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
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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.

- 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 GWₑ. The market for BGCC capacity could be up to 30 GWₑ.

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

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)
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 Weyerhaeuser 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 c/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 consensus 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 desirable. 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 Jonsson

2. Biomass Systems
   - Chair: George McDonald, Union Camp
     Carbona -- Jim Patel
     Foster-Wheeler -- Folke Engstrom
     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 purview 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.](image-url)
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 Weyerhaeuser of one of its facilities found that combined BLGCC plus BGCC technology would permit some 100 MW of electricity to be
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 c/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].
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<sub>e</sub> BGCC system using this technology—the first of its kind [7].) After five units at the 30 MW<sub>e</sub> scale, Shell projects the cost to fall to $1500/kW<sub>e</sub> (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<sub>e</sub>) 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<sub>e</sub> BLGCC—a scale appropriate for modern pulp mills (1300-1500 tons per day pulp production)—would be about $280 million.
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 rewarded by a royalty arrangement with the technology suppliers for future units sold.
4.4. References


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 NOx, 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<sub>e</sub> 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<sub>e</sub> 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<sup>th</sup> to 10<sup>th</sup> unit. Systems based on pressurized gasification will likely be preferred in the 60 to 80 MW<sub>e</sub> size range, while atmospheric-pressure systems will likely be preferred at 30 MW<sub>e</sub> 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<sup>th</sup> 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 focused on positioning a Weyerhaeuser mill for commercial implementation of a BGCC system (most likely 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 consensus 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

to

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
Princeton University, Princeton, NJ
16-17 January 1997

Organizers:

Eric D. Larson
Center for Energy & Environmental Studies
Princeton University

Delmar Raymond
Strategic Energy Alternatives Division
The Weyerhaeuser Company

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The W. Alton Jones Foundation
The Geraldine R. Dodge Foundation

20 March 1997
ANNEX 1: OVERHEAD TRANSPARENCIES PRESENTED AT THE WORKSHOP

Context and Technology Overviews, Day 1

Black Liquor Technical Breakout Session, Day 1
- Vic White, Noell, Inc: untitled.
- Andrew Jones, ABB: Black Liquor Gasification at ABB.
- Momtaz Mansour, MTCo, 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.
- Michael Morris, TPS: untitled.

Review of Princeton’s Research, Day 1

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.
Context and Technology Overviews, Day 1

Delmar Raymond
Weyerhaeuser Company

"Biomass & Black Liquor Gasification Combined Cycle, an Industry Priority"
Biomass & Black Liquor Gasification

Combined Cycle

An Industry Priority

Princeton University

January 16, 1997
The "Mountain" of Death

Source: EPRI Technical Assessment Guide
Commercialization of BGCC & BLGCC Technologies - Why Now?
Industry Pressures

- Low cost raw material
- Lower quality recycled fibers
- Loss of technology leadership
- Emphasis on environmental priorities
- Cost of energy & dependence on purchased power
- Government response to greenhouse gas issues
- Increasing capital intensity
Industry Pressures
Loss of Technology Leadership

- Majority of new innovations over last 30 years from non-US sources
- Low cost fiber supplies moving to southern hemisphere
- Majority of capacity growth is off shore
- Newest technology being implemented in off-shore mills
Industry Pressures
Emphasis on Environmental Priorities

- Industry’s approach to environmental priorities over last 30 years - unprecedented
- Exemplary results but with significant capital cost
- Significant additional expenditures in our future
- Continuing need for more environmentally compatible technologies
Industry Pressures
Cost of Energy & Dependence on Purchased Power

- Low energy cost has been a basis for competition in the past
- Current prices appear stable but ..... 
- Forest products industry is nearly 60% self sufficient and could be more
- Steam power balance in most plants is drifting toward more purchased power
- Future cost of power is uncertain
Industry Pressures
Government Response to Greenhouse Gas Issues

- Impact on unbundled power costs - an example (cost breakdown charts)
- The industry's level of self sufficiency may be an advantage
Industry Pressures
Increasing Capital Intensity

- Capital intensity compared to other industries
- Rate of increasing capital intensity
Capital Compared to Other Industries

Capital expenditures as a percent of sales (Source: Dept. of Commerce, API)
Rate of Capital Increase

Capital expenditures as a percent of sales (Source: Dept. of Commerce, API)
Industry Pressures
What BGCC & BLGCC Offer

- Opportunity for technological leadership
- Improved operational safety
- Environmental compatibility
- Reduced dependence on purchased energy
  (increased energy self sufficiency)
- Shelter from greenhouse gas mitigation
  and/or energy tax initiatives
- Lower capital
Industry Pressures
The Gasification Model

- Fuel from biomass model - an example
- A possible powerhouse configuration
- The efficiency potential
Alternative Fuel Options - A Plausible Model

Electricity Export (-100 MW)

Pulp Production 525,000 BDT
Pulpwod and/or Chips 1,050,000 BDT
Black Liquor 525,000 BDT

Conversion to Energy

Lumber, Particleboard, Flakeboard 381,000 BDT

Thinnings, Tops, Branches and Residuals 681,000 BDT

600,000 Acres Loblolly Pine 32 Year Rotation 3 Thinnings

Reforestation

Basis: 1 Year
Power Recovery Island of 2010
Possible Configuration

Source: Adapted from data provided by the Swedish National Board for Industrial & Technical Development
Power-Recovery Island of 2010
Power Generation Efficiency Comparison
Commercialization of BGCC & BLGCC Technologies - Why Now?

BGCC/BLGCC Commercially Successful

- Readiness of Technologies
- Industry Pressures
  - The Need
- Window of Opportunity
  - The Time
- Enabling Mechanism
  - Agenda 2020
Agenda 2020

An Enabling Mechanism for Advancing BLGCC & BGCC Technology
The Background of 2020

- History of Federal investment in industry, e.g., textiles, auto, steel
- CTO-driven vision of Forest Products Industry catalyzed by DOE
- TAPPI sponsored "Future Research Needs" workshops
- CEO direction provided through AF&PA Board with "2020" approval, October, '94
- "Compact" with DOE signed November, '94 and will be renewed in January, '97
What is Agenda 2020?

“Agenda 2020” defines and communicates the technology-related gaps that must be addressed to achieve a desired industry state in the year 2020.
Agenda 2020 Purpose

- Improve global competitiveness through collaborative and targeted, precompetitive, fundamental research and new technology commercialization
- More effective allocation of industry research funds (‘95-'96 environmental R&D expenditures alone in excess of $72 million)
- Consistent basis for communication of industry technical, environmental, capital and energy performance
Agenda 2020 Execution Principles

- Improve the efficiency and productivity with which the industry allocates cooperative research dollars
- Reduce the bureaucracy involved in guiding industry cooperative research
- Provide a “strategic” — as opposed to an “institutional” — focus for program selection
"Agenda 2020" Focus Areas

- Sustainable Forest Management
- Environmental Performance
- Energy Performance
- Improved Capital Effectiveness
- Recycling
- Sensors and Controls
Operating Model for Federal Government-Forest & Paper Industry Partnership

AF&PA Board
Policy & Approval
CEO Work Group
CEO’s
Coordinating Group Chair & Co-Chair
Selection & Guidance
Coordinating Group
6 Focus Area Chairs
At-large CTO’s

Federal Agency Coordinating Group

Industry Advisory Group
Industry
Government
Academia

Focus Area Advisory Group
Industry
Government
Academia

Sustainable Forestry
Environmental Performance
Energy Performance
Recycling
Capital Effectiveness
Sensors & Controls

Results & Technology Demonstration

Operating Companies and Facilities
Capital Effectiveness
Areas of Priority

- Improve materials of fabrication and reduce corrosion in core process areas
- **Simplify existing process technologies or develop major breakthroughs in new process technologies that significantly lower costs, improve safety or increase efficiency**
- Significantly improve fabrication and construction methods
- Improve skill capabilities through education
- Improve the efficiency of capital intensive processes through intelligent manufacturing concepts
Energy Performance Areas of Priority

- Create, develop and demonstrate new approaches to drying & water removal
- Energy efficient processes to use recovered paper
- Commercialization of combined cycle gasification technologies for both black liquor and biomass
- Increase fundamental understanding of the process in the Tomlinson furnace, ultimately leading to optimization of its performance
- Understand the fundamental physico-chemical behavior of non-process elements (NPEs) in recovery area streams
Agenda 2020
Key Messages from the January 8 CTO Meeting

- BLGCC & BGCC technologies are a strategic area of emphasis
- A path forward for their commercialization must be found
- Input from suppliers on how to proceed is needed
- A set of principles and ground rules for moving forward should be developed
- Additional Agenda 2020 priority projects are expected as a result of the Princeton meeting
Context and Technology Overviews, Day 1

Tom Foust
U.S. Department of Energy

"DOE Initiatives in Gasification/Biomass Power"
DOE Initiatives in Gasification/Biomass Power

Workshop on Commercialization of Black Liquor and Biomass Gasification for Gas Turbine Applications in the Pulp and Paper Industry

Doug Faulkner - Agriculture
Tom Foust - Forest Products
Valri Robinson - Forest Products
Pat Hoffman - ATS
William Parks - Cross Cut Technologies
Gloria Kulesa - Alternative Feedstocks

EE - Biomass

Thrust Areas:
Gasification, Combustion Feedstocks, Power Generation Integration
OIT - Biomass

- Biomass Power Program
- Forest Products Agenda 2020
  - Black liquor gasification
  - Biomass gasification combined cycle
  - Advanced technologies for biomass-energy in the Pulp and Paper Industry
  - Energy Performance Working Group
- Cogeneration/ATS Program
  - Assessment of turbine modification for biomass fuels
  - Biomass turbine

OIT - Biomass

- Agriculture Industry Team
  - Biobased Renewables Vision and Workshop
  - USDA/US DOE MOU
- Alternative Feedstocks Program
  - Biomass conversion to chemicals
Biomass Power Program

**Mission**
The mission of the DOE Biomass Power Program is to expand domestic and global markets for renewable electricity from sustainable biomass resources by fostering partnerships with US industry, agriculture and forestry.

**Vision**
The integration of sustainable farms and forests with efficient biomass power production from dedicated feedstocks will be a major cost-competitive contributor to power supplies in both domestic and international markets.

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Forest Products Industrial Team

- **Vision of the Future - Agenda 2020**
  - Completed November 1994
- **Collaborative program to address industry defined R&D needs**
- **Six Long-Range Thrust Areas (Pathways)**
  - Sustainable Forest Management
  - Environmental Performance
  - Energy Performance
  - Improved Capital Effectiveness
  - Recycling
  - Sensors and Controls
Program Operational Details:
**MAJOR PROGRAM PROJECTS**

**Hawaii Biomass Gasifier/HGCU Scale-up Project**
- **Location:** Maui, Hawaii
- **DOE Partners:**
  - Westinghouse Electric Corp.
  - IGT
  - PICHTR
  - AMFAC/JMB Hawaii, Inc.
  - Amoco Corporation
  - Electric Power Research Institute
  - Maui Electric Company
  - Pioneer Mill Company, Ltd.
  - County of Maui
  - Hualalai Engineering, Inc.
  - Hawaiian Electric Company
- **Project Details:**
  - **Project Size/Capacity:** 5-20 MW
  - **Technologies:** Direct Gasification, Hot-Gas Clean-up, Gas Turbine
  - **Feedstock:** Sugar Cane (Bagasse), 100 tons/day

**PROJECT COST-SHARING**
- **TOTAL FUNDING:** $62.1 million
- **35%** Federal, **65%** Private

**PROJECT DURATION**
- **% DURATION COMPLETED:** 56%

**Vermont IGCC Scale-up Project**
- **Location:** Burlington, Vermont
- **DOE Partners:**
  - FERCO
  - Burlington Electric Corp.
  - Battelle Laboratories
  - McNeil Power Station
- **Project Details:**
  - **Project Size/Capacity:** 15 MW
  - **Technology:** Indirect Gasification
  - **Feedstock:** Willow (200 ton/day)

**PROJECT COST-SHARING**
- **TOTAL FUNDING:** $35.1 million
- **50%** Federal, **50%** Private

**PROJECT DURATION**
- **% DURATION COMPLETED:** 49%
Program Operational Details: MAJOR PROGRAM PROJECTS

Minnesota Agri-Power Project (MnVAP)

- **Location:** Granite Falls, MN
- **DOE Partners:**
  - Minnesota Valley Alfalfa Producers
  - Northern States Power
  - Westinghouse Electric Corp.
  - Stone & Webster
  - Polsky Energy Corp.
  - City of Granite Falls
  - Tampella Power Systems
  - University of Minnesota
  - IGT
  - USDA

- **Project Details:**
  - **Project Size/Capacity:** 75 MW
  - **Technology:** Gasification Combined Cycle
  - **Feedstock:** Alfalfa, 2000 tons/day
  - **Products:** Electricity, Animal Feed

Chariton Valley Gasification/Co-firing Project

- **Location:** South-central Iowa
- **DOE Partners:**
  - Chariton Valley RC&D
  - IES Utilities
  - Local Farmers & Landowners
  - Iowa Farm Bureau Federation
  - Iowa State University
  - R.W. Beck (Engineering Firm)
  - Iowa Dept. of Natural Resources
  - Iowa Division of Soil Conservation
  - Biofuels Corp.
  - Energy Products of Idaho
  - Energy Research Corp.
  - Soil and Water Conservation Districts

- **Project Details:**
  - **Project Size/Capacity:** 35 MW cofiring, 5-6 MW gasification
  - **Technology:** Co-firing, Gasification, Fuel Cells
  - **Feedstock:** Wood Residues, Switchgrass (40,000 acres)
Agenda 2020 Process

- Industry led task groups develop research pathways - revisited annually
- February - Task groups issue Request for Proposals (RFP) for idea sheets on research needs
- Mid-April - Idea sheets due
- Mid-June - Industry task groups select top ideas for 5-page proposals
- September - Poster session plus on-going project review
- Mid-October - 5-page proposals due
- December - Industry task groups make final selections

Combined Cycle Biomass Gasification

Location: New Bern or Plymouth, North Carolina

Partners:
- Weyerhaeuser Co.
- FERCO
- Zurn/NEPCO
- Stone and Webster
- Strategic Energy Limited

Project Details:
- Assess technology for a pulp mill demonstration
- Evaluate 16 capital cost reduction opportunities
- Participation in Burlington
- Raw Material Availability
- Energy Crop Possibilities
- Medium Btu Gas Replacement Study
Black Liquor Gasification/Pulsed Combustion

Project Partners:
- MTCI
- StoneChem
- ThermoChem
- Weyerhaeuser Co.

