2. *Biomass Systems*
   - **Chair: George McDonald, Union Camp**
   Carbona -- Jim Patel
   Foster-Wheeler -- Folke Engström
   TPS -- Michael Morris
   Zurn-NEPCO -- John Rohrer

12:30 **LUNCH**
1:30 **Continue breakout sessions**
3:45 **Break**
4:05 **Presentation and discussion of CEES research program**
5:45 **Reception**

DAY 2: IDENTIFYING STEPS TO FACILITATE TIMELY COMMERCIALIZATION OF BIOMASS AND BLACK LIQUOR GASIFIER/GAS TURBINE SYSTEMS

7:30 **Continental breakfast**
8:00

Presentations to motivate discussion on identifying next steps for achieving timely commercial implementation of biomass and black liquor gasifier/gas turbine systems

1. Summary of Day-1 Breakout Sessions
   -- Denny Hunter (black liquor)
   -- George McDonald (biomass)
2. The Critical Importance of Timing in Commercialization
   -- Del Raymond
3. Framework for the discussion
   -- David Cooper

9:15 **Discussion**
10:45 **Break**
11:00 **Discussion (continued)**
12:00 **Summarize next steps, close workshop**
12:30 **Lunch**

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4. PERSPECTIVES OF THE ORGANIZERS

4.1. Background

A unique opportunity now exists for commercializing black liquor gasifier/combined cycle (BLGCC) and biomass-gasifier/combined cycle (BGCC) technologies for pulp and paper industry applications in the United States. Four factors are contributing to creating this opportunity.

First, the competitive position of the North American pulp and paper industry is increasingly threatened by a diverse set of pressures, some of which would be relieved (or even converted into economic opportunities) by the successful introduction of BLGCC and BGCC technologies. Pressures facing the U.S. industry include:

- Capital expenditures as a percentage of sales that historically have been double those for manufacturing as a whole and increasing at a faster rate (Fig. 1).
- The need to continue to be successful in environmental improvements, implying continuing significant capital expenditures: over $72 million was spent by the U.S. industry in 1995 alone on research and development relating to environmental improvement.
- Increasing dependence on purchased electricity, despite being nearly 60% self-sufficient in energy today; power-to-steam requirements are drifting up at most plants.
- Uncertainty regarding the longer-term impact on power prices of the deregulation of electricity generation.
- Uncertainty regarding the impact on electricity and other energy prices of government initiatives that might be taken to meet international commitments to reduce greenhouse gas emissions. Assuming energy price increases postulated in a recent Department of Energy study assessing the impact on the forest products industry of greenhouse gas mitigation measures [1], energy costs at some mills could double.
- Detrimental impacts of losing technological leadership: most technology innovations in the paper industry over the past 30 years have been introduced off-shore.

Second, together with the large investments that have been made in the development of coal integrated gasification/combined cycle technology, sufficient research, development, and demonstration appears to have been done relating to BLGCC and BGCC technology that commercialization might be accomplished relatively quickly. A remaining hurdle to full commercialization is the high cost of the initial few units, a generic problem faced by new powerplant technologies (Fig. 2)

Third, Agenda 2020, the forest and paper industry's technology visioning process catalyzed and supported by the U.S. Department of Energy, provides a mechanism for the industry to work together toward commercialization of new technologies. Agenda 2020 defines

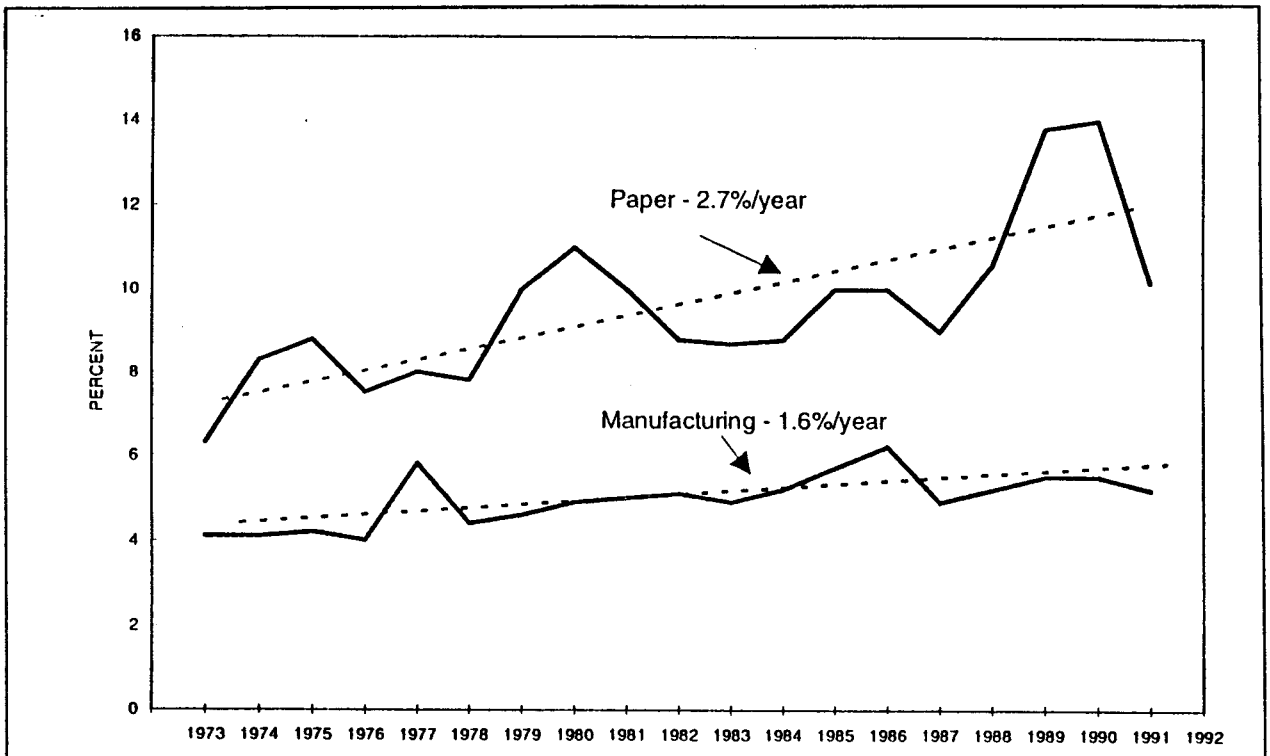

Fig. 1: Capital expenditures as percent of sales. Source: Dept. of Commerce, API. (See Annex 1.)