Project Details:
- Pulse Enhanced Steam Reforming
- Indirectly heated, steam-fluidized
- Medium Btu gas and inorganic salts
- 25 TPD unit in operation since 3/92
- 500-hour continuous test of a 50 TPD unit in Summer 1995

Advanced Technologies for Biomass Energy in the Pulp & Paper Industry

- Assess alternative future pulp and paper mill energy-technology configurations, with an emphasis on understanding the performance and cost of advanced biomass-energy conversion technologies (Total cost: $780K; cost share 45%)
- Participants: Weyerhaeuser Co., Princeton University
- Approach: Utilize Consonni model to predict plant mass and energy flows with a focus on kraft mills and BLIGCC and BIGCC
- Start: October 1995
- Duration: 2 years
Advanced Turbine Systems
Program

- Cooperative program between OIT (industrial turbines) and FE/FETC (utility turbines)
- Goals:
  - Efficiency (Utility: 60%; Industrial: 15% improvement)
  - Emissions (10% reduction in NOx)
  - Cost of electricity (10% reduction)
  - Fuel flexibility
  - RAMD equivalent to today
  - Commercial introduction in 2000
- Opportunity power generation/distributed generation

Assessment of Turbine Modification

- Limited assessment by Solar Turbines and Allison Engines
  - Alternative Fuel Flexibility (coal and biomass gasification)
- Solar Saturn on loan at Battelle
  - Initial data on performance
- Concerns:
  - Alkali concentration
  - Char
**Biomass ATS**

- Combustor development for biomass gases
- Composition analysis of biomass gases
- Thermal barrier coatings (RAMD)
  - 30,000 hours life
  - repair
  - cost-effective

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**Agriculture Industry Team**

- Develop of a industrial vision/roadmap
- St. Louis press conference/signing
  - corn fiber project with NCGA
- Biobased Renewables Vision
  - draft in circulation
- Biobased Renewables Workshops
  - 12/17 in St. Louis for agricultural, chemicals and forestry sectors
- USDA/ US DOE MOU
  - signed 11/25
Alternative Feedstocks Program

- Mission to promote cost-effective industrial use of renewable biomass resources (agricultural or forestry crops and biomass residues) as feedstocks for the manufacture of chemicals
- Feedstocks: Corn starch/sugar, corn fiber, hard & soft woods, paper mill sludge, recycled newspaper, herbaceous crops
- Products: plastics, apparel, solvents, food additives, antifreeze, shaving cream, suntan lotion, laundry detergents, fiber glass reinforced plastics, de-icers, gasoline additive, pesticide, herbicide, photographic films, thermoplastics, home furnishings (drapery, carpeting)

Alternative Feedstocks Program

- One effort uses utility residues to make added-value chemicals.
  - several conversations with EPRI
- Participants: ANL, INEL, NREL, ORNL, PNNL, with industrial Partners
- Start: 1991
- Funds to date: $17 M
Context and Technology Overviews, Day 1

Eric Larson
Princeton University

"Overview of Black Liquor & Biomass Gasification/Gas Turbine Systems"
Overview of Black Liquor and Biomass Gasification/Gas Turbine Systems

Eric D. Larson
Center for Energy & Environmental Studies
School of Engineering/Applied Science
Princeton University

Workshop on Commercialization of Black Liquor and Biomass Gasification for Gas Turbine Applications in the Pulp and Paper Industry
Princeton University, Princeton, NJ
16-17 January 1997
Prospective Benefits of Gasifier/Gas Turbines vs. Boiler/Steam Cycles

- For biomass and black liquor:
  » Higher overall efficiency; large increase in electrical efficiency.
  » Reduced environmental impact.
  » Reduced capital costs.
  » Improved availability.

- For black liquor:
  » Improved safety
  » Added flexibility in preparing pulping chemicals.
  » Opportunity for direct causticizing.
Potential Power Generation at a Bleached Market Kraft Pulp Mill

(Preliminary estimates)

Modern U.S. Mill:
>> ~1250 air-dry metric tonnes pulp per day
>> Process steam: 15.5 Million Btu/admt
(Net of powerhouse)

- Black liquor + biomass gasification/gas turbine
- Tomlinson + biomass boiler/steam turbine
Efficiency vs. Power Output for Gas Turbines Burning Natural Gas (GE)

Systems Committed & Under Study

Net Efficiency (%) vs. Output (MW)

- Geared & Aero Derivative Machines
- Medium Machines
- Large Machines

- Novel Bottoming Cycle - Kalina
  - Aeroderivative - Adds Up to 4 Pts.
  - Large Utility - Adds 2 to 3 Pts.
Black Liquor Gasifiers
Under Development

- Low-temp. designs (< 700°C, inorganics removed as dry solids), atm. pressure, bubbling fluidized beds:
  » **ABB**: Air-blown, mild pressurization.
  » **MTCI**: In-bed heat exchanger tubes.
  » **B&W**: Air-blown, early development

- High-temp. designs (> 950°C, inorganic smelt), pressurized, entrained beds:
  » **Kvaerner/Chemrec**: Air-blown, planning for \( \text{O}_2 \)
  » **Noell**: Oxygen-blown
  » **Tampella and Ahlstrom**: not active
Black Liquor Gasifier/Gas Turbine Cogeneration System (Noell Gasifier)
Biomass Gasifiers
Under Development

- Atmospheric pressure fluidized beds:
  - **Battelle (BCL)**: indirectly-heated, twin-bed; 200 tpd demo in Vermont.
  - **TPS**: air-blown CFB; projects in Brazil, UK, Holland.
  - **Lurgi**: air-blown CFB; Italy project.

- Pressurized fluidized beds:
  - **Carbona**: Air-blown bubbling bed technology of IGT; projects in Hawaii and Minnesota.
  - **Foster-Wheeler**: Ahlstrom's air-blown CFB; 100 tpd demo at Varnamo.
Biomass Gasifier Gas Turbine Cogeneration System (TPS Gasifier)
Key Technological Challenges for Gasification Systems

- For biomass and black liquor:
  - Gas clean up to meet gas turbine specifications.
  - Production of gas with sufficient heat content for gas turbine combustion.
  - High-temperature heat recovery from raw product gas.
  - Thermal integration of gasifier, power cycle, and mill.

- For black liquor:
  - Cost-effective, efficient chemical recovery
  - Realizing direct causticizing.

- For biomass:
  - Handling and feeding biomass.
Context and Technology Overviews, Day 1

Stefano Consonni
Politecnico di Milano

"Black Liquor and Biomass Gasification in the Pulp and Paper Industry, Gas Turbine Issues"
Black Liquor and Biomass Gasification in the Pulp and Paper Industry

Gas Turbine Issues

Stefano Consonni
Politecnico di Milano
Milano, Italy

Princeton
January 16-17, 1997
The use of gas turbines in black liquor and biomass gasification systems raises issues in three basic areas:

1) Combustion

2) Turbomachinery

3) Materials

One further, relevant concern relates to:

4) Use of commercial turbines designed for natural gas/distillate fuels
COMBUSTION

Concerns and/or need for R&D and demonstration relate to:

1) Flame stability
   - low-medium-Btu fuel
   - high speed flow
   - fuel composition

2) Combustor design
   - large fuel volume flow
   - fuel pressure drop
   - combustor cooling
   - noise-induced vibrations
   - control of fuel flow

3) Emissions
   - complete oxidation of CO, HC
   - fuel-bound NO$_x$
   - thermal NO$_x$
TURBOMACHINERY

1) Turbine flow may be much larger than compressor flow

2) Integration with gasifier constrains procedures for:
   start-up
   shut-down
   power output control

3) At reduced load, large variations of turbine flow

4) Multi-shaft configurations desirable
MATERIALS

1) Super-alloys and coatings are very sensitive to alkali metals

2) Solid particles can cause erosion of turbine blades and plugging of film cooling holes

3) Deposition of solid particles and tar on the blade surface causes power and efficiency degradation

To maintain reliability and acceptable turbine life, may derate TIT
Table 1. Guidelines for Contaminants in Gases from Coal-Based Power Systems

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Concern</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate Matter</td>
<td>Erosion</td>
<td>All particles less than 10 micrometers diameter, with 90 percent less than 5 micrometers.</td>
</tr>
<tr>
<td></td>
<td>Deposition</td>
<td>Less than 100 ppmw.</td>
</tr>
<tr>
<td></td>
<td>Environmental</td>
<td>.03 lb/MMBtu, HHV¹.</td>
</tr>
<tr>
<td>Alkali</td>
<td>Corrosion</td>
<td>Total alkali (sodium plus potassium) less than 20 ppbw.</td>
</tr>
<tr>
<td></td>
<td>Environmental</td>
<td>1.2 lb SO₂/MMBtu, HHV and 90% reduction¹.</td>
</tr>
</tbody>
</table>

¹ Refer to New Source Performance Standards for complete statement of regulations.
USE OF COMMERCIAL ENGINES: TURBOMACHINERY ISSUES

1) Large fuel flow calls for higher pressure at turbine inlet

2) Higher combustor pressure moves compressor toward stall region

3) Larger turbine flow substantially increase power output

Compressor stall can be avoided by one or more of the following:

a) reduce compressor air flow by acting on compressor inlet guide vanes

b) bleed air at compressor exit (or along the compressor)

c) modify turbine
   - increase height of turbine blades
   - modify stagger angle of turbine blades
OTHER ISSUES RELATED TO COMMERCIAL ENGINES

- Fuel nozzles pressure drop
- Maximum fuel gas temperature
- Torque which can be transmitted by engine shaft
- Operating experience: power degradation, maintenance schedule, etc.
POSSIBLE GAS TURBINE INTERVENTIONS
IN FUNCTION OF THE FUEL GAS LHV

MODIFIED COMBUSTORS

STANDARD COMBUSTORS

AIR EXTRACTION

NO AIR EXTRACTION

LHV

[kCaVN m³]

[kJ/Nm³]

10.000 20.000 30.000 40.000 50.000 60.000

Blast Furn. Gas

O2

IGCC

Coal

TAR

Cokeoven Gas

NAT. Gas

REFINERY GAS
USE OF COMMERCIAL ENGINES:
COMBUSTION - EXPERIENCE

- In most cases must modify fuel nozzles
- When fuel heating value is below 8-10 MJ/nm$^3$ may need combustor modifications
- Typically, aeroderivatives have larger compressor stall margin and can accept larger fuel flow increases
- However, there is ample experience also with heavy-duties
- Substantial experience gained by most major gas turbine manufacturers in petro-chemical and steel industry
Black Liquor Technical Breakout Session, Day 1

Vic White
Noell, Inc.
PRESENTATION OUTLINE

- Introduction to Preussag Noell
- Noell Black Liquor Gasification
- Program Overview
- Gasification Technology Issues
- Commercialization Issues
PREUSSAG GROUP
OPERATING DATA

- Principle Shareholder: Westdeutsche Landesbank
- Annual Sales (’94-’95): $18 billion
- Group Companies: ~150 worldwide
- Employees: ~63,600 worldwide

NOELL, INC.
A Member of the Preussag Group
PREUSSAG GROUP

Steel and Non-Ferrous Metals
Production
Energy and Commodities
Trading and Transportation
Plant Engineering and Shipbuilding
Building Engineering and Components

NOELL, INC.