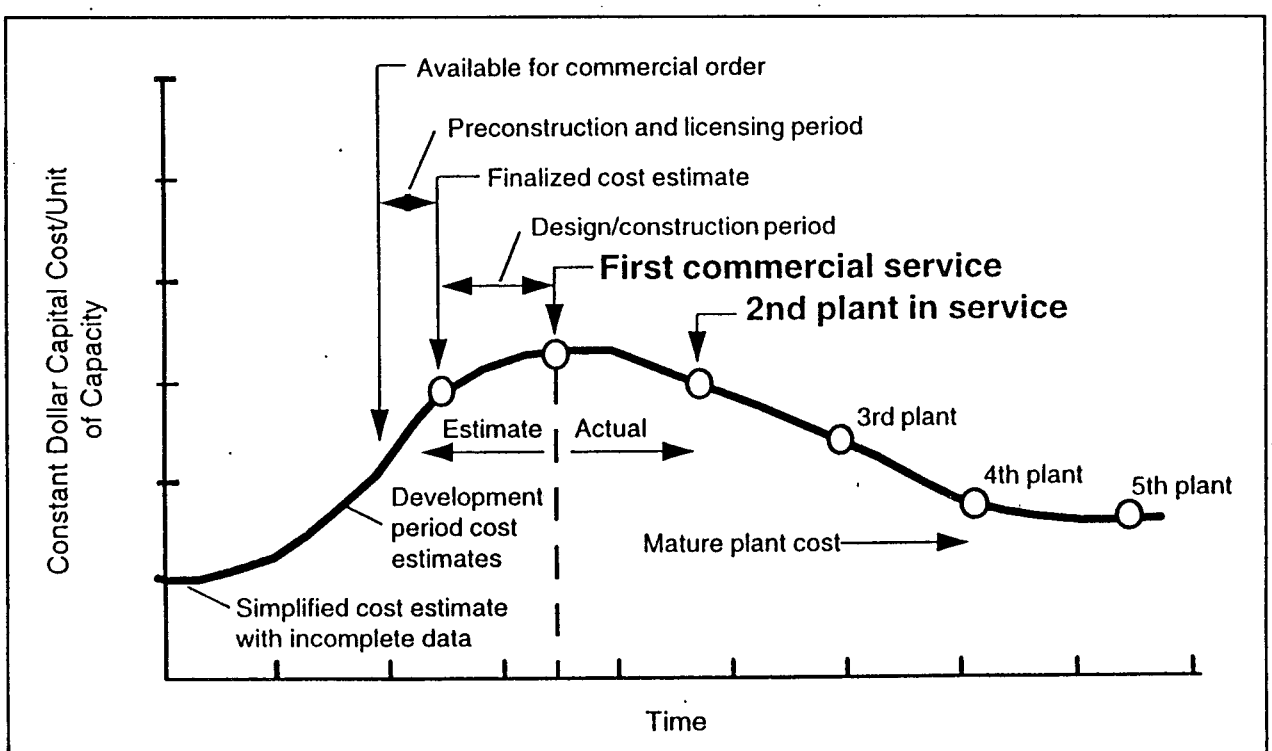

Fig. 2: Generic capital cost trend for early commercial units of a new powerplant technology, based on Technical Assessment Guide of the Electric Power Research Institute [2].

and communicates the technology-related gaps that need to be addressed to achieve a desired industry state in the year 2020 [3]. Precompetitive research, development, and demonstration activities are funded under Agenda 2020 jointly by the industry and the Department of Energy. The development of BGCC and BLGCC systems fall under the purvue of three of the six Agenda 2020 focus areas: sustainable forest management, environmental performance, energy performance, improved capital effectiveness, recycling, and sensors and controls.

Fourth, existing powerhouse systems at the majority of U.S. pulp and paper mills are approaching the age (30-40 years) at which they will need to be replaced or have major rebuild work (Fig. 3). Thus, the next 5-15 years represents a once-in-thirty or once-in-forty year opportunity for introducing BLGCC and BGCC technology within the natural capital equipment turnover cycle of the industry. For equipment suppliers, the potential market is substantial: if GCC systems were to replace existing systems at end-of-life retirements starting in 2005, the total replacement market alone for BLGCC capacity through 2030 would be some 8 GW_e (Fig. 4). The market for BGCC capacity could be some 2 GW_e (assuming use of existing mill residues only) or as large as 30 GW_e (assuming additional forest and other-mill residues were brought to BGCC sites).

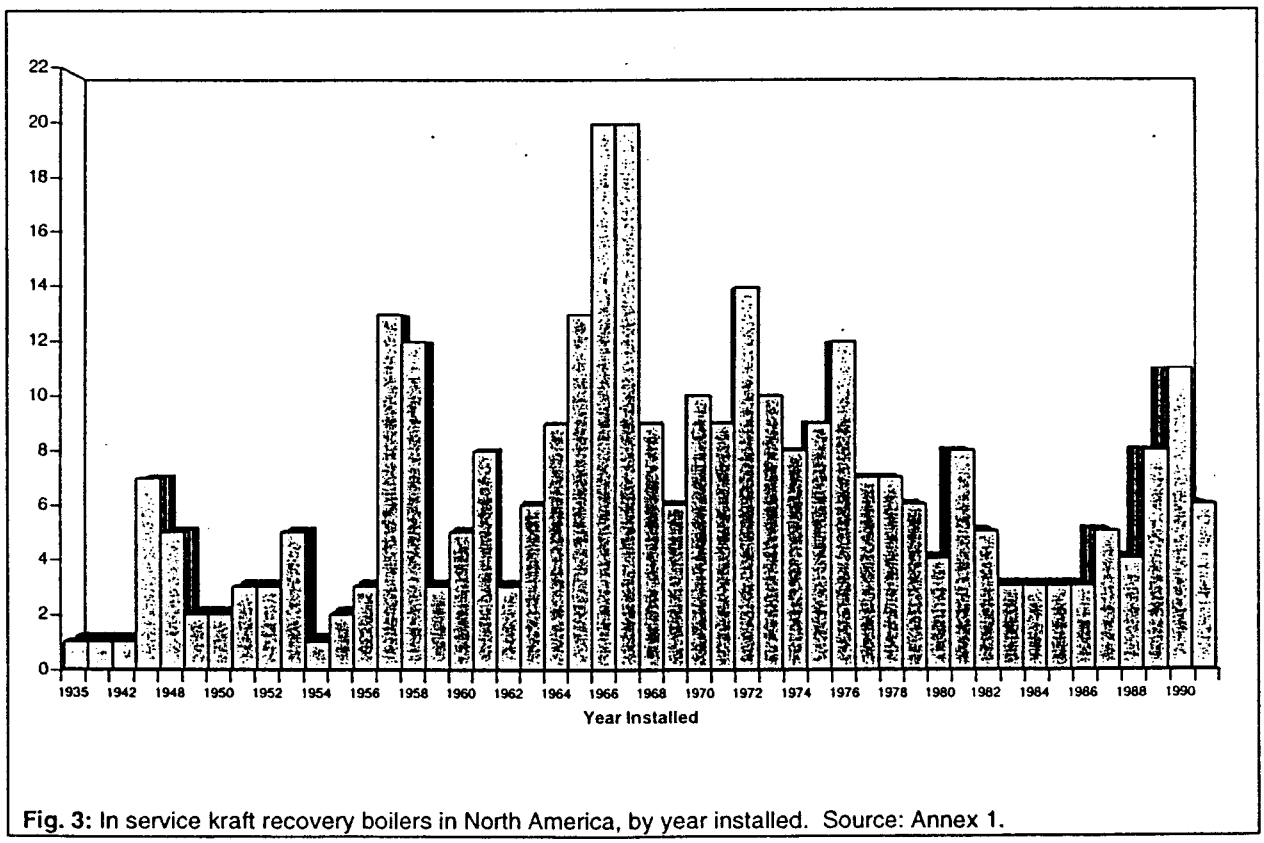

Fig. 3: In service kraft recovery boilers in North America, by year installed. Source: Annex 1.

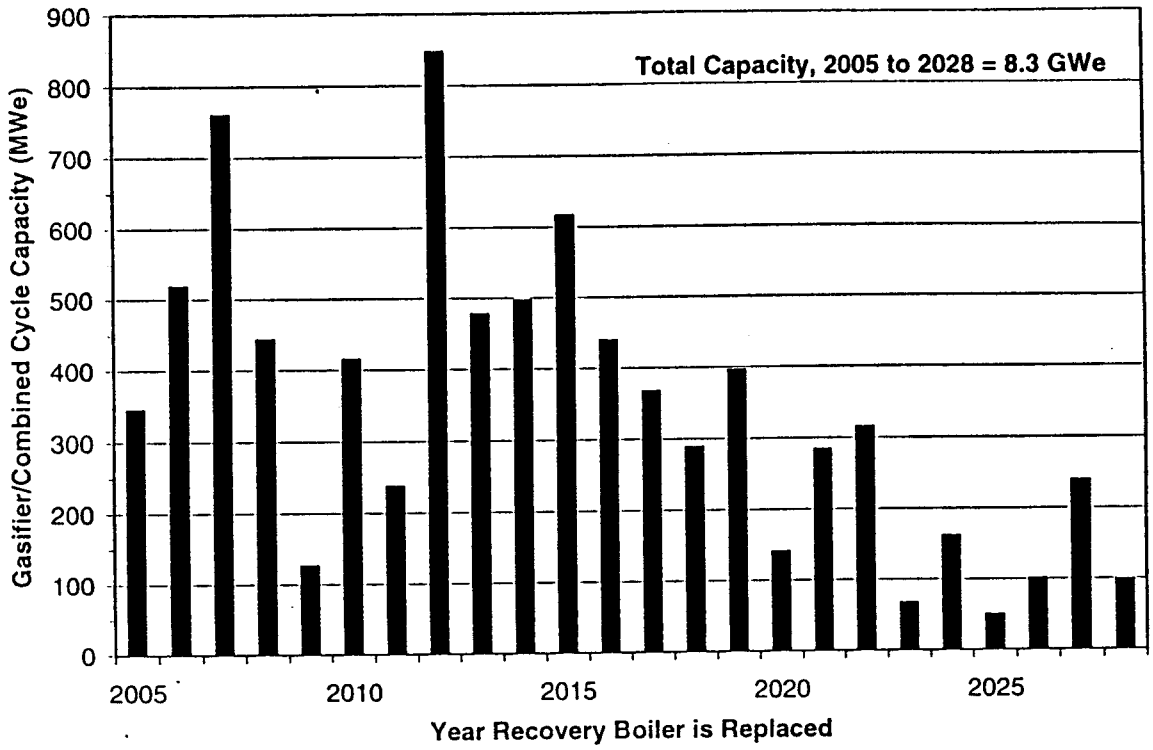

Fig. 4: Potential market for black liquor gasifier/combined cycles in North American pulp and paper mills, based on annual recovery boiler capacities installed starting in 1965 and assuming replacement of this capacity after 40-year unit lifetimes with BLGCC cogeneration (25% electric efficiency).

4.2. Why BGCC and BLGCC Technologies?

The commercial implementation of BGCC and BLGCC technologies has the potential for relieving some of the pressures facing pulp and paper producers or for converting them into economic opportunities: the U.S. industry would reclaim technological leadership in the powerhouse area; powerhouse environmental performance could be enhanced at prospectively lower levels of capital investment than with current state-of-the-art technology; reliance on purchased electricity could be reduced; greenhouse gas issues could be positively impacted; and there may be a variety of process-related improvements that accompany gasification.

The most readily apparent feature of gasification-based powerhouses compared to existing powerhouses will be the much higher levels of electricity production resulting from the high efficiencies of gas turbine cycles compared to steam turbines (Fig. 5). Analyses at Princeton [4] and elsewhere have shown that power production at a pulp mill could be doubled or tripled with BLGCC technology. A detailed study by Weyehaeuser of one of its facilities found that combined BLGCC plus BGCC technology would permit some 100 MW_e of electricity to be

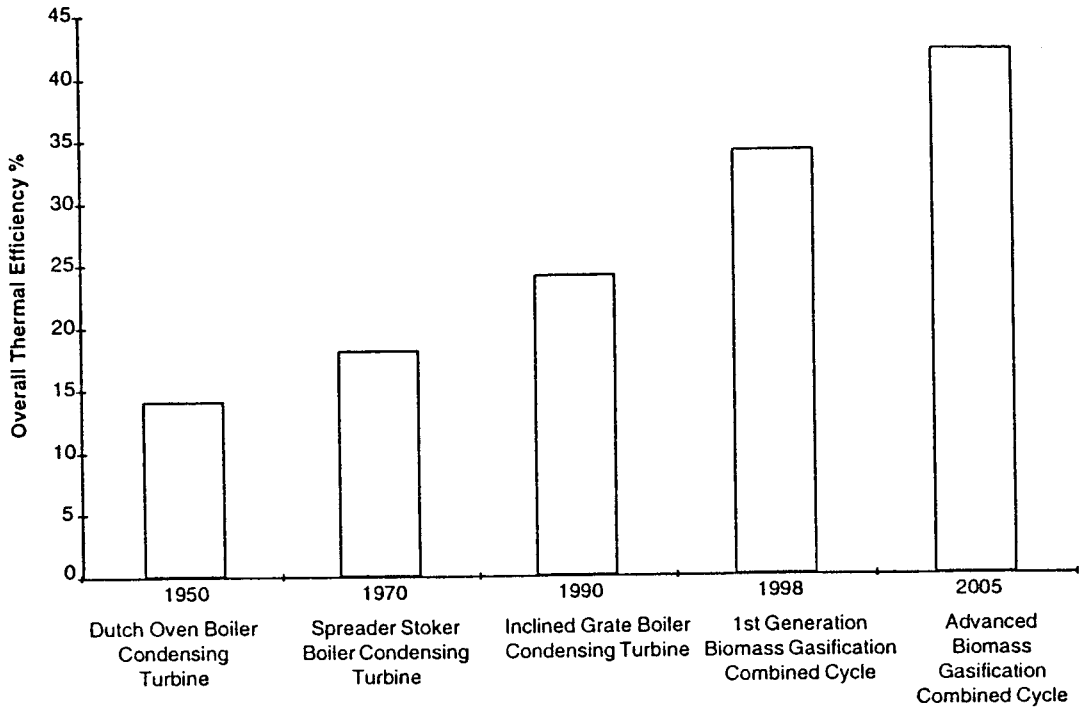

Fig. 5: Power-recovery island of 2010--power generation efficiency comparison [2].

generated in excess of mill demands using biomass fuels available to the mill (Fig. 6). In a similar BGCC-only study [5], an electricity sale price in excess of 3.5 ¢/kWh was found to be sufficient for a positive project net present value (Fig. 7).

Knowing well their present and future costs for biomass and black liquor fuels, such mills may be in favorable positions to negotiate long-term contracts for electricity sales. The guarantee of long-term price stability and the "green-ness" of the power might command premium prices in an electricity market that is deregulated and/or feeling the impact of government-imposed greenhouse gas emissions mitigation measures.

From a longer-term perspective, the development of biomass and black liquor gasification will enable the paper industry to remain at the cutting edge of power generation technology in the decades ahead. Gas turbines already account for the lion's share of new power generating capacity being installed in the world today, and will continue to be dominant for the next several decades as steady advances are made in the technology. Fig. 8 shows the relentless increase in gas turbine firing temperatures and resulting efficiency for one manufacturer's machines. This trend is representative of that for the gas turbine industry as a whole.

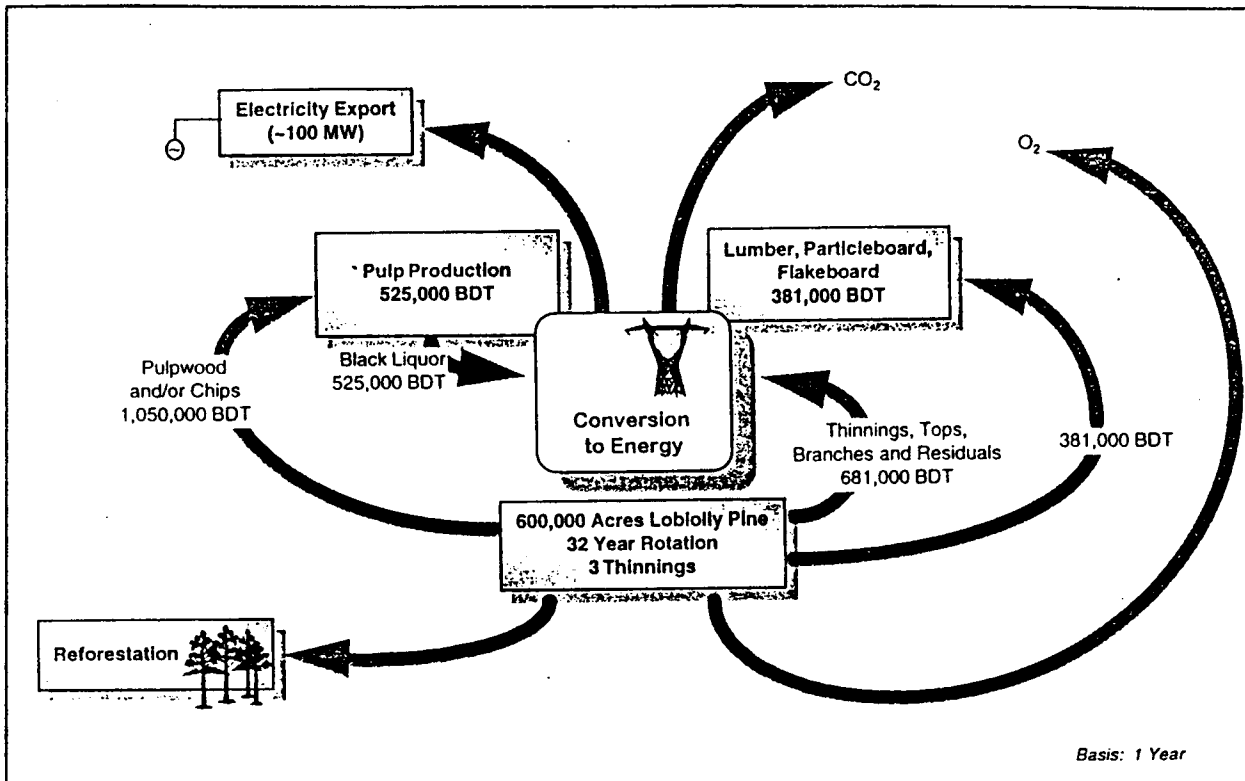

Fig. 6: Schematic representation of electricity export potential with BLGCC/BGCC at one Weyerhaeuser location.