A Member of the Preussag Group
PREUSSAG NOELL GmbH

OPERATING DATA

- Principle Shareholder
- Annual Sales ('94-'95)
- Group Companies
- Employees

Preussag AG
$1.5 billion
~15 worldwide
~3,400 worldwide

NOELL, INC.

A Member of the Preussag Group
NOELL-KRC

Environmental Technologies

- Air Pollution Control Technologies
  - Flue Gas Desulfurization and Cleaning
  - NOx Removal (DeNOx)
- Thermal Treatment Technologies
  - Incineration
  - Entrained Flow Gasification
  - Pyrolysis

NOELL, INC.

A Member of the Preussag Group
TECHNOLOGY ASSESSMENT

(Jun '95 - Dec '96)

- Determine Application Objectives
- Evaluate Technology Issues
- Conduct Pilot Tests
- Evaluate Test Results

A Member of the Preussag Group

NOELL, INC.
EVALUATION OF TEST RESULTS

- Carbon conversion rate is higher than 99.7% if the gasification temperature is above 1200 °C.
- Pilot test equipment is suitable for black liquor gasification.
- Gas composition and green liquor quality are in the range of expected values.
- On the whole, black liquor gasification test results confirm that further development work is technically justified.

NOELL, INC.  A Member of the Preussag Group
TECHNOLOGY DEVELOPMENT
(Jan '97 - Jun '97)

- Establish Development Objectives
- Develop Technology
- Conduct Additional Pilot Tests
- Define Demonstration Plant
- Secure Host/Funding/Arrangements for Demonstration Plant

NOELL, INC. A Member of the Preussag Group
FUTURE WORK

1/97

- Conduct long-term testing under constant test conditions to study the behavior of cooling screen refractory and the smelt lining.
- Develop application-specific equipment.
- Nozzle cooling or heating system.
- Evaluate alternative cooling screen linings.
TECHNOLOGY DEMONSTRATION
(Jan '97 - Jun '00)

- Build and Operate Demonstration Plant for Approx. One Year

NOELL, INC.

A Member of the Preussag Group
COMMERCIALIZATION ISSUES

- Confirmation of key process objectives to assure involvement of all relevant parties from outset.
- Solicit participation from all parties to benefit from successful implementation.
- Even with extensive pre-commercial development to mitigate risks, high cost to build and prove technology will require cost/risk sharing.

NOELL, INC.

A Member of the Preussag Group
COMMERCIALIZATION ISSUES

- Will support be focused on single "best" technology or across multiple technologies?
- Can USDOE or other support be expected soon?
- What performance will be required in demonstration plant, and can industry be relied upon to subsidize results?
Black Liquor Technical Breakout Session, Day 1

Andrew Jones
ABB

"Black Liquor Gasification at ABB"
Black Liquor Gasification at ABB

Princeton University Seminar
Jan 16th, 1997
Dr. Andrew K. Jones
Presentation Overview

- ABB BLG Technology
- Key Drivers Required to Replace the Tomlinson CRU
- Major Technology Uncertainties
- Critical Path for Development
- How Can the P&P Industry Help
- Summary
ABB/CE BLG Process Description

- Non-Smelting Process
  - Low Temperature Operation: 1300 - 1380°F (700 - 750°C)

- Air Blown Gasification

- Gasifies With Circulating Fluid Bed Technology
  - Reactor, cyclone, seal pot & solids return line

- Incorporates Equipment Proven In Other Processes
Direct Causticization Of Sodium Will Simplify Mill Operations

Direct causticization with metal oxide is a potential process with ABB's BLG system

Produce NaOH directly from bed solids
No NaCO₃ Formed
Key Drivers to Replace Tomlinson

- **Availability**
  - New Tomlinson typical 96% availability
  - Many years of optimization to achieve this
  - BLG has more unit operations
    - More that can go wrong
    - Availability product of individual availabilities
    - No track record
  - Availability more important as greater fraction of mill liquor gasified
    - Incremental capacity less important
    - Full replacement must match Tomlinson
  - Cost of downtime can be as much as $500K/day in lost profit
    - Small gains in other areas quickly negated
Key Drivers to Replace Tomlinson

- **Capital Cost**
  - Pressurization seems necessary in order to match Tomlinson on initial cost evaluation
  - Estimate of costs (250 tonnes/day - similar scope)
    - Mini-CRU - $20-25M
    - ABB BLG (Atmospheric) - $40M
    - ABB BLG (5 bar) - $15-20M
  - Keys for ABB Technology
    - Impact of pressurization on fluid bed capacity
      - Limits on solid loading
    - High pressure gas cleanup implications
      - H2S/CO2 selectivity
    - Major uncertainties still present
Key Drivers to Replace Tomlinson

- **Electrical Efficiency**
  - Can BLG make more KW out of same amount of black liquor
  - Encourages pressurization (ABB process less so)
  - Should not require "exotic" heat exchange
  - Gas turbine operation key
    - impact of dirty gas
    - lower efficiencies
  - Must be looked at in overall mill context
    - parasitic losses
    - pinch points
  - Creation of steam deficiency must be addressed
    - What will be the relative value of electricity versus steam
  - Major impact on economics
Key Drivers to Replace Tomlinson

• Improved Chemistry
  - Split sulphidity
  - Can mills take advantage of different sulphidity white liquors
  - Will sulphur separation be sufficient
  - Economic impact on pulping?
  - Major economic impact $5-$10/tonne pulp possible savings
  - ABB process well suited
  - Promising demonstrations with TiO2 have been conducted
  - Recovery of TiO2 has major influence on economics

• Lower carbon loss
• May be major challenge
• Higher reduction efficiency
• Surprisingly low economic impact
Key Drivers to Replace Tomlinson

- **Red Herrings**
  - **Emissions**
    - Possible reduction in NOx
    - Little other benefit
  - **Safety**
    - Smelt/Water explosion limited
    - Pressurized explosive poisonous gas added
    - Pressure vessels added
    - More unit operations
Major Technology Uncertainties

- Gasification uncertainties
  - Impact of variations in liquor chemistry
    - heating value
    - solids level
    - non-process elements (K, Cl)
  - Gasification rate at pressurized conditions
    - will this be reduced and thus negate pressurization benefit?
  - Agglomeration - ABB Process
    - maximum operating temperature?

- Materials questions
  - Gasifier material selection
    - Corrosion/erosion resistance
    - Impact of high sulphur gases in heat exchangers
Major Technology Uncertainties

- **Direct Causticizing - ABB Process**
  - TiO2 recovery/recycle
  - NaO/TiO2 ratio
  - Causticizing efficiency

- **Gas cleanup requirements**
  - Alkalis will present major challenge
  - Can this be done in an economical manner?

- **Turbine requirements**
  - How much derating of turbines be required
  - Will electrical efficiency loss be acceptable
  - Variability in gas heating value
Major Technology Uncertainties

• Mill Integration
  – Pinch points (Match of heat sources and sinks)
  – Reduced steam production
    • More biomass burning required
  – Increased condensate volumes
  – Larger footprint of all equipment?
Critical Path For Development

For ABB

- Large pilot plant - 10-30 tonnes/day
  - Demonstrate long term operation (30 days)
  - Quantify pressurization benefits
  - Quantify impact of direct causticizing
  - Determine cost of demonstration
- Demonstration Plant - 200-300 tonnes/day
  - Availability demonstrated
  - Tie-in with gas turbine
  - Economics of operation
- Commercial operation
**Critical Path for Development**

- **Current Status**
  - Project on hold due to lack of funding for 1997
    - No demonstrated market demand
    - Many other competing projects within ABB
    - Quick return cannot be realized (3-5 years before profit)
    - Pilot stage next step
  - PFBC Impact
    - Large investment in this technology
    - Limited sales thus far
    - Potential is an excellent source of expertise on turbine tie-in issues and pressurization design
How Can the P&P Industry Help

- Ensure that New Bern Unit is successful technically and commercially
- Clearly demonstrate desire to pursue this technology
- Co-sponsor ABB pilot demonstration
Summary

- Key drivers to replace Tomlinson
  - Availability
  - Electrical Efficiency
  - Capital Cost
  - Improved Chemistry

- Major technical uncertainties
  - Gasification process
  - Material selection
  - Gas cleanup
  - Gas turbine operation
  - Mill Integration

- Critical Path for ABB
  - Pilot plant
Black Liquor Technical Breakout Session, Day 1

Momtaz Monsour
MTCI, Inc.

(no transparancies)
Black Liquor Technical Breakout Session, Day 1

Chris Verrill
Babcock & Wilcox

"Commercialization of Black Liquor Gasification,
B&W Perspectives on Steps Needed to Commercialize Gasifier/Gas Turbine Systems"
Commercialization of Black Liquor Gasification

B&W Perspective on Steps Needed to Commercialize Gasifier/Gas Turbine Systems

BLACK LIQUOR / BIOMASS GASIFICATION WORKSHOP
PRINCETON, NEW JERSEY
JANUARY 16, 1997
Commercialization of Black Liquor Gasification

Presentation Outline

♦ B&W Development Program
♦ Obstacles to Commercialization
♦ Successful Demonstration of BLG
Current Status

- Internal Design Study (1990-1993)
- Proof-of-Concept Testing (co-funded by DOE)
  - Designed & constructed bench-scale facility
  - Conducted bench-scale test program
  - Completed comparative economic evaluation
  - Defined pilot plant design, test plan & modeling needs
- Proposals to AFPA Agenda 2020 Program
Results of Bench-Scale Tests

- Low-Temperature Gasification Feasible
  - Low HHV gas produced at 1200°F \( (650^\circ C) \)

- Tar Formation was Observed
  - Small quantity & most condensed at low temperature

- Incomplete Char Conversion
  - Char accumulation noted at 1000-1200°F \( (550-650^\circ C) \)

- Bed Material Free-Flowing when Fluidized

- More Testing Required
  - Must address char and tar control
B&W Development Program

Economics Evaluation

- First commercial-scale units (450,000 lb BLS/day)
- Annual cash-flow based analysis
- BLG & BLG-CC compared with small recovery boiler
- Development expenses not considered
- Sensitivity of financial performance tested:
  - Displaced fuel price
  - Capital and OTF costs
  - Annual fixed O&M costs
  - Gasifier energy performance
Economics Evaluation

- Economic Performance
  - BLG producing gas equal or superior to modular recovery boiler for all cases except high capital & OTF cost scenario
  - BLG-CC equal or superior for all cases

- Technology Assessment
  - greater energy output flexibility
  - greater process flexibility (split sulfidity liquors)
B&W Development Program

Pilot-Scale Gasifier Design

♦ Based on concept prior to bench-scale testing
♦ Developed preliminary specifications
♦ Developed test and modeling plan
  ■ Model development and validation coordinated with test plans
  ■ Modeling used to screen test conditions, interpret findings, and scale results
Obstacles to Commercialization

Low-Temperature Processes:

♦ Slow Gasification Kinetics
♦ Incomplete Conversion of Tars
♦ More $\text{H}_2\text{S}$ in Product Gas
♦ Development Costs, esp. Tar Control
Obstacles to Commercialization

High-Temperature Processes:

- Low Fuel Conversion
- Low-Grade Heat Rejection
- Inorganic Fume Formation
- Molten Smelt Attack
- Incomplete Sulfate Reduction

- Development Costs, esp. Hot Gas Clean Up
# Obstacles to Commercialization

## Energy Penalties (MBtu/ADTP)

<table>
<thead>
<tr>
<th></th>
<th>High-Temp Air, 1 atm</th>
<th>Low-Temp Air, 1 atm</th>
<th>Conv. Boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>5.92</td>
<td>0.53</td>
<td>~ 0</td>
</tr>
<tr>
<td>Causticizing</td>
<td>2.38</td>
<td>2.93</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*3000 lb BLS/ADTP (Bleached)*
Obstacles to Commercialization

Causticizing Requirements

- H₂S and CO₂ absorption forms NaHCO₃
- CO₂ coabsorption minimized by good scrubber design
- Bicarbonate requires twice the lime to causticize
- 25% higher lime demand for high-temperature BLG
- 50% higher lime demand for low-temperature BLG
- Kiln capacity may require increase but balance of caustic plant equipment unaffected
Successful Demonstration of BLG

Definition of Commercial Success

♦ Must Equal or Exceed Conventional Technology:
  ■ Maintenance, reliability & safety
  ■ Chemical recovery & thermal performance
  ■ Emissions
  ■ Sensitivity to liquor variations
  ■ Turn-down capability

♦ Must Realize Additional Benefits:
  ■ More favorable electrical-to-steam ratio
  ■ More process flexibility (split-sulfidity liquors)
♦ Practical means to utilize char and tar byproducts
♦ Adequate product gas heating value for IGCC
♦ Complete sodium and sulfur recovery
♦ No organic contamination of green liquor
♦ Minimal NaHCO₃ formation during product gas scrubbing
Successful Demonstration of BLG

High Temperature Processes:

- Energy efficient gas cleanup
- Product gas quality for gas turbine integration
- Complete Na & S recovery
- Minimal impact on causticizing
- Suitable materials to withstand smelt attack
Successful Demonstration of BLG

Approach for Commercialization

♦ Concept sufficiently proven at bench-scale
♦ Process performance evaluated at pilot scale
  ■ Paper industry partners
♦ Modeling used to scale pilot results to commercial
♦ Extended operation of small commercial installation
  ■ Paper industry & turbomachinery partners
♦ Validated modeling to support commercial designs
Successful Demonstration of BLG

Numerical Modeling Capabilities

♦ Flow & combustion models for fossil fuel applications since 1970

♦ Recovery boiler models utilized since 1991
  ■ 110 cases for 12 units

♦ Advanced black liquor combustion model
  ■ Scaling laboratory data to commercial conditions
  ■ Applicable to gasification systems
Successful Demonstration of BLG

Modeling Gasification Systems

- Entrained-flow gasifier models
  - 2 Laboratory, air & oxygen blown
  - 2 Commercial, oxygen blown
  - 1 Commercial design replacement, oxygen blown

- Fuels considered
  - Pulverized coal
  - Coal-water slurry
  - Distillate fuel
Successful Demonstration of BLG

Paper Industry Support

♦ Technology cannot be solely developed by suppliers:
  ■ Prohibitive liquor supply and product disposal costs
  ■ Lack of resources to test mill integration

♦ In-kind support of paper companies needed:
  ■ Sites for pilot plants and demonstration units
  ■ Systems engineering for mill integration
  ■ Backing U.S. suppliers for support by Agenda 2020
Black Liquor Technical Breakout Session, Day 1

Stefan Jönsson
Kvaerner/Chemrec
A venture company in the Kværner Pulp & Paper business area

Kraft chemicals recovery and power generation based on black liquor gasification

Commercialize basic proprietary technologies
Develop expanded and stepout technologies
Prepare and implement plant projects based on new technologies

Executive management
Control and administration
Contracts and negotiations
Technology
Studies and commercial configurations
Projects and plants
CHEMREC® Recovery
Two major applications

CHEMREC Recovery capacity booster
- Relieve overloaded recovery boilers
- Capacity expansion projects

CHEMREC IGCC (Integrated Gasification Combined Cycle)
- Replace old recovery systems
- Recovery technology for greenfield mills
**CHMREC® Recovery Milestones**

<table>
<thead>
<tr>
<th>Type</th>
<th>Capacity (TDS/24 h)</th>
<th>Company</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot plant</td>
<td>3</td>
<td>SKF Hofors</td>
<td>1987–1990</td>
</tr>
<tr>
<td>Demonstration plant</td>
<td>100</td>
<td>AssiDomän</td>
<td>1992–</td>
</tr>
<tr>
<td>Pressurized pilot plant</td>
<td>6</td>
<td>STORA</td>
<td>1994–</td>
</tr>
<tr>
<td>Commercial plant</td>
<td>350</td>
<td>Weyerhaeuser</td>
<td>1996–</td>
</tr>
<tr>
<td>Financing and engineering, pressurized demo plant</td>
<td>1996–</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHEMREC® vs Recovery boiler
Energy flows Cogeneration

HHV-basis

Electricity 12%

Modern Recovery boiler
Steam 54%
Losses 34%

Electricity 24%

CHEMREC® IGCC
Steam 53%
Losses 23%
CHEMREC

1) Commercial Considerations
   - Bottom-line Benefits
   - Efficiency
   - Environmental Credits
   - Competitiveness vs Alternate Technologies
   - Replacement/Greenfield/Capacity Addition
   - Trade-off Investment/Operating Benefits

2) Technical Issues
   - Availability
     Backup/Spares/Operating Patterns
   - Gasification
     Pressurization
     Oxidant Use
     Maintenance Cycle
   - Gas Clean-up
     Conventional
     Novel - P1, P2
   - Gas Turbine Compatibility
     Medium BTU Gas
     Alkali Control
- Mill Integration
  Energy
  Chemicals Streams
  Host Plant Process Closure

- Chemicals Recovery
  Stream Specs Requirements

- Lime-burning Requirement
  Status Quo
  Ultimate Elimination

3) Critical Path Issues

- Scale-up
  3, 15, 300, 600

- Understanding the Investor Logic

- Bankability/Stand-alone Financing

- The Commercial Proposition

4) Cellulose Industry Facilitating Actions

- Long Term Replacement Strategy for CR Boilers

- IPP Alliances or Analogues
Biomass Technical Breakout Session, Day 1

Jim Patel
Carbona Corporation
Workshop on Commercialization of Biomass Gasification in Pulp and Paper Industry

by J. G. Patel
CARBONA CORPORATION
Atlanta, GA

January 16-17, 1997
Princeton, NJ
Minnesota Agri-Power Project

- Farms
  - Alfalfa from Fields
  - Direct to Plant
- Storage
  - Bales
  - Alfalfa from Fields
- Dryer/Separator
  - Stems
  - Leaf
- Co-Product Processing
  - Alfalfa Products
- Gasifier
  - Fuel Gas
- Hot Gas Cleanup
- Combustion Turbine
  - Electricity 50 MW
- Natural Gas
- Heat Recovery Steam Generator
  - Stack
  - Steam
- Steam Turbine
  - Electricity 30 MW
CARBONA INC.

- Continue the gasification business of Tampella Power and Enviropower
- All technology rights acquired by Carbona
- All development and know-how transferred to Carbona
- Pilot facilities in Finland available
- Will continue the commercialization of Enviropower gasification technology
- Competence network with old partners
IGCC Process

PARTICULATE REMOVAL

NATURAL GAS

GAS TURBINE

STEAM TURBINE

FINE ASH

AIR

FUEL GAS

STEAM BOOSTER

STEAM

ASH AND SPENT SORBENT

GASIFIER

BIOMASS SORBENT

GAS COOLER

CYCLOINES

BFW
Process Development

- Biomass feed system
- Drying
- Gasification
- Gas clean-up
- Gas combustion
- Biomass and coal
- 1991 to 1995
- Support for 2 demonstration plants
Enviropower's Gasification Pilot Plant
Pilot Plant Test Program

Coal for Clean Coal Project
Forest & Paper Mill Residue for Summa Project
Willow Residue for Biocycle Project
Process Design Information
Equipment Design Data
Environmental Design Data
Feed Characteristics

- Paper mill residue
  - bark, sludge, paper, plastic, sawdust
- Forestry residue
  - trunk wood, branches, needles, bark representing spruce, aspen, birch and adler
The Range of Feedstock Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate analysis wt%, dry</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>49.7 - 52.0</td>
</tr>
<tr>
<td>H</td>
<td>5.5 - 5.9</td>
</tr>
<tr>
<td>N</td>
<td>0.5 - 0.7</td>
</tr>
<tr>
<td>S</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>As</td>
<td>2.7 - 5.4</td>
</tr>
<tr>
<td>Moisture (as fed), wt%</td>
<td>18 - 42</td>
</tr>
<tr>
<td>Fuel LHV (dry) MJ/kg</td>
<td>18.6 - 19.3</td>
</tr>
<tr>
<td></td>
<td>8000 - 8300</td>
</tr>
<tr>
<td></td>
<td>Btu/lb</td>
</tr>
</tbody>
</table>
Biomass Pilot Test Runs

Operation pressure  14 - 18 - 22 bar
Operation Temperature  800 - 950 °C
Plant Capacity  15 - 17 MJ/s (MWth), 100 ton/day

FUELS GASIFIED (1993 - 1995)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Amount/tn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Chips</td>
<td>1630</td>
</tr>
<tr>
<td>Forest Residue</td>
<td>1750</td>
</tr>
<tr>
<td>Paper Mill Waste (bark, paper, sludge)</td>
<td>1180</td>
</tr>
<tr>
<td>Willow</td>
<td>400</td>
</tr>
<tr>
<td>Straw with Coal</td>
<td>20 (+120 tn coal)</td>
</tr>
</tbody>
</table>
The Range of Main Operating Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Equivalent Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier pressure</td>
<td>13 - 19 bar(g)</td>
<td>189 - 276 psig</td>
</tr>
<tr>
<td>Bed Temperature</td>
<td>850 - 880 °C</td>
<td>1560 - 1620 °F</td>
</tr>
<tr>
<td>Fuel feed rate (as fed)</td>
<td>0.38 - 0.98 kg/s</td>
<td>3016 - 7778 lb/h</td>
</tr>
<tr>
<td>Thermal input (LHV)</td>
<td>5.0 - 13.3 MJ/s</td>
<td>17.1 - 45.5 MMBtu/h</td>
</tr>
<tr>
<td>Air feed rate</td>
<td>0.60 - 1.43 kg/s</td>
<td>4762 - 11350 lb/h</td>
</tr>
<tr>
<td>Steam feed rate</td>
<td>0 kg/s</td>
<td>0 lb/h</td>
</tr>
<tr>
<td>Fluidization velocity</td>
<td>0.5 - 1.2 m/s</td>
<td>1.6 - 3.9 ft/s</td>
</tr>
<tr>
<td>Filter temperature</td>
<td>450 - 570 °C</td>
<td>840 - 1060 °F</td>
</tr>
</tbody>
</table>
### Biomass Gasification

#### Pilot Test Program/Test Results

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>During</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot plant fuel input</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Product gas LHV (dry)</td>
<td>4.5 - 5.6</td>
<td>4.5 - 5.6</td>
<td></td>
</tr>
<tr>
<td>Fuel conversion</td>
<td>97 - 99</td>
<td>97 - 99</td>
<td></td>
</tr>
<tr>
<td>Product gas dust content</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
<td></td>
</tr>
<tr>
<td>after ceramic filter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkalines (K + Na)</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Product gas H₂S content</td>
<td>15 - 50</td>
<td>-200</td>
<td></td>
</tr>
<tr>
<td>Product gas NH₃ content</td>
<td>500 - 1500</td>
<td>-2200</td>
<td></td>
</tr>
</tbody>
</table>
Fuel Gas Characteristics

- Caloric value suitable for GT
- LHV of wet gas varied between 3.4 - 5.0 MJ/Nm\(^3\) with feed moisture of 18 - 33 wt\%. With design value of 30 wt\% LHV = 4.2 MJ/Nm\(^3\).
- Tars & Oils
  - Very low light tars are benzone & naphthalene 5 to 10 g/Nm\(^3\).
  - Heavy tars before filter 25 - 100 mg/Nm\(^3\)
  - After filter less than 4 ppmw
  - Affected by freeboard temperature and residence time.
- Nitrogen Compounds of Fuel Nitrogen
  - HCN and NH\(_3\). 40-55\% converted.
Biomass Pilot Test Runs

Operation pressure
14 - 18 - 22 bar

Operation Temperature
800 - 950 ºC

Plant Capacity
15 - 17 MJ/s (MWth),
100 ton/day

FUELS GASIFIED (1993 - 1995)

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<td></td>
</tr>
<tr>
<td>Willow</td>
<td></td>
</tr>
<tr>
<td>Straw with Coal</td>
<td>20 (+120 tn coal)</td>
</tr>
<tr>
<td>Turbine Type</td>
<td>Heat Input (MW)</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>EGT, Typhoon</td>
<td>7.5</td>
</tr>
<tr>
<td>Mitsubishi, MW151</td>
<td>39</td>
</tr>
<tr>
<td>GE, F6B</td>
<td>62</td>
</tr>
<tr>
<td>Westinghouse, CW251</td>
<td>72</td>
</tr>
<tr>
<td>Siemens, V64.3</td>
<td>97</td>
</tr>
<tr>
<td>GE, F6FA</td>
<td>110</td>
</tr>
</tbody>
</table>

Assumptions: 8000 h/a, wood waste of 50% moisture AR, condensing plant
Specific Investment Cost

![Graph showing specific investment cost vs. power plant size. The graph compares IGCC Power Plant and Conventional Power Plant costs.]