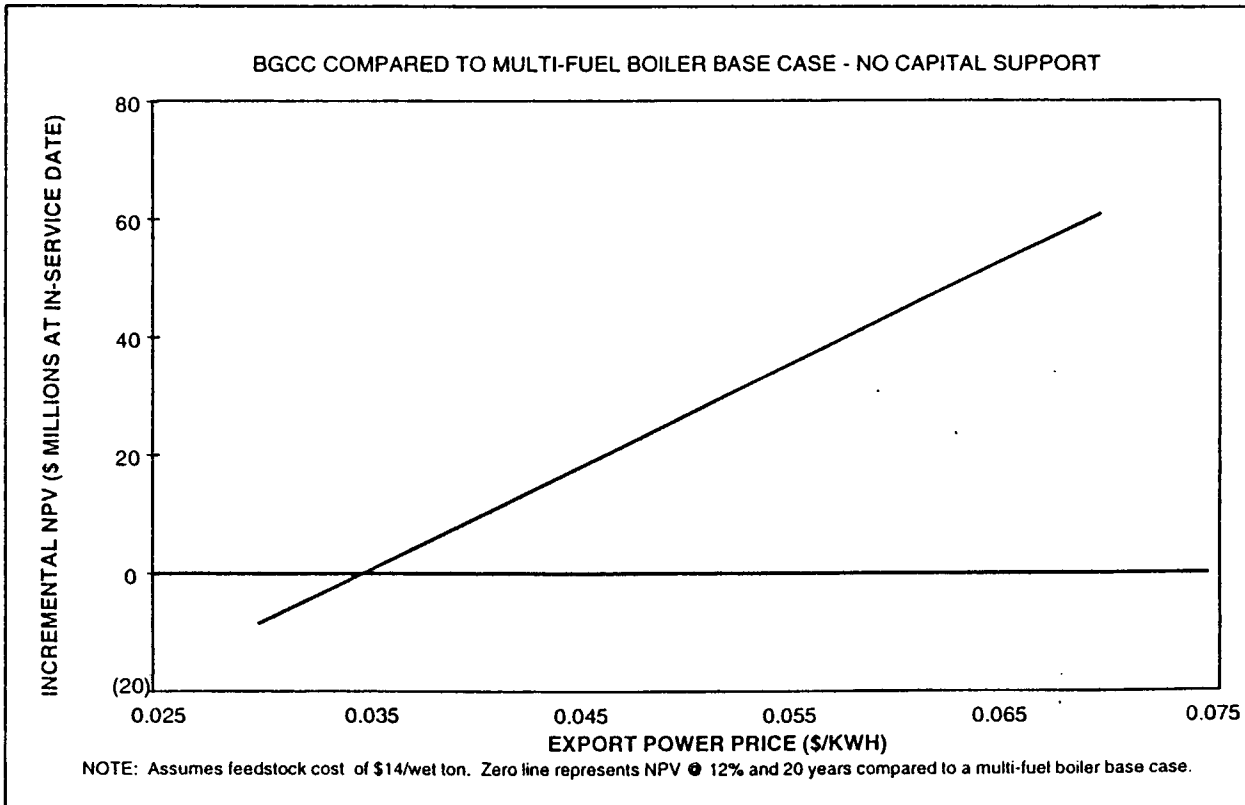

Fig. 7: Net present value of a BGCC project at a Weyerhaeuser mill as a function of export-electricity sale price [5].

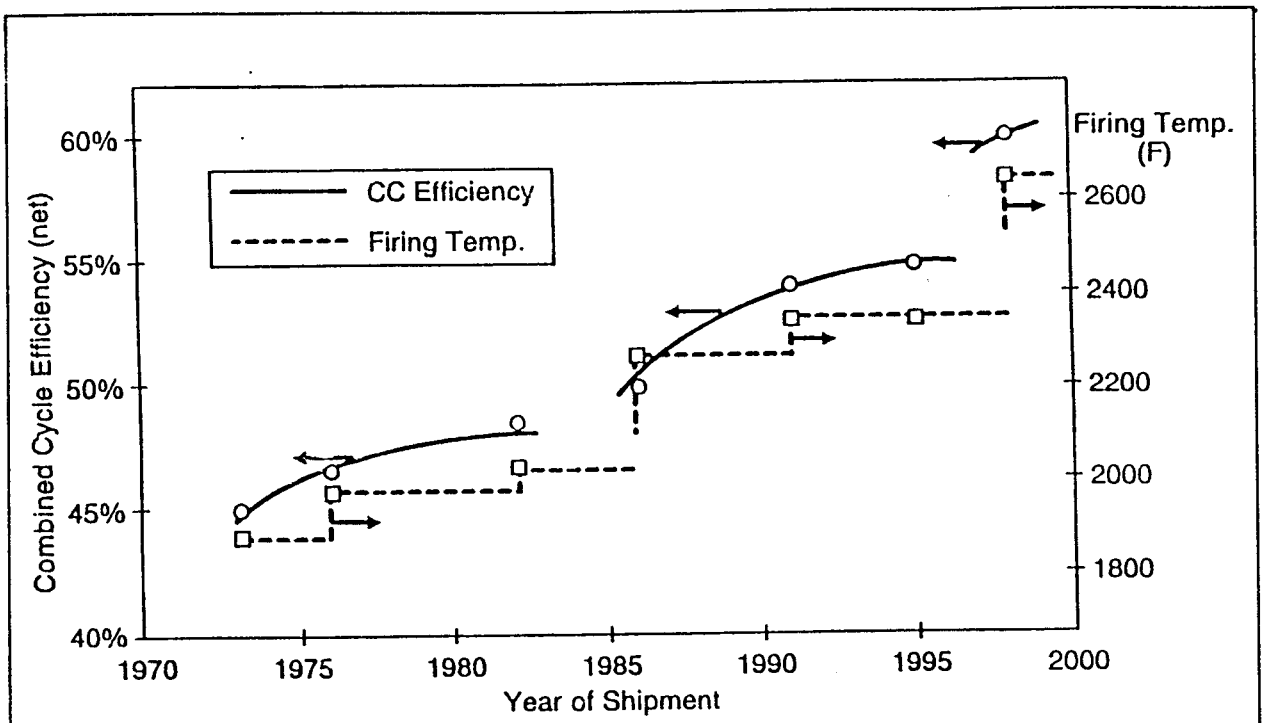

Fig. 8: Natural gas combined cycle efficiencies and firing temperatures for General Electric machines [6].

4.3. What Will Commercialization Cost?

Based on presentations and discussions at the workshop, it appears that completion of several commercial-scale demonstration projects will be needed to bring costs for BGCC and BLGCC technology down to commercially-mature levels. The Shell International Petroleum Company has estimated costs for an initial few BGCC plants that would use air-blown, atmospheric-pressure gasification. (Shell is an equity partner in a project in Brazil that will build a 30 MW_e BGCC system using this technology--the first of its kind [7].) After five units at the 30 MW_e scale, Shell projects the cost to fall to \$1500/kW_e (Fig. 9), a level at which BGCC technology may be competitive in many pulp and paper mills. From Fig. 9, the **total** investment required to reach the fifth-of-a-kind unit is about \$300 million. Of this total, the development cost (that which is in excess of the commercially-competitive level of \$1500/kW_e) is estimated at some \$85 million.

If the cost-learning curve for BLGCC technology is similar to that shown in Fig. 9 for BGCC technology, then the development costs to reach the fifth-of-a-kind 100-MW_e BLGCC--a scale appropriate for modern pulp mills (1300-1500 tons per day pulp production)--would be about \$280 million.