- **IGCC Power Plant**
- **Conventional Power Plant**

**Power Plant Size, MW**

**USD/kW**
Cost of Electricity
Process Heat for Pulp and Paper Industry

![Graph showing the relationship between the cost of electricity (mills/kWh) and heat demand (MJ/s) for different types of electricity generation: IGCC (Integrated Gasification Combined Cycle) and Conventional Generation.](image-url)
Challenges of Commercialization

- Demonstration Projects & Efforts
  - Summa Project
  - Biocycle Project
  - MAP Project
- Technology
- First of a kind plants
- Competitiveness & Economics
- Performance & Guarantees
- Cost Reduction
- Corporate decision making
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Biomass Gas</th>
<th>Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dried biomass feed rate, lb/h (9.4% moisture)</td>
<td>91,300</td>
<td>0</td>
</tr>
<tr>
<td>Gasifier heat input (hhv), MMBtu/h</td>
<td>669</td>
<td>574</td>
</tr>
<tr>
<td>Combustion turbine firing rate (hhv), MMBtu/h</td>
<td>50.1</td>
<td>53.3</td>
</tr>
<tr>
<td>Heat export to leaf processing plant, MMBtu/h</td>
<td>29.3</td>
<td>19.8</td>
</tr>
<tr>
<td>Steam @ 4,100 lb/h</td>
<td>79.4</td>
<td>73.1</td>
</tr>
<tr>
<td>Power production, MW</td>
<td>-4.3</td>
<td>-2.7</td>
</tr>
<tr>
<td>Flue gas @ 310,000 lb/h</td>
<td>75.1</td>
<td>70.4</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>8,910</td>
<td>8,155</td>
</tr>
<tr>
<td>Steam turbine</td>
<td>38.3</td>
<td>41.9</td>
</tr>
<tr>
<td>Gross</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating rate (hhv), Btu/kWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall efficiency, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Biomass gas temperature 1,020 F, HHV = 155 Btu/SCF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Technology

- Feeding system
- Gasification
- Gas clean-up
- Integration & control
Operating Experience

- IGT Pilot Plants
- U-GAS low pressure
- U-GAS high pressure
- Renugas PDU
- Large Test Plants
- Enviropower Plant
- Hawaiian Plant
- Commercial Plants
- Shanghai Project - China
- Sanghi Project - India
Pulp & Paper Industry

- Needs a demonstration plant
  - cost
  - economics
  - performance
  - environmental impacts
  - Fuel mix

- Financing & Risks
  - DOE clean coal program
  - 50/50 cost sharing
  - Partnership of vendors/users
  - Payback by technology owners from future profits
INCREASING EFFICIENCY AND DECREASING COSTS IN IGCC DEVELOPMENT

The graph illustrates the trend of capital cost ($/kW) over time from 1985 to 2020. The capital cost decreases significantly from 3000 $/kW in 1985 to 500 $/kW by 2020. Simultaneously, the efficiency increases from 30% in 1985 to 55% by 2020. This trend indicates a significant improvement in IGCC technology over the years.
application to biomass gasification.

- WILL provide valuable data & information for
  
  GE6EF A turbine: 61 MW
  - Pinnon Pine, Nevada, Sierra Pacific
  
  GE 7FA turbine: 196 MW
  - Polk, Florida, TECO

  GE7FA turbine: 192 MW
  - Wabash River, Indiana, PSI

- 3 IGCC Coal Projects

Clean Coal Programs
### Exhibit 3-2
Annual CCT Program Funding, by Appropriations and Subprogram Budgets
(Dollars in Thousands)

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td><strong>Adjusted Appropriations</strong>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P.L. 99-190</td>
<td>248,500</td>
<td>149,100</td>
<td>50,000</td>
<td>190,000</td>
<td>135,000</td>
<td>199,997</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>397,600</td>
</tr>
<tr>
<td>P.L. 100-202</td>
<td>419,000</td>
<td>155,998</td>
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<td></td>
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<td>574,997</td>
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<tr>
<td>P.L. 101-446</td>
<td>35,000</td>
<td>315,000</td>
<td>50,000</td>
<td>190,000</td>
<td>135,000</td>
<td>199,997</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>574,998</td>
</tr>
<tr>
<td>P.L. 101-121p</td>
<td>100,000</td>
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<td>600,000</td>
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<tr>
<td>P.L. 101-121p</td>
<td>225,000</td>
<td>37,121</td>
<td>200,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>287,879</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>248,500</td>
<td>199,100</td>
<td>190,000</td>
<td>554,000</td>
<td>390,995</td>
<td>415,000</td>
<td>0</td>
<td>225,000</td>
<td>37,121</td>
<td>200,000</td>
<td>287,879</td>
<td>2,747,595</td>
</tr>
</tbody>
</table>
Biomass Technical Breakout Session, Day 1

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"
ACCELERATED BIOMASS GASIFICATION COMMERCIALIZATION

The Perspective of a Thermal Equipment Supplier, Turnkey Facility
Engineer/Constructor, and Independent Power Developer/Financer

By John W. Rohrer

Vice President - Zurn/NEPCO and Industrial Energy Partners
South Portland, Maine

Presented at the Biomass Gasification Commercialization Workshop
January 16 - 17, 1997
Princeton University, Center for Energy and Environmental Studies
Overview

This presentation is given from the perspective of a firm, Zurn/NEPCO, currently responsible for both equipment supply and turnkey facility engineering and construction of the 15 MW FERCO/BCL commercial demonstration facility now nearing completion in Burlington, Vermont. Zurn/NEPCO is a U.S. market share leading turnkey engineering and construction firm in both biomass power plants and gas turbine combined cycle plants. Zurn's Energy Division is a leading supplier of biomass boilers and combined cycle heat recover steam generators (HRSG's). I am also a principal of Industrial Energy Partners, an independent power producer partnership between Zurn Industries, American Electric Power, and Cogentrix focusing on development, financing, and ownership of industrial powerhouses for large energy intensive industries. The Independent Power Producer (IPP) or Non-Utility Generator (NUG) perspective is, therefore, also included.

The Commercialization Challenge

As new technologies move from the laboratory to industry succeeding plant generations undergo continuing changes and improvements. Most of the Nth plant economic benefits can be achieved by generation 3 or 4 if the risks of revolutionary improvements can be justified. If a more risk adverse evolutionary process is necessary, it may take generation 6 to 10 to realize the bulk of Nth plant economic benefits. Nth plant benefits (vs. The 1st commercial prototype) might include a 50% or greater reduction in capital cost per unit of output, a 25% improvement in conversion or thermal efficiency, and a two to ten-fold increase in maximum unit scale versus the first commercial unit. Scale alone is a powerful economic improvement because thermal process plant and equipment costs typically are not proportional to unit throughput, but rather increase at a 0.6 to 0.8 exponential scale factor (i.e., a four-fold scale up might result in a 2.65 fold capital cost increase at a 0.7 exponential scale factor).

For a promising biomass gasification technology to reach Nth plant economics, performance, and reliability obviously there must be a clear and timely path from the development laboratory through plant generations 1, 2, and perhaps 3. The severe reductions in federal renewable and biomass energy commercialization funding, the suspension of new U.S. generating capacity additions, due to the uncertainties of utility industry deregulation, and the availability of 3c to 4c power (producible with modern gas turbine combined cycle technology from $2 to $3/MMBtu natural gas), makes this an especially challenging time to try to commercialize new biomass gasification technologies.

No doubt, the most cost effective initial applications probably occur where oil or gas prices or power rates are highest and biomass residuals (bark, sawdust, sugar cane waste, rice hulls, etc.) are unutilized or underutilized. These conditions are prevalent in Latin America and the Pacific Rim where, in many locations, expensive diesels ($1 million/MW capital investment) are fueled with increasingly expensive high sulfur residual oil ($4/MMBtu). It is extremely challenging, however, to evolve and learn from equipment and facility designs for second and third generation plants which are so remote from their technology development teams. Project
development, contractual arrangements, and financing of Latin American and Pacific Rim energy projects (especially small ones) are also more challenging and time consuming.

There are many cost effective applications here in North America for biomass gasification, even in today’s depressed energy markets, if we had Nth plant economics. Fortunately we have at least some specialized applications here in North America for second and third generation plant economics with some of the more promising technologies.

The biomass gasification community, including its university, government, and private sector members, can advance biomass gasification technology worldwide by identifying, developing, and promoting these most promising second and third generation applications and opportunities and by addressing generic technical issues having major impacts on biomass gasification plant costs and performance.

**Fuel Choices**

The most promising biomass gasification opportunities for second and third generation units will come in areas where oil or gas is currently used at relatively high prices ($2.50 to $5/MBtu), biomass feeds are available at very low costs and perhaps negative cost (-$2 to +$1/MBtu), and biomass gas use equipment is currently available or can be installed at low capital cost (i.e., existing gas turbines, direct substitution for oil or gas without turbines, or direct utilization of biomass gas turbine waste heat in existing boilers and dryers).

I think the biomass energy community has focused too little attention on low cost and negative cost waste fuels and residuals and perhaps spent too much effort on dedicated energy crops. It is unlikely over the next several decades that we will develop any energy crops which can be grown, harvested, prepared, and gasified at a cost competitive with $2 to $3/MBtu natural gas or $4/MBtu residual oil. This effort might better be spent developing fast growing food or fiber crops that also produce residual biomass fuel. We also need better methods to co-harvest the residuals with these crops.

We should also remember that we currently have substantial underutilized and unutilized negative cost waste fuels which remain at low or negative cost even after processing and preparation for biomass gasification systems. These include refuse derived fuel, tire chips, material recycling facility (MRF), unmarketable paper “out throws”, de-watered industrial and municipal water treatment sludges, industrial scrap, auto shredder fluff, and a host of other materials. Perhaps my bias towards low and negative cost fuels is a result of my 15 years in the waste-to-energy business, an industry which badly needs a technological breakthrough like biomass gasification to regain economic viability.

**Equipment vs. Facility Development**

Most people associated with new gasification technologies and other thermal facility technologies make the mistake of thinking that the major challenge is to develop better integrated facility designs. In actuality, the primary challenge and the greatest economic
improvement will come from improved equipment design. Rearranging relatively standard reactor vessels utilizing standard refractory and insulation systems exhausting into standard refractory lined cyclones exhausting into standard heat recovery and gas cleaning equipment may yield evolutionary improvements if we have the time, patience, and money to allow those evolutions to take place over 6 to 10 equipment generations. More revolutionary improvements in capital cost reduction will occur through creative equipment builders who get greater throughput out of smaller, lower cost vessels, lined with lighter weight, more wear resistant refractory insulation systems utilizing less costly particle separators than expensive refractory lined hot cyclones, perhaps with integral heat recovery and inexpensive gas cleaning systems. The whole equipment package should be modularized and factory assembled with high productivity, low wage rate factory workers rather than low productivity, high wage rate on-site field construction personnel. Often multiple factory assembled modular units can be substantially lower in cost than single huge field erected units. The multiple units also provide important unit redundancy during outages.

**Generic Biomass Gasification Equipment Improvement Needs**

Actual gasifier reactor vessels are technology specific and their improvement is best left to the individual technology developers. Surprisingly, however, a relatively small portion of a biomass gas plant cost is invested in the gasifier vessels. There are many pieces of equipment common to all gas plants which contribute to high gas plant costs and/or reliability and performance problems.

Biomass dryers are high on the list of necessary generic improvements. While some gasifiers can operate with feed moistures up to 50%, it is always more cost effective to pre-dry typically wet biomass feeds rather than use the gasifier itself as an inefficient dryer (which reduces throughput and gas quality). Biomass dryers typically represent 15% to 30% of the cost of a biomass gas plant! Historically, pre-drying of biomass fuels for boiler applications resulted in generally bad experiences for forest products companies where most dryers have since been abandoned due to mechanical reliability and/or fire hazard problems.

To make dryers small and inexpensive high drying gas temperatures are required. This drastically increases dryer VOC emissions. Even at low temperatures (below 400°F) biomass dryers produce substantial VOC emissions. There is no evidence that these low temperature emissions have any adverse health affects (any more than a sweet smelling sawdust pile). Well intentioned, uninformed environmental regulators, however, may inadvertently fail in upcoming legislation and regulations to distinguish between low temperature, non hazardous biomass VOC emissions and compounds released at higher temperatures which may have some bio-hazard. This would be a serious setback for biomass gasification.

The industry has to find lower cost, more compact, higher throughput dryers or combined drying, shredding, and air classification systems compatible with low grade, low temperature waste heat produced by the gas plant and/or gas turbine exhaust (after it is first passed through a heat recovery steam generator). Single and multi-pass drum dryers are tried and true, but expensive and large. Innovative, compact, high throughput systems which will not overdry
fine particles while underdrying large particles are needed. The ultimate solution might be a
direct contact dryer that recovers sensible heat directly from the gasifier product gas (after
some initial high temperature heat recovery). Sensible heat recovery below 1000°F is
troublesome because even relatively well cracked biomass gas will have condensable which
will rapidly foul heat exchange surfaces. Losing this heat, however, can result in a 5% to
10% efficiency loss. This direct contact product gas dryer would also have major
environmental benefits because all VOC’s would either be condensed out on the feed material
or in the product gas scrubber or left in the product gas and combusted.

Hot and cold product gas cleaning also has areas of common generic interest although it is
somewhat gasifier process specific. I think the initial focus should be on cleaning a cold
quenched gas via low pressure drop scrubbing methods followed by effective mist elimination
and subsequent wet ESP or filtration, if necessary, to achieve gas turbine fuel inlet
specifications. There is a miss-perception within the industry that biomass gas from some
processes contain organic aerosols which cannot be effectively scrubbed out by conventional
means. Success depends upon quenching the product gas temperature well before it enters the
scrubber to allow time for aerosol coalescing prior to the scrubber. High tar content coal gas
and steel mill coke oven gas also require ESP’s after mist eliminators. They have proved
extremely effective and are relatively inexpensive.

Hot gas clean-up involves many technical challenges and should probably be put on a back
burner. The few vendors working in this area have not yet perfected the technology for coal
gas and will be reluctant to spend development money on biomass gas (from several different
types of gasifiers) until coal gas technology is better developed. Biomass gas contains
substantial amounts of ammonia which require a secondary absorption step after hot filtration
(to avoid high gas turbine NOx emissions). Biomass gas contains higher volatile alkali
compounds than coal gas, some of which condense at lower temperatures. They are disastrous
to gas turbine blading. Finally, most turbine manufacturers will not develop special small gas
turbine combustors to accept hot fuel gas.

Gasifier hot duct and hot cyclone refractories are another major gas plant cost. In atmospheric
pressure gas plants, vessel wall thickness and structural support steel requirements are dictated
by refractory weight, not vessel pressure. A major portion of vessel, hot duct, and cyclone
volume (i.e., 20% to 40%) is occupied by a refractory and insulation and, therefore, not
available to process flows. Field installed refractories often cost as much as the vessels they
are placed into. What is needed is thinner, lower density refractories with high wear resistant
and thermally shock resistant tile or surface coatings (i.e., silicone carbide tiles). The thermal
insulating properties of refractories are also important. A 300°F vessel skin temperature will
lose 5% to 6% of thermal input in a small gasifier system and 2% to 3% even in a large one.

Expensive gasifier feed mechanisms are another area of generic interest. Here both low
pressure and high pressure feed systems must be addressed. I feel low pressure biomass
gasifiers will prove less costly and commercialized first. I would, therefore, place initial
development focus on these systems. The generic design of a 15 psi and 15 atmosphere
pressurized feed system, however, may not be very different for some designs. A good feed
system involves good safe sealing (no explosive gas backflow into feed hoppers) combined with low cost, compact size, and minimum or no purged gas requirements. Plug flow auger or plunger type feed systems show the most promise for cost reduction. Establishing a good gas tight plug (without plugging the feed) is a challenge, however, especially when the biomass feed is variable with respect to particle size, geometry, and moisture content. Loose feed behind the feed plug must be kept above gasifier pressure or purged with inert gas to avoid explosion hazard. If inert purge gas is required it should be flue gas or you'll quickly go broke buying bottled nitrogen. Rotary lock hoppers should be avoided due to continuous jamming problems with heterogeneous biomass feed. Multi-valve lock hopper chambers provide fuel flexibility and reasonably reliable sealing, but are large and expensive.

Particulate/gas separation cyclones represent another major area for cost improvement. In fluid bed systems, hot refractory lined cyclones are often as expensive as the gasifier vessel itself. Chevron type impact separators or multiple small uninsulated ceramic cyclones in a common insulated containment are promising alternatives. Impact type separators may not be as efficient as cyclones, but remaining particulate can be removed after initial high temperature heat recovery using conventional high efficiency steel multi-clones. High temperature uninsulated ceramic multi-clones, unfortunately, do not exist. They would, however, be more efficient and less costly than the single large refractory lined insulated steel cyclones currently used.

Promising Cost Effective Second Generation North American Applications

Second generation gas plants will not be as cost effective as Nth generation plants for reasons previously described. The most cost effective applications will occur where the spread between biomass fuel price and current fossil fuel cost is greatest. Delivered natural gas to pulp & paper mills and other large North American industrial facilities ranges from $2 to $3/MMBtu. High sulfur residual oil, the primary alternative industrial fuel choice at those pulp & paper mills not serviced by natural gas (approximately 50% of all mills), currently runs about $4/MMBtu. Environmental restrictions are forcing many of those mills to go to low sulfur residual oil (0.7% to 1.0% sulfur) at a 50c to $1/MMBtu premium. The most prevalent pulp & paper biomass feedstocks (pulp mill bark and/or local sawmill bark and sawdust) ranges from -$1.50/MMBtu to +$1.50/MMBtu at North American mill sites. The most expensive biomass feedstock, but one virtually unlimited in quantity at almost all North American pulp & paper mill sites, is hardwood and softwood whole tree chips, mill delivered at $1.75 to $2.25/MMBtu. Obviously, if you are buying whole tree chips at $2.25/million and trying to convert it into a fuel gas, competing with $2 delivered natural gas (the lowest gas price only available in gulfl states and western Canada), you have -25c to cover capital and operating costs of the gas plant; not very promising. At the other extreme, however, there are sites not serviced by natural gas pipelines paying $4 to $5/MMBtu for residual oil. In rare instances they or local sawmills might have excess mill waste, costing 50c to $1.50/MMBtu, to landfill or incinerate. These limited situations are where crucial second generation gas plants will make the most sense.
Small (5 MW to 30 MW condensing equivalent) gas turbine combined cycle plants cost about $1 million/net MW installed. Simple cycle gas turbine plants (no heat recovery steam generator or steam turbine) cost about half that. The second generation gas plants necessary to support them add an additional $0.5 to $2.0 million/MW depending on scale and technology selected. Large, indirect or air blown atmospheric units tend to be the least costly alternatives. In addition to the largest possible biomass to current fuel price spread, the most attractive second generation applications should not involve any additional equipment investment other than the gas plant. The fuel gas can be directly used in existing on-site gas turbines, oil or gas fired power boilers, or chemical recovery kilns. If a gas turbine is required, simple cycle applications are more promising than combined cycle, especially if the hot turbine exhaust can be directly utilized for pulp drying, paper drying (on tissue hoods or hot air enhanced steam can drying), or for hot windbox repowering of existing fossil or biomass fired power boilers. Adding a 15 MW simple cycle gas turbine at the Burlington site (the Phase III plan) will increase that 50 MW plant’s efficiency from 22% currently to almost 30% through a combination of hot windbox repowering and furnace exhausting. All the turbine exhaust is used at 100% efficiency to displace current fuel purchases. The existing Burlington boiler makes the new gas turbine a combined cycle facility with no additional capital investment beyond the gas turbine purchase.

I do not think that the biomass gasification industry will be successful in encouraging turbine manufacturers to develop new specialized engines for biomass gas. The Big 4 (GE, ABB, Siemens, Westinghouse/Mitsubishi) combined only have a few large engines capable of running on 100 to 300 Btu/scf coal gas. All of these are rated over 70 MW simple cycle on natural gas. Encouraging these or other smaller engine manufacturers to adapt engines to low Btu biomass gas is unlikely given the major changes in combustor and compressor design necessary and the likely low sales volume combined with the current high cost of biomass gasification. I feel it is more promising to develop a biomass gas which is capable of operating in existing small and large gas turbines. This is why we favor an indirect gasification approach (it produces a 500 Btu/scf gas compatible with all existing turbines). This also reduces gas cleaning equipment, sizing, and gas compression equipment sizing and cost two to four-fold vs. low Btu gas. It might be easier to convince engine manufacturers to accommodate low or medium Btu biomass gas in future gas turbines currently under development. GE, for example, designed the 6FA and 7FA for both natural gas and low or medium Btu coal gas. New small turbine models could do the same thing. The new engines will have the benefits of higher efficiency and lower emissions. The pace of gas turbine engine development is startling and new large engine improvements will trickle down to smaller engines over the next several years.

IC engines for biomass gas don’t offer great promise. The high Hydrogen content of most biomass gases can create engine detonation problems. The large gas volume can also present a problem, especially in direct injection engines. Some engines also require 5% or more pilot distillate fuel co-fired with gas. Historically, IC engines have had an efficiency advantage (38% to 45% HHV) over gas turbines (30% to 40% simple cycle HHV). Gas turbine improvements are rapidly erasing this advantage, however, and gas turbines are two to four times cheaper than IC engines (depending on scale) and produce a higher volume and higher
temperature exhaust for combined cycle or industrial thermal use, resulting in higher overall efficiency than IC engines.

Technology developers will have to take the lead role in finding their most promising second generation applications. Universities, the Department of Energy, and trade organizations, however, can do much to study and publicize the advantages of some of these more promising applications to allow good second generation applications to surface.

**Financing Considerations in Second Generation Applications**

Pulp & paper mill applications represent the best near term prospects for biomass gasification commercialization in North America. Pulp & paper is highly capital intensive, however, requiring most firms to be extremely conservative and risk adverse with respect to capital investment in new technologies. The technology owner/developer, his preferred engineering and construction company, his equipment vendors, and perhaps a third party developer/financer given preferential rights to future projects, may all have more to gain from a second generation gas plant application than the host pulp & paper mill that will be realizing second generation economics, performance, and reliability for 15 to 30 years rather than waiting for the Nth generation to evolve. Waiting might, therefore, be a better career decision for the mill manager and engineering manager vs. being a second generation pioneer (it is said you can recognize pioneers by the arrows in their backs).

Independent developers/financiers (IPP’s and NUG’s) can play a valuable role in allowing second generation projects to proceed. Often projects can be structured with “tolling” arrangements. The mill might provide the biomass waste and buy biomass gas as it is produced and metered. Technological risks in such an arrangement is taken by the technology developer, equipment vendors, and IPP/NUG, not the mill. Because the mill is investing no capital and only paying for what it receives, it might be willing to proceed with such a project based on a 10% to 20% savings from current oil or gas cost where a 25% to 50% savings might otherwise be necessary to justify the risks involved.

IPP’s and NUG’s also can provide lower cost capital than most pulp & paper companies. Most pulp & paper companies are 25% to 50% debt financed, with the balance being equity. Stockholders require a higher return on equity than bond holders do for debt. IPP’s and NUG’s typically use 75% or more debt to finance their projects. Even if they require a higher return on equity than a typical pulp & paper company’s stockholder, their higher debt to equity ratio makes the cost of gas plant capital cheaper than if it was financed internally by the pulp & paper company at its higher weighted average internal cost of capital.

**Political Considerations**

I previously explained that the first applications will be driven by the biomass feedstock to alternative fuel price spread at any given mill which ranges from $0 to $5 for North American mills. Federal Section 29 tax credits are scheduled to expire unless substantial political support is mobilized to extend them. This tax credit was about $1/MMBtu for biomass gas
(paid to the producer when sold to a third party user). The “fuel free” cost (includes both capital and O&M) of converting biomass to clean gas currently ranges from $2 to $4/MMBtu of gas produced (again, depending upon scale and technology). With Nth generation technology and some of the technical advances discussed previously it may be possible to get the “fuel free” conversion cost to $1 to $1.50/MMBtu. The Section 29 credits could become a powerful incentive and substantially increase the likelihood of finding viable second generation applications to advance promising biomass gasification technologies. They cost the federal budget very little (because very few second generation plants were ready to be built to use them). The benefit of biomass gasification advancing renewable energy technologies for North American and worldwide use, however, is tremendous. Biomass energy plants currently enjoy a 5 year accelerated depreciation (vs. 20 year for conventional fossil fuel energy facilities). It is important that these tax benefits be maintained at least until second and third generation plants are operational.