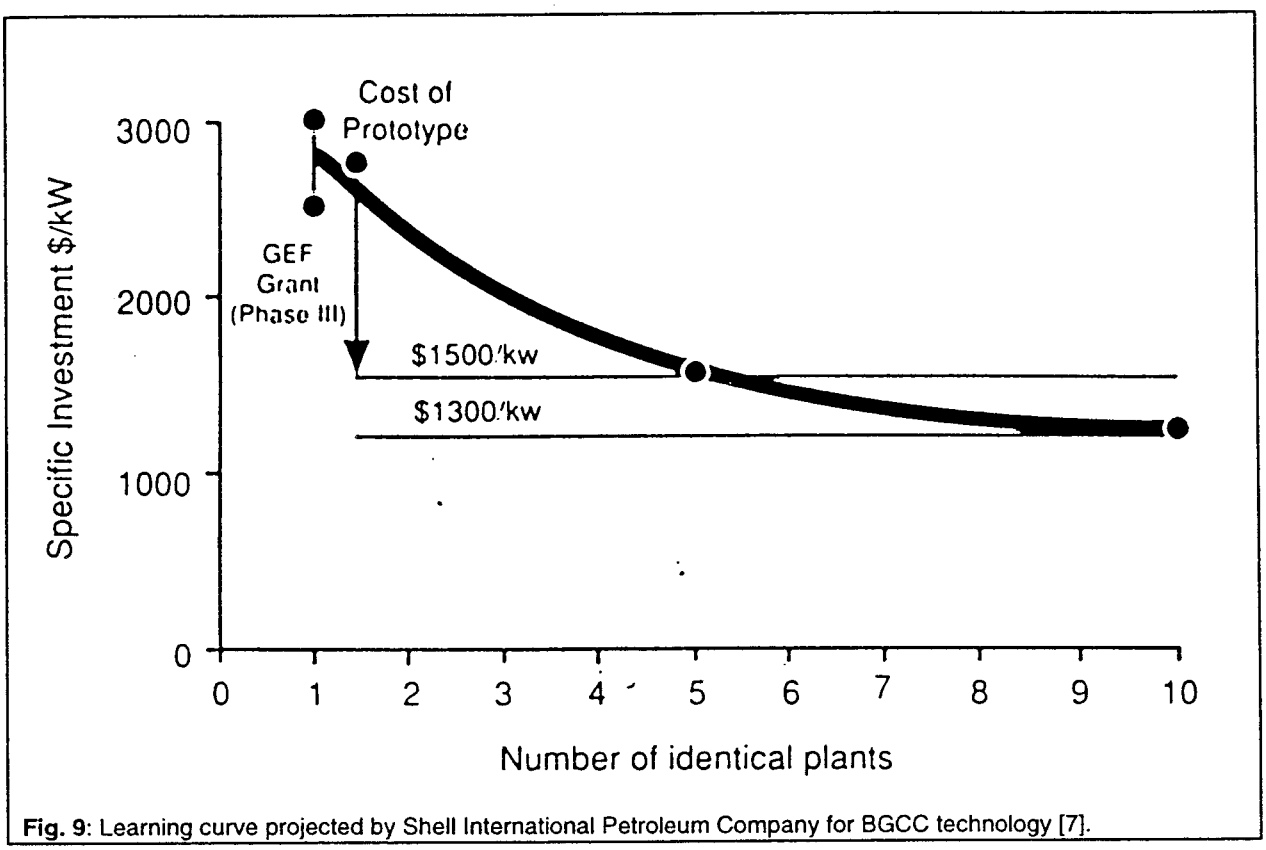

Fig. 9: Learning curve projected by Shell International Petroleum Company for BGCC technology [7].

The cost of commercializing BLGCC and BGCC technologies is modest in large part because commercialization would piggy-back on much larger investments that have been made in the development of coal integrated-gasifier/combined cycle and other technologies with spin-off value for BGCC and BLGCC development.

Government cost-sharing (with the paper industry) of commercialization costs might be appropriate given the potential impact the technologies would have on the industry's global competitiveness and associated positive impacts on national employment, environment, and energy independence. Cost-sharing by technology suppliers and engineering firms would also be appropriate given the potential for profits on future units. The pioneering firms financing the commercialization effort might be rewared by a royalty arrangement with the technology suppliers for future units sold.

4.4. References

1. R.J. Slinn, "The Potential Impacts on the U.S. Paper and Allied Products Industry (SIC26) of Increased Fuel Prices Resulting from Coordinated Global Public Policy Commitments to Mitigate Greenhouse Gas Emissions," draft prepared for Argonne National Laboratory, U.S. Dept. of Energy, July 11, 1996.

2. D.R. Raymond, "Alternative Energy Sources and Technologies for the Pulp and Paper Industry," *Applied Biochemistry and Biotechnology*, Vol. 57/58, 1996, pp. 763-775.

3. American Forest & Paper Association, *Agenda 2020: A Technology Vision and Research Agenda for America's Forest, Wood, and Paper Industry*, AF&PA, Washington, DC, Nov. 1994.

4. S. Consonni, E.D. Larson, and N. Berglin, "Black Liquor-Gasifier/Gas Turbine Cogeneration," prepared for Turbo-Expo '97, The 42nd ASME Gas Turbine and Aeroengine Congress, Exposition, and Users Symposium, Orlando, Florida, 2-5 June, 1997.

5. Weyerhaeuser Co., Stone & Webster, Amoco Oil, and Carolina Power & Light, *New Bern Biomass to Energy Project Phase I Feasibility Study*, published by National Renewable Energy Laboratory (Golden, CO) and Electric Power Research Institute (Palo Alto, CA) 1995.

6. J.C. Corman, "Gas Turbine Power Generation Market Trends and Product Direction," presented at the *Energy Daily's* 3rd Annual Conference on Advanced Combustion Turbines, Washington, DC, May 1996.

7. P. Elliott and R. Booth, *Brazilian Biomass Power Demonstration Project*, Special Project Brief, Shell International Petroleum Company, Shell Centre, London, September 1993.

5. WORKSHOP SUMMARY

The first day of the workshop was devoted to illuminating the potential impact of BGCC and BLGCC systems on the pulp and paper industry, to reviewing the development status of these technologies, and to understanding remaining technological uncertainties to commercialization. One session was also held to review Princeton's research program focussing on the assessment of BLGCC and BGCC technologies. The second day of the workshop consisted primarily of an open discussion aimed at identifying steps that might be taken by the paper industry and others to help insure timely commercialization of gasification/gas turbine systems for paper-industry applications. Overhead transparencies that were presented by speakers during the workshop are included as Annex 1 to this report. An informal record of comments made during the second-day's discussion session are included as Annex 2. The discussion below follows the chronology of the workshop agenda.

5.1. Setting the Context

To set the context for the workshop, initial presentations were made on Day-1 by Del Raymond of Weyerhaeuser and Tom Foust of the Office of Industrial Technologies of the Department of Energy. Raymond offered his perspective on the drivers behind paper industry interest in BGCC and BLGCC technologies (see above "Perspectives of the Organizers") and presented a vision of the gasification-based power-recovery island of the future. He highlighted the challenge posed by commercialization of the technologies, and identified opportunities presented by the Agenda 2020 partnership for accelerating commercialization. Foust reviewed the breadth of research and demonstration activities supported by DOE in biomass energy and related areas. He described the industry-DOE partnerships involved in some key biomass gasifier and black liquor gasifier demonstration projects, and he reiterated the opportunities presented by the Agenda 2020 partnership for catalyzing commercialization efforts.

5.2. Technology Background and Issues

Eric Larson and Stefano Consonni (who collaborates with Princeton University researchers) then presented overviews of biomass and black liquor gasification technologies and issues relating to their application with gas turbines. Larson highlighted the large increase in power generation that could be realized with gasifier/gas turbine systems at pulp mills compared to existing steam-turbine based systems and noted other prospective benefits of BGCC and BLGCC systems, including an improved environmental profile for the powerhouse at lower capital investment. Additionally with BLGCC, powerhouse safety might be improved, there might be

added flexibility in preparing pulping chemicals, and there may be opportunities for reconstituting pulping chemicals directly out of the gasifier (direct causticization) rather than by the capital- and energy-intensive lime-based recovery process used today.

Larson noted important technological challenges to the successful commercialization of BGCC and BLGCC technology, including gas cleanup to meet gas turbine specifications, production of gas with sufficient heat content for gas turbine combustion, high-temperature heat recovery from raw gasifier product gas, and effective thermal integration of the gasifier, power cycle, and mill. Additionally for BLGCC systems, cost-effective, efficient chemical recovery must be proven, and for BGCC systems, handling, drying and feeding of biomass are key challenges.

Stefano Consonni offered some perspectives on combustion, turbomachinery, and materials issues that must be considered in fueling gas turbines with gasified black liquor or biomass. Many of the concerns can be traced to the low energy content of gasifier product gas compared to natural gas or distillate fuels for which gas turbines are typically designed. For example, controlling fuel flow to the combustor, maintaining flame stability, and matching turbine and compressor flows are particularly challenging. Emissions, particularly of fuel-bound NO_x, can also be of concern. The sensitivity of super-alloys and blade coating materials to alkali metals and particulates in the flow stream is a major concern that requires very effective gas cleanup. Consonni finished by noting that while there are challenges to commercially operating gas turbines with gasified biomass and black liquor, there do not appear to be any fundamental technological road blocks. Sufficiently long test periods at full-scale demonstration facilities are needed to confirm this. He noted that the likelihood of success is good, given that most major gas turbine manufacturers already have substantial experience in the use of low-btu gases in commercial applications in the petrochemical and steel industries, and additional experience in coal integrated-gasifier/combined cycle demonstration projects.

5.3. Gasifier Supplier Perspectives

The largest part of Day-1 of the workshop was devoted to hearing from companies pursuing development of BLGCC and BGCC systems. Parallel sessions were held addressing black liquor and biomass. Each speaker in both sessions was asked to address four questions:

- How can doubts about the benefits to the paper industry of BLGCC and BGCC be overcome?
- What are remaining technological uncertainties?
- What are possible critical paths to achieving rapid commercialization?
- What steps can the paper industry take to accelerate the commercialization process?

Black Liquor Gasifier Suppliers

Five companies with varying levels of effort in developing black liquor gasifiers for gas turbine applications offered their perspectives during this session: ABB, Noell, MTCI, Babcock & Wilcox, and Kvaerner/Chemrec. The session was chaired by Denny Hunter (Weyerhauser), who presented a summary of the session to the full workshop on Day-2.

Hunter's summary noted that some of the workshop participants have doubts as to the technical advantages of gasification over existing technology, and that uncertainty about future electric power prices provides an additional reason for caution. To address these concerns, better evidence is needed to demonstrate the benefits of the BLGCC approach. In light of the uncertainty over future electricity prices, it would be especially important to understand other process-related benefits that might drive the adoption of the technology. Demonstration of commercial success would ultimately be the most convincing evidence of the value of BLGCC.

As for remaining technological uncertainties, some speakers indicated that additional work was needed in the corrosion/materials area, in pressurization, and in gas cleaning, but that such issues could be addressed successfully by drawing on existing knowledge bases. The most optimistic speakers indicated that the remaining obstacles are not technological, but rather are in the level of understanding of the customers.

Reaching commercialization requires a progression from bench, to pilot, to demonstration, to first commercial plant. Suppliers need partners in the paper industry to help with the last phase of this path, which in turn requires improved communication (over the present situation) with potential customers. The first commercial facility must be successful to insure the long-term success of the technology.

Suggestions offered by suppliers for how the paper industry might help accelerate commercialization included: help suppliers define and articulate the benefits of black liquor gasification, be forthcoming in discussion of replacement strategies, provide pilot and demonstration host sites, form an industry group to evaluate competing processes under confidential disclosure.

In concluding, Hunter summarized the session as follows. Suppliers have not seen convincing evidence of market opportunity or industry commitment to the development of BLGCC systems. It will be important that different paper companies work together to facilitate commercialization despite the challenge in doing so. Early opportunities to help catalyze commercialization will most likely arise where there are unique and compelling needs for technology change. For paper companies, the task of comparing a mature (existing) technology with an emerging (gasification) technology is difficult. The tendency is to value the near-term

more heavily, while having to live with the consequences of a choice for the 30- or 40-year life of the technology.

Biomass Gasifier Suppliers

Four companies involved in developing BGCC technologies presented their perspectives on the state of the technology and obstacles to commercialization. Carbona and Foster Wheeler are developing pressurized air-blown gasifiers for gas turbine applications. TPS is pursuing atmospheric-pressure air-blown gasification, and Zurn-NEPCO is involved in building the first commercial-scale demonstration of the indirectly-heated Battelle Columbus Laboratory gasifier for which the Future Energy Resources Company (FERCO) holds a license. George McDonald (Union Camp) chaired the session and presented a summary to the full workshop on Day 2.

Biomass gasification is technologically closer to commercial readiness for gas turbine applications than black liquor gasification. A number of air-blown, atmospheric-pressure gasifiers are commercially operating to provide fuel to pulp mill lime kilns. Several pressurized and other gasifier/gas cleanup demonstration projects are ongoing. One fully integrated BGCC cogeneration system (8 MW_e equivalent) has been undergoing testing since 1993 and is scheduled for commercial operation beginning in 1997, and several additional full-BGCC demonstration projects are well underway, including a 30-MW_e facility in Brazil, construction of which is scheduled to begin at the end of 1997.

The next few BGCC plants (regardless of gasifier design) will have relatively high capital costs--in the $1500-$2500/kW range. Because of these high costs, it will be necessary to find a few situations (in the North American pulp and paper industry) where overall economics are favored by low or negative feedstock costs, high costs for competing fossil fuels, availability of lower-cost capital, or other factors. Even these sites may need a way of mitigating financial risk through shared-cost or other mechanisms. Together with additional development work, these few demonstration plants will allow capital costs for BGCC technology to be reduced--perhaps by 40% by the 5^{th} to 10^{th} unit. Systems based on pressurized gasification will likely be preferred in the 60 to 80 MW_e size range, while atmospheric-pressure systems will likely be preferred at 30 MW_e or smaller.

A number of areas were pointed out by the speakers where additional development work would be beneficial, especially to reduce capital costs and improve confidence in future performance of BGCC facilities. One speaker emphasized the need for improved equipment designs rather than better integrated-facility designs to reduce capital costs for the N^{th} plant, as well as modularity and factory-over-field fabrication. In the gasification area, there exist

operating data for only a limited set of fuels; an expansion of this database is needed. Better refractory materials might reduce gasification costs. Improved biomass drying and feeding systems (especially into pressurized reactors) need to be demonstrated under commercial operating conditions. Hot gas cleanup has been demonstrated at pilot scales, but requires further demonstration under commercial operating conditions. Quench/cold-gas cleanup has been demonstrated to be effective and relatively inexpensive in a wide range of other applications, though there is some associated efficiency penalty. Integration of the gasifier/gas cleanup system with the gas turbine requires further demonstration and operating experience. It was noted that there are several demonstration facilities worldwide (e.g., Värnamo, Tampere, Hawaii, Vermont) which might be used to advantage, if an international cooperative effort were launched to commercialize BGCC technology. The need for cooperation was emphasized by one speaker, e.g. to insure appropriate sequencing of demonstration projects and exchange of information among projects to maximize the learning from each.

There was agreement among the speakers that technically and economically successful demonstrations were critical for reaching commercial maturity with BGCC systems. These are essential to achieve customer acceptance of the technology. Reaching customer acceptance will require competitive economics in the long term, and creative financing/risk sharing arrangements in the short term. One approach suggested for the short-term was to have a paper mill take no capital risk, but provide a host site for a demonstration plant, mobilize and sell biomass to the facility, and buy back energy products. A consortium consisting of a technology developer, an engineering/construction firm, and an independent power producer might take the capital risk, since they might have more to gain from involvement in initial projects than the host mill, and their cost of capital may be lower than the paper company's due to a higher fraction of debt financing. An alternative approach would involve relying on grants or soft loans to cover the non-commercial costs of a demonstration project--the approach being taken in the 30 MW_e Brazilian project. A third approach might involve vendor/user/government partnerships (as in the Clean Coal Program), whereby the technology owners would pay back the partners from the revenues on sale of future units. To the extent that they can be used to advantage, tax credits, premium prices for sale of "green" power, siting where low/negative-cost feedstocks are available, and other factors will obviously improve the economics of demonstration plants.