The Department of Energy Renewables budget has been slashed, but still exists. It is important that DOE utilize these limited resources on those commercialization programs, yielding the highest and most immediate payback. Perhaps DOE can leverage their limited biomass energy funds by forming international collaborations with other organizations and countries. Focusing government, university, and industrial resources on some of the key common generic technical challenges facing biomass gasification and identifying and promoting some of the most promising industrial applications for second generation plants will go a long way in advancing biomass gasification technology on a timely basis.
ACCELERATED BIOMASS GASIFICATION COMMERCIALIZATION

The Perspective of a Thermal Equipment Supplier, Turnkey Facility Engineer/Constructor, and Independent Power Developer/Financer

By John W. Rohrer

Vice President - Zurn/NEPCO and Industrial Energy Partners
South Portland, Maine

Presented at the Biomass Gasification Commercialization Workshop
January 16 - 17, 1997
Princeton University, Center for Energy and Environmental Studies

J. Rohrer
Zurn/IEP
1/16/97
The Biomass Gasification Challenge

1st vs. Nth Commercial Plant

- 50% capital cost reduction (plus scale effect)
- 25% efficiency improvement
- Cheaper “waste” feedstocks

Challenging North American Energy Market

- Low natural gas prices
- Utility deregulation with regulatory uncertainty

Requires Technology/Cost Improvement

Requires Best 2nd Plant Application Identification
## Biomass Gasification Feedstock Costs
*(Shredded and Delivered)*

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Cost ($/MMBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp mill and sawmill wastes (bark &amp; sawdust)</td>
<td>-1.50 to +1.50</td>
</tr>
<tr>
<td>Whole tree chips (hardwood and softwood)</td>
<td>1.75 to 2.25</td>
</tr>
<tr>
<td>Energy crops (woody and grasses)</td>
<td>2.00 to 3.00</td>
</tr>
<tr>
<td>Sugar can waste</td>
<td>-0.50 to +1.0</td>
</tr>
<tr>
<td>Rice hulls</td>
<td>-0.50 to +1.50</td>
</tr>
<tr>
<td>Urban and demolition wood</td>
<td>-1.00 to +1.50</td>
</tr>
<tr>
<td>Refuse derived fuel (RDF)</td>
<td>-1.00 to 0</td>
</tr>
<tr>
<td>MRF waste paper rejects (&quot;outthrows&quot;)</td>
<td>-1.00 to 0</td>
</tr>
<tr>
<td>Shredded (sheared) tire chips</td>
<td>-2.00 to +0.50</td>
</tr>
<tr>
<td>Water treatment sludges (at 65% moisture)</td>
<td>-10.00 to -3.00</td>
</tr>
</tbody>
</table>

J. Rohrer  
Zurn/IEP  
1/16/97
Equipment vs. Facility Development

- “It's the equipment stupid”

- Integrated plant design plays lesser role

- Modularization and factory assembly packaging will lower cost
Major Generic Biomass Gasification Equipment Improvement Needs

1. Dryer
   - Now 15% - 30% of gas plant cost
   - Pulp mills hate bark dryers (fires and plugs)
   - VOC dryer emissions problems
   - Traditional drum types too slow and expensive
   - Promising Concepts:
     - Direct contact product gas dryers
     - Combination classifiers/shredders/dryers

2. Cold (and later, Hot) Gas Clean-up
   - Removing Condensables
   - Pre-quenchers, scrubbers, mist eliminators, wet ESPs
   - Hot Gas Clean-up Challenges
     (reliability, alkali aerosols, ammonia, turbine compatibility)

J. Rohrer
Zurn/IEP
1/16/97
Major Generic Biomass Gas Equipment Improvement Needs (continued)

3. Refractories and Insulation
   - Current systems consume 20% to 40% of usable volume
   - Costs more than vessels
   - Loses 2% to 6% of thermal input
   - Promising Concepts:
     * low density, ceramic tile lining, factory installation

4. Gasifier Feed Systems
   - Forget rotary and flapper valve lock hoppers
   - Watch purge gas type and consumption
   - Watch leak back explosion hazards
   - Develop pressurized systems later (less cost effective)
   - Promising Concepts:
     * Auger or ram sealing plug systems promising, but very feed specific and need testing/development

5. Gas/Particle Separation Systems
   - Refractory lined steel cyclones cost more than gasifier vessels
   - Impact type separators (chevron types) much cheaper, but less efficient
   - Ceramic multi-clones (in common insulated enclosure) would be great, but don’t exist

J. Rohrer
Zurn/IEP
1/16/97
Low Btu Small Gas Turbine Engine Development

- Small turbine makers will not do low Btu engine modifications

- 500 Btu/scf gas does not need engine modifications

- IC engines are twice the cost of gas turbines
Most Promising North American Applications for Plant #2

- Greatest price spread between biomass feed and gas or #6 oil

- Find existing gas use equipment; turbines, boilers, kilns

- Simple cycle over combined cycle

- Find direct oil/gas substitution uses for hot turbine exhaust (pulp or paper dryers; power boiler hot windbox repowering)

- Universities, trade groups, DOE, and technology developers should work together to identify and promote applications
Second Generation Plant Financing Considerations

- Pulp and paper mills best N.A. prospects

- IPP's and NUG's can:
  - insulate mills from technology risks
  - provide cheaper capital than paper companies
  - identify, develop, and finance initial applications
Political Considerations for Biomass Gasification Commercialization

- Extension of Section 29 tax credits at $1/MMBtu would greatly increase plant #2 prospects
  - biomass vs. Gas/oil fuel spreads are $0 - $5/MMBtu
  - Fuel free conversion costs are $2 - $4/MMBtu

- Extension of 5 year biomass tax depreciation also helps

- Effectively targeted DOE and university programs and international collaborations will be major help
Biomass Technical Breakout Session, Day 1

Michael Morris
TPS
Engineering Services:
- Licensing of CFB Combustion Technology
- Licensing of CFB Combustion Technology
- Special Flow Measurement Devices
- Engineering Consultancy and Services

Energy Related Contract R&D with Emphasis on:
- Environment
- Combustion and Gasification
- Electricity and Heat Generation

No. of Personnel: 45 (1994)

Turnover: 45 million SEK (1994)
COMMERCIAL BIOMASS GASIFIERS

IMBERT

VØLUND BIONEER

GÖTAVERKEN LURGI AHLSTRÖM TPS

HTW/LURGI ENVIROPOWER BIOFLOW

Product gas cooling
Hot gas filter

Biofuels
Gas

Biofuels
Gas

Air

Air

Sorbent Fuel
Air Nitrogen

Gas

Gas

Steam

Ash removal

DOWNDRAFT FIX BED
UPDRAFT FIX BED
CFB

CFB or FB Pressure > 1.0 MPa

1kW 100kW 1000kW 1 MW 10MW 100MW

1000 MW FUEL CAPACITY

Conv. Fluid bed
Gas chromatograph values recorded before and after the dolomite cracker (laboratory experiments)
Fuels Tested in Laboratory or Bench-scale Apparatus:

- Peat
- Straw
- Wood chips (e.g. Swedish, Spanish, Brazilian)
- Industrial Waste
- Pelletised RDF (Refuse Derived Fuel)
- Lignite
- Waste paper
- Sewage sludge

Fuels Tested in TPS’s 2MW CFB Gasification Pilot Plant:

- Wood chips (e.g. Swedish, Spanish, Brazilian, English)
- Bark
- Wood pellets
- Pelletised Industrial Waste
- Pelletised RDF (Refuse Derived Fuel)
- Lignite
CFBG Combined-cycle Scheme
Gasification Projects:

- Gréve-in-Chianti 2 x 15 MWth RDF-fuelled Gasification Plant, Italy
- World Bank-financed 30 MWe Biomass Integrated Combined Gasification - Gas Turbine Project, Brazil
- EU Thermie Project. Short Rotation Forestry-fuelled 8 to 12 MWe Gasification Combined-cycle Project
- Noord Holland Biomass/Waste-fuelled 30 MWe Gasification Combined-cycle Project Study
Grève-in-Chianti

2 Gasifiers, 15 MW\textsubscript{t} each
Gas Boiler and Flue Gas Cleaning
Power from 6.7 MW\textsubscript{e} Condensing Turbine
Fuel Gas to Cement Factory

Licensee: Ansaldo Aerimpianti

Start-up of Gasifier No.1: Nov. 1991
Turned over to Client: Aug. 1992
Start-up of Gasifier No.2: Sep. 1992
Turned over to Client: March 1993
BIG-GT Demonstration Project

* General Plant Data, Fuel input 60 MW
  - Type: Eucalyptus
  - Bulk density: 500 kg D.S./m³
  - Moisture, avg: 35%
  - Ash: 0.3-0.5%
  - LHV: 18.4 MJ/kg D.S.
  - Type: Bagasse
  - Bulk density: 150 kg D.S./m³
  - Moisture, avg: 35%
  - Ash: 3-5%
  - LHV: 17.8 MJ/kg D.S.
BIG-GT Technology Learning Curve

Specific Investment $/kW

Cost of Prototype

GEF Grant (Phase III)

$1500/kw

$1300/kw

Number of identical plants

Figure 2
EC Targeted Thermie Biomass Gasification Project

Description:
Short rotation forestry (SRF)
Biomass gasification
Electricity and heat production (8 to 12 MWe)

Others:
Fluidised bed IGCC technology
Sale of electricity and heat
At least 3 different EC Member countries
EU Thermie Programme

8 MWe Combined-cycle Plant

Overall cost = £26 million
EU contribution = 40%
Other grants from Forestry Commission

Partners: Yorkshire Water, TPS and others
Interested parties: Department of Trade and Industry (ETSU)

Fuels: Short rotation forestry (poplar wood)

NFFO
Set aside land
Sewage sludge disposal
Combined-cycle Plant Study for Noord-Holland

Project: Basic Design of 30MWe combined-cycle plant (TPS and Royal Schelde)

Fuels: Wood chips (upto 65% moisture)
       Demolition wood

GE LM2500 gas turbine

Overall plant efficiency = 42% (based on NCV)
Plant cost = approx. 2500$/kWe

Parties involved: PEN, Province of North Holland, UNA and ECN
TPS TERMISKA PROCESSER'S IGCC ACTIVITIES

TPS
World Bank sponsored
Brazilian BIG-GT project
30 MWe Demo Plant

TPS
Research & Development
Feasibility Studies
Engineering

TPS
Study of Biomass IGCC plant for
Borås Energi, Sweden

Royal Schelde/TPS
Netherlands
Study of 30 MWe biomass demo

Royal Schelde/Delta/OLAZ/TPS
Waste-fuelled gasification plant study

ARBRE Energy Limited
Development of EU biomass-demo plant
Energy forestry/gasification

1997-01-14   25

TPS GASIFICATION R&D PROJECT ACTIVITIES IN 1997

Installation of gas compressor and gas turbine in TPS 2 MW ACFBG pilot plant

Evaluation of suitable location for Swedish BIG-CC demo. plant

Pilot plant tests and economic feasibility assessment of RDF gasifier and tar cracker for the Netherlands

Installation of low density feedstock feeding system in TPS 2 MW ACFBG pilot plant

Long term SRF-fuelled test (700 hours) for Project ARBRE in TPS2 MW ACFBG pilot plant

Process studies and Component design
Commercializing Biomass
ACFB Gasification Technology
Princeton Workshop, 16 - 17 January 1997

* Technical issues

Remaining uncertainties:

- **gasification** - limited fuels database
  - not limiting for known fuels
- **gas clean-up** - limited experience
  - dependent on fuel gas application
  - demonstration required
  - for 'dirty' fuels more R&D required
- **gas turbines integration** - very limited experience
  - demonstration and operating experiences required
- **plant integration**
  - project dependent
Commercializing Biomass
ACFB Gasification Technology
Princeton Workshop, 16 - 17 January 1997

* Commercialisation

Critical paths:
- customer technology acceptance
  - successful demo. plants required
- long-term economics
  - must be competitive
- short-term financing/risk sharing
  - demonstration support required
Commercializing Biomass
ACFB Gasification Technology
Princeton Workshop, 16 - 17 January 1997

* Commercialisation

Accelerating the process 1

Plant financing

- third party funds for demonstration plants (grants, soft loans, etc.)
  [or alternatively, development companies own resources]
- 'green' prices for power, heat, steam
- tax breaks
Commercializing Biomass
ACFB Gasification Technology
Princeton Workshop, 16 - 17 January 1997

* Commercialisation
  Accelerating the process 2

Co-operation
  - financing for continuing R&D (pilot plant testing, etc.)
  - technical information exchange
  - controlled development of complementary projects (i.e. sequencing)
  - 'piggy-backing' on other projects

Market development/education
  - development of fuel supply industry (e.g. paper and sugar industry)
Commercializing Biomass
ACFB Gasification Technology
Princeton Workshop, 16 - 17 January 1997

Requirement for full commercialization:
Successful technical and economic
demonstration at commercial scale

* Next steps required to stimulate market
  - fast tracking of demonstration plants already in progress
  - co-operation (market education, information exchange, piggy-backing)
  - initiating complementary demonstration plants
  - continue value engineering and R&D
  - promote preferential treatment for technology (e.g. 'green' electricity prices)
Commercializing Biomass
ACFB Gasification Technology
Princeton Workshop, 16 - 17 January 1997

Requirements of TPS to accelerate commercial exploitation of TPS's gasification/combined-cycle technology:

- fast tracking of existing projects (i.e. Project ARBRE and Brazil WBP)
- development of biomass fuel supply industry
- economic advantages for environmentally-friendly technologies (e.g. green prices, low interest loans)
- attractive 3rd party financing possibilities for demonstration plants
- funding for R&D to support laboratory, pilot plant and desktop work to expand application to new fuels (e.g. bagasse) and development of demo. plants
Review of Princeton's Research, Day 1

Eric Larson
Princeton University

"Advanced Technologies for Biomass-Energy Utilization in the Pulp and Paper Industry"
Advanced Technologies for Biomass-Energy Utilization in the Pulp & Paper Industry

Research at the Center for Energy & Environmental Studies Princeton University

With cost-shared contributions from The Weyerhaeuser Company


Presented at the Workshop on Commercialization of Black Liquor and Biomass Gasification for Gas Turbine Applications in the Pulp and Paper Industry

16-17 January 1997
Princeton University Princeton, NJ
Project Objectives


- Assess development status and commercial prospects for gasifier/gas turbine technology for paper industry applications.
Summary of Project Tasks

- Define steam and power demands for ~2000 and ~2020 mills.
  - Future-mill features: closed bleach cycle, direct drying with gas turbine exhaust (?)

- Assess status and commercial prospects for gasifier/g.t. cogeneration systems

- Model heat/mass balances for gasifier/g.t. cogeneration in context of different mill demands.