5.4. Steps to Timely Commercialization of BGCC and BLGCC Technology

After a summary of the Day-1 activities, the final (half) day of the workshop was devoted to discussion to identify steps to achieving timely commercialization of BGCC and BLGCC

technology. Weyerhaeuser is pursuing a number of relevant activities, which Del Raymond outlined in an opening presentation. A detailed assessment of BGCC opportunities at their New Bern, North Carolina mill helped convince Weyerhaeuser to pursue commercialization of BGCC technology. Present activity is focussed on positioning a Weyerhaeuser mill for commercial implementation of a BGCC system (most likley to be based on the indirectly-heated Battelle Columbus Laboratory gasifier) in the 1999-2001 timeframe. If a suitable Weyerhaeuser mill cannot be identified, a non-Weyerhaeuser location will be sought, so that momentum toward BGCC commercialization can be maintained.

Raymond finished his presentation by emphasizing the fact that as a very capital-intensive industry, major technology changes must be linked to the normal capital investment cycle of the industry. Given that many of the recovery boilers and biomass boilers in the U.S. pulp and paper industry will be reaching retirement age in the next 5 to 15 years, the window of opportunity for making a change to BGCC and BLGCC technology is approaching quickly. As a challenge to motivate subsequent roundtable discussion by the workshop participants, Raymond asked how commercialization could be made to happen before this window of opportunity closes.

By the end of the discussion period moderated by David Cooper, there was general agreement among the participants that commercializing both black liquor and biomass gasifier/gas turbine technology was, indeed, desireable. It was noted that gas turbines account for the majority of new generating capacity being installed worldwide, and that they will continue to do so for the foreseeable future as a result of ongoing efficiency and cost advances. Leading the development of biomass and black liquor gasification for gas turbine applications in the paper industry will provide the opportunity for the industry to use this historic shift in power generation technology to advantage in dealing with competitive pressures it faces.

There was also general agreement among the workshop participants that no single paper company would be able to commercialize gasification technology on its own and that forming a consortium of companies in partnership with the government was an approach that should be pursued. There was concensus that commercialization should be pursued in a manner that promotes healthy competition between technology suppliers, while developing the data and demonstration experience needed to allow more informed choices about gasification technology on the part of paper companies and to demonstrate clearly the market demand to technology suppliers.

It was agreed that additional work is needed at this stage to quantify the full range of potential benefits of gasification technology. An approach that allows individual companies to insert their own beliefs (regarding future energy prices, the value of process-related benefits of

gasification, etc.) would be desireable. Because capital costs for BGCC and BLGCC systems are high at present, it was agreed that there would be benefits to defining and pursuing major pre-competitive leverage points for reducing capital costs. With respect to this effort, the problem should be divided between cost reductions for near-term commercial demonstrations and much more major reductions (50-60% from present levels) that might result from significant technical breakthroughs in the longer term. Facilities such as those at Värnamo and Burlington might be made available for such research and demonstration efforts.

A final recommendation was made that serious consideration be given to forming a consortium of paper companies to work with the government to fund the demonstration program needed to commercialize BGCC and BLGCC technology. As a first step toward a consortium, the suggestion was made that a joint task force of representatives from four Agenda 2020 committees (Forestry, Environment, Energy, and Capital) be formed for the purpose of better defining the benefits of BGCC and BLGCC technology to allow more informed choices by paper companies relating to participation in the consortium (and to GCC technologies more generally) and to provide a better understanding of the potential GCC market to equipment suppliers.

ANNEX 1: OVERHEAD TRANSPARENCIES PRESENTED AT THE WORKSHOP

Context and Technology Overviews, Day 1

- Delmar Raymond, Weyerhaeuser: Biomass & Black Liquor Gasification Combined Cycle, an Industry Priority.
- Tom Foust, U.S. Department of Energy: DOE Initiatives in Gasification/Biomass Power.
- Eric Larson, Princeton University: Overview of Black Liquor & Biomass Gasification/Gas Turbine Systems.
- Stefano Consonni, Politecnico di Milano: Black Liquor and Biomass Gasification in the Pulp and Paper Industry, Gas Turbine Issues.

Black Liquor Technical Breakout Session, Day 1

- Vic White, Noell, Inc: untitled.
- Andrew Jones, ABB: Black Liquor Gasification at ABB.
- Chris Verrill, Babcock & Wilcox: Commercialization of Black Liquor Gasification, B&W Perspectives on Steps Needed to Commercialize Gasifier/Gas Turbine Systems.
- Momtaz Mansour, MTCI, Inc: no transparencies.
- Stefan Jönsson, Kvaerner/Chemrec: untitled.

Biomass Technical Breakout Session, Day 1

- Jim Patel, Carbona Corp: untitled.
- Folke Engström, Foster Wheeler Development Corp: Development and Commercialization of Biomass Technology.
- John Rohrer, Zurn/NEPCO and Industrial Energy Partners: Accelerated Biomass Gasification Commercialization, the Perspective of a Thermal Equipment Supplier, Turnkey Facility Engineer/Constructor, and Independent Power Developer/Financer.
- Michael Morris, TPS: untitled.

Review of Princeton's Research, Day 1

- Eric Larson, Princeton University: Advanced Technologies for Biomass-Energy Utilization in the Pulp and Paper Industry.

Motivating a Discussion to Identify Steps to Timely Commercialization, Day 2

- Denny Hunter, Weyerhaeuser: Summary of Day-1 black liquor technical breakout session.
- George McDonald, Union Camp: Summary of Day-1 biomass technical breakout session.
- Delmar Raymond, Weyerhaeuser: Biomass & Black Liquor Gasification Combined Cycle, Timing is Critical.

ANNEX 2: COMMENTS MADE DURING DAY-2 DISCUSSION

What follows is an informal recording of comments that were made by participants during the roundtable discussion on Day-2 of the workshop. Four questions were posed to the participants in advance of the discussion:

- What do equipment suppliers need to do to convince the producers that BGCC and BLGCC technologies are viable, affordable, desirable?

- What does the paper industry need to do to allow the suppliers to provide the GCC options?

- To make GCC commercial, what specific tasks/roles are there for the paper industry, the supplier industry, government, engineering companies, investors, others?

- What does the overall schedule look like for specific tasks--what needs to get done over the next 6-9 months and by whom?

Although the questions were not all explicitly addressed during the discussion, they were useful in helping to identify key themes around which the discussion evolved. In preparing this annex, we (the organizers) have taken the liberty of explicitly identifying these themes and grouping related comments under them to provide a more coherent presentation of the lively discussion that took place at the workshop. The four thematic areas are:

- Technology Issues/Readiness
- Value of Gasification/Combined Cycle to Paper Industry
- Demonstration Issues/Strategies
- Consortium/Collaborative Approach to Commercialization

TECHNOLOGY ISSUES/READINESS

- We're ready to take commercial orders, but we need secrecy agreements to talk specific applications (quote from some gasifier suppliers).

- Union Camp has some recovery boilers on the curve that will need replacement soon, but has some concerns with the technology as it has been described.
  - Will the gasifier produce a chemically viable liquor for the pulping process?
  - We need to understand in more detail how these gasification processes (especially high pressure) affect the core need for conversion of black liquor to green and white liquor.
  - What will be the sensitivity of the turbine to the high alkalinity of black liquor?
  - We need increased understanding of how to manage any chemical changes in the liquor.

- Technology has not yet been demonstrated to be acceptable for commercial demonstration.

- This is a financing issue and not a technical one. The technical issues that remain are pretty clear cut, and we can figure out what it will cost to solve them.

- Gas quality from the gasifier and the products of combustion in the turbine need to be better defined. However, there is a consensus that given a reliable gasifier operation the gas will fit well with standard turbines and that only minor modifications, if any, will be required.

- All gasification systems need to supply approximately the same gas quality so that the turbine has a viable life. However, the research community needs to define some technical targets. Turbine manufacturers may need some special coatings, etc., to protect from oxidation/corrosion of blades.

- Can't modify the engines to meet the gas—need to have the gas CLEAN.

- Possible big ticket items that would fit the definition of pre-competitive research are:
  - Biomass supply
  - Insulation and refractory
  - Increased activity in fundamental understanding of chemical kinetics of gasification reactions
  - Interaction with pulping chemistry; e.g., flexibility to improve the primary pulping process

  Agenda 2020 could be a useful enabling mechanism for advancement in the above areas.

- With respect to black liquor, don't be too sure that the technical questions for BLGCC have all been answered. Some caution is in order.