- Examine economics of gasifier/g.t. cogeneration.

- Outreach to decision makers.
Results to Date

- Mill energy demands estimated
- Spreadsheet modeling of present-technology mills in progress
- Detailed mill modeling ongoing

- Baseline cogen performance modeling based on Seimens V64.3a gas turbine:
  - Black liquor: ABB, Noell, Kvaerner
  - Biomass: TPS, BCL, Ahlstrom
Bleached Kraft Market Pulp Steam and Power Demands (excluding powerhouse)

![Graph showing process power demand versus process steam demand.]

- Four Swedish Mills (1995 data)
- Old (1960s) SE U.S.
- Modern (1980s) SE U.S.
- "Best" Swedish Mill, 1993
- Swedish Model Mills
Sample Black Liquor Cogeneration Model (ABB Gasifier)
Sample Biomass Cogeneration Model (Battelle Gasifier)
Performance Comparison for Black Liquor Cogeneration Systems

(preliminary)

![Graph showing electricity, net of powerhouse (kWh per admt) vs. process steam, net of powerhouse (Million Btu/air-dry metric tonne pulp).]

- ABB - combined cycle
- Chemrec Combined cycle
- Noell (1000 C)
- Noell - combined cycle (1400 C)
- Simple Cycle

Seimens V64.3a gas turbine

Adavanced
Present
Tomlinson Boilers
Performance Estimate for Biomass-Gasifier/Gas Turbine Cogeneration

(preliminary)

- Power per ton biomass
- Efficiency (% HHV)
- Net Electric Efficiency (% Higher Heating Value)
- Maximum process steam production

>> Pressurized CFB gasifier
>> Siemens V64.3a gas turbine

Process Steam (Million Btu per dry ton biomass) vs Net Electricity (kWh/dry ton biomass)
Combined Performance Using Black Liquor and Biomass Gasification

(preliminary)

Mill #1: Typical Swedish mill
Mill #2: Modern U.S mill
Mill #3: Older U.S. mill

Range of Mill Power Demands

Power Generated

Biomass Required

Mill #1
Mill #2
Mill #3

>> Siemens V64.3a gas turbine simple cycle
>> Chemrec black liquor gasifier
>> Pressurized CFB gasifier

Process Steam Demand (Million Btu per air-dry metric tonne pulp)
Potential Power Generation at a Bleached Market Kraft Pulp Mill

(preliminary estimates)

<table>
<thead>
<tr>
<th>Modern U.S. Mill:</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;&gt; ~1250 air-dry metric tonnes pulp per day</td>
</tr>
<tr>
<td>&gt;&gt; Process steam: 15.5 Million Btu/admtpp</td>
</tr>
<tr>
<td>(Net of powerhouse)</td>
</tr>
</tbody>
</table>

![Graph showing electricity generation versus biomass consumed](image)

- Black liquor + biomass gasification/gas turbine
- Tomlinson + biomass boiler/steam turbine
Future Work Planned

- Finish baseline modeling for all gasifiers with Siemens turbine.
- With A&E firm, develop capital and operating cost estimates to examine overall economics.
- Examine impact of alternative gas turbines, e.g., aeroderivatives.
- Develop energy demand estimates for ~2020 mills.
- Examine cogeneration systems for ~2020 mills, considering also advanced gas turbine options.
- Explore:
  » energy impacts of direct causticizing.
  » gasifier/fuel cell cogeneration issues and performance.
Motivating a Discussion to Identify Steps to Timely Commercialization, Day 2

Denny Hunter
Weyerhaeuser Company

(summary of Day 1 black liquor technical breakout session)
Black Liquor Gasification
Supplier and Market Segments

Three categories of suppliers
- Boiler suppliers who don’t want to be left out if the market develops
- Companies with gasification expertise who want to expand their markets
- Companies offering commercial systems frustrated by the sluggish market response

Two market segments
- Booster
- Replacement
Question Posed to the Speakers

- How to overcome the doubters?
- What are the remaining technological uncertainties?
- Critical paths to rapid commercialization?
- Steps the paper industry might take to accelerate the commercialization process?
How to Overcome the Doubters?

- Several doubters in this audience
  - Concern that the advantages may not be large enough
    - safety, environmental
  - Concern that there are some disadvantages
    - efficiency, reliability, increased recaust load
  - Uncertainty about future power prices
How to Overcome the Doubters?

- Need to see commercial success in order to be convinced
- Need to understand other potential drivers
  - split sulfidity, Cl removal, direct causticizing, byproducts
- We need to see more evidence that the value is significant
Remaining Technical Obstacles?

- Several different views
  - corrosion/materials, pressurization, gas cleaning
  - The issues seem to be within the realm of our experience
  - “We don’t see any; the obstacles are in the level of understanding of the customers.”
Critical Paths to Rapid Commercialization

- Bench - pilot - demo - first commercial
- First commercial plant needs to succeed
- Paper industry partners
- Better communication with potential market
How the Industry Might Accelerate Commercialization

- “Open up to us in discussions of replacement strategies”
- Help define and articulate the needs
- Host sites for pilot and demo facilities
- Industry group to evaluate competing processes under confidential disclosure
Conclusions

- Suppliers have not seen convincing evidence of market opportunity or industry commitment
- The early opportunities most likely will arise where there are unique and compelling needs for technology change
- There is valuable and relevant experience outside our industry
Conclusions (continued)

- It is very difficult to compare mature technology and emerging technology.
- Our tendency is to weigh the near term value - but we live with the consequences of the selection for the life of the technology.
- Working as an industry to facilitate commercialization might be important, but it is likely to be very hard to do.
Motivating a Discussion to Identify Steps to Timely Commercialization, Day 2

George McDonald
Union Camp

(summary of Day 1 biomass technical breakout session)
Technology developer's perspectives on steps needed to commercialize biomass gasifier/gas turbine systems

- **Speakers**
  - Jim Patel - Carbona (pressurized bubbling bed gasifier)
  - Folke Engstrom - Foster-Wheeler (Ahlstrom pressurized CFB gasifier)
  - Michael Morris - TPS (atmospheric CFB gasifier)
  - Harry Morehead - Westinghouse (Hawaii project with pressurized bubbling bed)
  - John Rohrer - Zum-NEPCO (BCL indirectly-heated gasifier - Vermont demonstration)

- **Objectives - questions to be answered**
  - Doubt exists that gasification will provide enough efficiency, environmental, capital and reliability benefits to justify a commercialization effort. How can these factors be demonstrated?
  - What are the remaining technological uncertainties regarding biomass handling/feeding, gasification, gas cleanup, compatibility with gas turbines, and mill integration of the cogen plant?
  - What are possible critical paths to achieving rapid commercialization?
  - What steps can the paper industry take to accelerate the commercialization process?
Commercializing biomass gasifier/gas turbine systems

- Speakers
  - Jim Patel - Carbona
  - Folke Engstrom - Foster-Wheeler
  - Michael Morris - TPS
  - John Rohrer - Zum-NEPC
Commercializing biomass gasifier/gas turbine systems

<table>
<thead>
<tr>
<th>Company</th>
<th>Type</th>
<th>Product gas (MJ/Nm³)</th>
<th>Demonstration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbona</td>
<td>Pressurized CFB</td>
<td>4.2</td>
<td>7 MW (1993)</td>
</tr>
<tr>
<td>FosterWheeler</td>
<td>Bubbling Bed</td>
<td>5 MJ/Nm³</td>
<td>5-6 MJ/Nm³</td>
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<tr>
<td></td>
<td>Atmospheric CFB</td>
<td></td>
<td>17 MJ/Nm³</td>
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<td></td>
<td>w/ tar cracker</td>
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<tr>
<td>TPS</td>
<td>Indirectly heated atmospheric gasifier</td>
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<tr>
<td>Zum-NEPCO</td>
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</tbody>
</table>
Key Comments

- Current systems are too expensive
  - Demonstration units run $1500 to $2500/kW
    - 50% reduction expected for the 10th unit
  - Pressurized units need 60-80 MW to be competitive
  - Emphasis should be on capital cost reduction/simplification

- Steps to speed implementation
  - Government subsidy of demonstration units
    - 50/50 cost sharing
    - Green pricing
  - Fuel cost and supply
    - Search for minimal fuel prices
    - Establish fuel supply industry
  - Creative financing
    - Independent power producers
Motivating a Discussion to Identify Steps to Timely Commercialization, Day 2

Delmar Raymond
Weyerhaeuser Company

"Biomass & Black Liquor Gasification Combined Cycle, Timing is Critical"
Biomass & Black Liquor Gasification
Combined Cycle

Timing is Critical

Princeton University
January 17, 1997
Commercialization of BGCC & BLGCC Technologies - Why Now?

BGCC/BLGCC Commercially Successful

Readiness of Technologies

Industry Pressures
The Need

Window of Opportunity
The Time

Enabling Mechanism
Agenda 2020
Summary of Recent Weyerhaeuser Gasification Technology Activities

- **BLGCC**
  - MTCI technology evaluated at New Bern
  - ChemRec technology coming on line at New Bern

- **BGCC**
  - Feasibility study complete for New Bern leveraged with DOE (NREL) funds – results encouraging
  - Proposal for next phase submitted through “Rural Electrification” initiative – not sufficiently funded
  - Proposal resubmitted through Agenda 2020 – contract signed in October
BGCC Economic Sensitivities

BGCC COMPARED TO MULTI-FUEL BOILER BASE CASE - NO CAPITAL SUPPORT

NOTE: Assumes feedstock cost of $14/wet ton. Zero line represents NPV @ 12% and 20 years compared to a multi-fuel boiler base case.
Possible Alternatives - New Bern

- Status Quo (Oil)
- Biomass in Existing Boiler
- New Biomass Boiler
- Natural Gas – Oil Replacement
- Natural Gas – LM-2500
- Biomass Gas – Oil Replacement
- Biomass Gas – LM-2500
- Natural Gas – 6B & 6F
- Biomass Gas – 6B & 6F
Key Leverage Points

- Power Values (or Chemical Values)
- Fuel Cost (Fossil)
- Fuel Cost (Biomass)
- Capital Cost
Biomass Gasification
Combined Cycle Project
Task Flows &
Significant Outcomes
Tasks 1 & 2

Significant Outcomes

Task 1
Gasifier Cost, Performance & Feasibility Engineering

- Lowest capital cost for gasifier island realistically bounded
- Time/knowledge to achieve capital cost reductions quantified
- Risk of implementation related to time/knowledge/cost

Task 2
Burlington Support
Tasks 3 & 4

Significant Outcomes

Raw material availability/cost for Weyerhaeuser NC implementation quantified

Realities of using municipal wastewater as a nutrient source for energy fiber production quantified
Task 5
Significant Outcomes

Task 6
Funding Options

Task 7
Economics 3
Site Selection

Task 8
Implementation Plan

Task 5
Gas Quality
Kiln/Boiler

Kiln/boiler impacts for Weyerhaeuser NC implementation understood
Task 6

Significant Outcomes

Task 1: Cost, Performance & Feasibility Engineering
Task 2: Burlington Support
Task 3: Material Availability
Task 4: Energy Crop Possibilities
Task 6: Gas Quality Kite/Boiler

Task 6
Funding Options

Best economics for a Weyerhaeuser NC implementation
Funding options identified

Task 7: Economics & Site Selection
Task 6: Implementation Plan
Task 7
Significant Outcomes

Task 1: Gasifier Cost, Performance, & Feasibility Engineering
Task 2: Burlington Support
Task 3: Raw Material Availability
Task 4: Energy Crop Feasibilities
Task 5: Gas Quality Kilo/Boiler
Task 6: Funding Options

Task 7: Economics & Site Selection

Best Weyerhaeuser NC site selected
Non-Weyerhaeuser options identified
Task 8
Significant Outcomes

Task 1: Generator Cost, Performance & Feasibility Engineering
Task 2: Burlington Support
Task 3: Raw Material Availability
Task 4: Energy Crop Feasibilities
Task 5: Gas Quality Analysis
Task 6: Funding Options
Task 7: Economics & Site Selection

Timing — Timing right for a sustainable (successful) project?
Selection — Location (situation) for a sustainable (successful) project?
Given timing & selection — Plan for implementation
Anticipated Biomass Gasification Combined Cycle Project Outcomes

- Weyerhaeuser location positioned for commercial implementation in 1999–2001 time frame (or)
- Non-Weyerhaeuser location positioned for commercial implementation in 1999–2001 time frame (or)
- Clear development path identified for low-risk implementation beyond 2000 (or)
- Clear quantification of reasons for delaying/abandoning implementation
In-service Kraft Recovery Boilers
BLGCC & BGCC Commercialization
Timing is Critical

- In a capital-intensive industry, technology improvements often must be linked to the normal capital cycle
- The technology is ready
- The need is there
- The enabling mechanism is in place
- The window of opportunity is now
- How do we make it happen?