- Chemrec has very good insight into the Tomlinson process and the fiber line. They know how to meet green liquor specifications, etc. Gasifier concepts that they are now marketing meet those parameters and exceed the specifications.

- One of the technical challenges is to get the costs down. It is also important that we establish and publish where we are today, what the second plant will be, what the N^{th} plant will be; and what is necessary to make the technologies economically viable.

VALUE OF GASIFICATION/COMBINED CYCLE TO PAPER INDUSTRY

- When it comes down to the commercial decision, what will be the compelling drivers for moving to BGCC/BLGCC technologies?
  - Safety?
  - Environment?
  - Energy substitution economics?
  - Process improvements; e.g., yield, causticizing, etc?
  - Maintenance/reliability?

- We need to understand these trade-offs well, certainly much better than we do now.
  - What are the long-term benefits over conventional technology?
  - What are the N^{th} generation economics?
  - What process flexibility does the technology offer, and what is its value?
  - What is the impact/synergy with mill close-up; e.g., NPEs?
  - Can we meet—improve on—green liquor quality?

- Are the split sulfidity benefits real?

- The paper industry needs to clearly define the future benefits to the industry in order to convince its decision makers to support a path forward. There needs to be a clear definition of the "harmony of needs" as there was for the clean coal program.

- Need to have definite, defined targets for what is success: the long-term benefits; process flexibility; NPE removal; the value of process differences; etc.

- Paper industry must demonstrate to vendors the value of collateral benefits of gasification, such as split-sulphidity pulping.

- In our biomass economics, are we looking at the costs for landfills and the disposal of waste fuels, sludges, etc.—including possible litigation in the future for disposing of this material. Look at the things we disposed of in landfills 20 years ago, and they are now superfund sites.

- Define gasification benefits in a generic way to permit each mill to make their own quantification of technology's benefits. Only benefit that is well defined so far is electric power.

- Benefits of gasification (environmental, pulping chemistry, energy efficiency, etc.) should be defined quantitatively to demonstrate value of the technology to paper industry.

- Agenda 2020 could be a useful mechanism for advancing work in the above areas.

- Don't feel technology is the real hurdle. It's ready. It comes down to what are we looking at this for. Power—some feel power cost will go down. Safety is not an issue in recovery boilers at this time. Feel it is really the economics. Don't see the economic benefits of putting in BLGCC/BGCC units now. If gas stays cheap, we could put in a natural gas unit and wheel power to ourselves. The economics to take that risk are not there today.

- There needs to be a better understanding, likely by managements of both supplier and producer industries, of the cost avoidance opportunities for the new technologies; e.g., waste disposal and incremental economic advantages, etc.

- There is often a mirage of cheap (free) fuel. What is the predictable, long-term biomass fuel price? How can continuity of supply be insured?

- The paper industry should know its cost for biomass to a very high degree of certainty. This provides a good basis for signing long-term (20-30 year) electricity sales contracts (which may offer better purchase prices) in the face of uncertainty about future costs of natural gas or other alternative fuels. This is an industry card-up-the-sleeve. A related point is that the incremental economics of exporting power are favored by the larger-scale of the powerhouse relative to a system that meets only on-site power needs--the generating cost for the incremental MWs will be less than that for the base MWs.

DEMONSTRATION ISSUES/STRATEGIES

- Suppliers are not going to continue to develop the technology and put their own money into it unless the industry is willing to take some risks now for technology they might not need for 5 to 10 years.

- There is a need to increase the understanding of the supplier company managements with respect to the impact the cyclicality of the producer industry has on decisions. The five year commercialization cycle for the gasification technologies is likely to span a producer industry's business cycle. This needs to be recognized and dealt with.

- It is up to each vendor to develop his own list of benefits and economics. Competent procurement officers at paper companies will seek them out. Don't complicate the issue. That is marketing 101. Financing is the real problem to work on.

- Coal gasification combined cycle will become competitive with conventional steam/electricity generation by the early 2000s. Rapid and substantial improvements in gas turbine performance and efficiency are being made.
    - How can biomass gasification be evolved to take advantage of this development?
    - How do we fund the higher cost of the first few BGCC & BLGCC units to be ready?
    - The industry needs a pathway to commercialize these technologies.

- There is an opportunity to use the large pilot-plant/semi-commercial facilities, now or soon to be in operation, to obtain the key development and feasibility data for future plants. Two examples of BGCC are the Värnamo and Burlington plants. There is some urgency with respect to Värnamo.

- Sydkraft would be very interested in having discussions with any users interested in investing in their commercial demonstration plant. They would be willing to provide access to the plant for running tests and to any information that would be learned (efficiencies, reliabilities, etc.). For carrying out crucial tests for BGCC development, this should be a reasonable investment and certainly cheaper than building a new plant.

- For the first few new units we should look hard for the absolute best fits with a situation that will create an economically sustainable project.
    - Where is the largest difference between biomass value and fossil fuel value?
    - Where is the largest opportunity to save capital compared with a conventional solution?
    - Where is the best opportunity for a collaborative partnership?
    - Where is the best opportunity for outside financing?
    - Where is the best opportunity for a long-term commercial package that would work?

- Show what is needed to prove the resulting liquors are okay. That could determine how large a demonstration plant needs to be.

- Have to be careful about role playing. Competition on the vendor side is healthy. There are numerous vendors moving the technology forward, but they need to see there are orders for first commercial demonstrations around the corner. Among the producers, there is enough of an understanding of what are good commercial sites. Be careful not to create any roles, but rely on the market.

- The units currently being offered are too expensive today, particularly with currently low fossil fuel costs and uncertain power values. .... there is not a lot of incentive to proceed at present, but we may need these technologies to protect our future. How do we fund plant #2?

- Divide the commercialization effort. In the near-term, go forward with options already on the table. For the long term, work on issues with promise of major (60% ?) cost-reduction.

- It is almost certainly true that the first Tomlinson unit placed in commercial operation was not cheaper than the kiln technology it replaced.

- The thermal technology of choice in the world today is gas turbine combined cycle. Where did this technology come from? Initially, there was enormous government investment in jet engines for air craft, but stationary gas turbine technology is now also receiving direct focus, e.g. the ATS Program. There has also been enormous moneys spent on coal gasification combined cycle. That these various technology investments have already been made means that getting over "death mountain" with BGCC and BLGCC technology will involve relatively small incremental cost.

CONSORTIUM/COLLABORATIVE APPROACH TO COMMERCIALIZATION

- The paper industry needs to provide a mechanism (consortium of paper companies/financial community/government) to fund the first few plants, while treating the suppliers on a purely commercial basis (let them bid for the jobs). The supplier community seems most comfortable with this approach, since it avoids proprietary issues.

- Georgia Pacific: As long as natural gas is cheap, it is not going to pay anyone to go to anything but that. The BLGCC technology has promise, however, and we would like to have the option when the time arrives to put in a recovery boiler. It will likely take government and consortia money to get this technology demonstrated. Let's build 2–3 of these plants and have the technology available. What is the minimum size we need.....how much is it going to cost?

- As one incentive for paper companies to participate in a consortium, the commercialization process might be structured so that the pioneering companies reap benefits from future installations of gasification technology in and out of the paper industry, e.g., through some sort of royalty or other arrangement, with royalties to each company in proportion to their participation in the commercialization effort. There are precedents for this type of arrangement with other technologies.

- Is there a role for government in commercializing GCC? Answer: definitely yes.

- DOE doesn't have enough money to do all the demonstration. Need consortium to spread the risk.

- Consortia work very well with government and users, but not so well with vendors. Put a consortium

together and go out for bids from vendors.

- Mill integration issues are important in considering gasification, but generic (consortium-backed) demonstrations should still be possible at mill sites without compromising proprietary aspects of mill operation.

- Look at the near term and also how to take 50% out of the costs. There are going to be better turbines developed because the pressure is there. Consortium could take a look at what is needed for working with black liquor and what the special needs are. We need better knowledge to work with.

- High reliability (even at expense of higher operating cost) is key requirement for gasification. Demonstrate reliability through industry-consortium backed demonstrations.

- Assemble small (half-dozen members?) paper-industry task force/consortium to flesh out benefits of gasification and move commercialization process forward.

- Paper-industry consortium can structure activities to enhance vendor competition.

- Publish 1st and Nth plant economics to help paper companies decide on whether or not to participate in consortium.