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

Financial support provided by
The Office of Industrial Technologies, U.S. Department of Energy
The Weyerhaeuser Company
and
The Energy Foundation
The W. Alton Jones Foundation
The Geraldine R. Dodge Foundation

20 March 1997

TABLE OF CONTENTS

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:

> **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)

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

This unique set of circumstances provided the motivation behind the Workshop on Commercialization of Black Liquor and Biomass Gasification for Gas Turbine Applications in the Pulp and Paper Industry. Specific objectives were to illuminate opportunities for gasification-based cogeneration in the pulp and paper industry, to review the status of black liquor and biomass integrated-gasifier/gas turbine technologies and remaining uncertainties to be addressed before commercial application, and to identify steps to insure timely commercialization of the technologies. The workshop was hosted by Princeton University's Center for Energy and Environmental Studies as part of its research program on advanced technologies for biomass energy utilization in the pulp and paper industry. Paper companies, gasifier and gas turbine suppliers, engineering firms serving the paper industry, universities, national labs, and the Department of Energy were represented among the 50 participants.

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

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

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

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

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

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

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

It was suggested that early opportunities to help catalyze commercialization will most likely arise where there are unique and compelling needs for technology change. It was also noted that comparing mature (existing) technology with emerging (gasification) technology is difficult for industry business and facility managers. The tendency is to value the near-term more heavily, even though a company must live with the consequences of a choice for the 30- or 40-year life of the asset.

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

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

2. WORKSHOP AGENDA

DAY 1 -- TECHNOLOGY ISSUES

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

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

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

10:50 **Break**

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

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

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

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

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

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

Presentations to motivate discussion on identifying next steps for achieving timely commercial implementation of biomass and black liquor gasifier/gas turbine systems
1. Summary of Day-1 Breakout Sessions
   -- Denny Hunter (black liquor)
   -- George McDonald (biomass)
2. The Critical Importance of Timing in Commercialization
   -- Del Raymond
3. Framework for the discussion
   -- David Cooper

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

3. PARTICIPANT LIST

Sy Ali, Director
Advanced Industrial Programs
Allison Engine Company
P.O. Box 420, U-5
Indianapolis, IN 46206-0420
317-230-6864
fax: 317-230-2900

Russ Andrews
International Paper
P.O. Box 160707
Mobile, AL 36616
334 470-4373
fax: 334 470-4691

Richard L. Bain, Senior Engineer
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
303 275-2946
fax: 303 275-2905

Craig A. Brown
Weyerhaeuser Company
Mailstop CCII-103
Federal Way, WA 98477-001
206 924-6993
fax: 206 924-6812
brownc@wdni.com

Gene Christiansen
Kvaerner Pulping Inc.
8008 Corporate Center Drive
Charlotte, NC 28226
704 541-1453
fax: 704 543-8172

David Cooper, consultant
American Forest & Paper Association
7238 Evans Mill Road
McLean, VA 22101
ph/fx: 703-821-2855
email: 76554.441@compuserve.com

Stefano Consonni, Professor
Department of Energetics
Politecnico di Milano
Piazza Leonardo da Vinci, 32
20133 Milan, Italy
39 2 2399-3917
fax: 39 2 2399-3940

Swep Davis
Tyone Partners
33 Witherspoon St.
Princeton, NJ 08540
609 921-8815
fax: 609 921-0969

Jules J. Dominguez, Manager
Utility Engineering
Georgia-Pacific Corporation
133 Peachtree Street NE (30303)
P.O. Box 195605
Atlanta, GA 30348-5605
404 652-4606 or 4634
fax: 404 654-4747

Folke Engström, Vice President
Global New Products & Karhula R&D Center
Foster-Wheeler Development Corp.
John Blizard Research Center
12 Peach Tree Hill Road
Livingston, NJ 07039
201 535-2332
fax: 201-535-2242

Tom Foust
US Department of Energy
Office of Industrial Technologies, EE22
1000 Independence Ave., SW
Washington, DC 20585
202 586-0198
fax: 202 586-3237
thomas.foust@hq.doe.gov

Jim Frederick, Professor
Institute of Paper Science and Technology
500 10th St. N.W.
Atlanta, GA 30318
404 894-5303
fax: 404-894-4778
jim.frederick@ipst.edu

Ed Gray
Antares Group
Two Metro Plaza, Suite 207
Landover, MD 20785
301 731-1900
fax: 301 731-1904

Patricia Hoffman, Program Manager
US Department of Energy
Office of Industrial Technologies, EE22
1000 Independence Ave., SW
Washington, DC 20585
202 586-6074
fax 202 586-7114 or 3237
patricia.hoffman@hq.doe.gov

Denny Hunter
Weyerhaeuser Company, WTC 2G22
Pulp Mill Process R&D
Tacoma, WA 98477
206-924-6578
fax: 206 924-4350

Fred Jahnke, Gasification Technology Manager
Alternate Energy and Resources Department
Texaco
2000 Westchester Ave.
White Plains, NY 10650
914-253-7946
fax: 914-253-7744
email: Jahnkfc@texaco.com

Alan Jones, Assistant to the Vice President
Corporate Engineering Division
Union Camp Corp.
P.O. Box 2310
Savannah, GA 31402
912 965-6014
fax: 912 965-6110

Andy Jones
ABB Power Generation
1410 Blair Place
Suite 600
Gloucester, Ontario
K1J 9B9 Canada
613 747-5137
fax: 613 747-5875
andrew.k.jones@CAABB.MAIL.ABB.COM

Stefan Jonssön, Managing Director
Kvaerner/Chemrec AB
Floragatan 10B
S-114 31 Stockholm, Sweden
46 8 411-0060
fax: 46 8 411-0066

William C. Julian
CRSS Inc.
1177 West Loop South
Houston, TX 77027-9006
713 552-2225
fax: 713-552-2011

Judith Kieffer
Weyerhaeuser Company
Mailstop CCII-103
Federal Way, WA 98477-001
206 924-6200
fax: 206 924-6812
kieffej@wdni.com

Robert B. Kinstrey, Director of Technology
OPTEC Pulp & Paper
Raytheon Engineers & Constructors, Inc.
100 Corporate Parkway
Birmingham, AL 35242-2928
205 995-7396
fax: 205 995-6929

Tom Kreutz, Research Staff
Center for Energy and Environmental Studies
Princeton University
Princeton, NJ 08544
609 258-5691
fax: 609 258-3661
email: kreutz@princeton.edu

Ingvar Landalv, Technology Director
Nykomb Synergetics AB
Floragatan 10 B
114 31 Stockholm, Sweden
46 8 411-0060
fax: 46 8 411-0066
email: info@nykomb.se

Eric Larson, Research Engineer
Center for Energy and Environmental Studies
Princeton University
Princeton, NJ 08544
609 258-4966
fax: 609 258-3661
email: elarson@princeton.edu

Heinz Lorson
Preussag Noell KRC
D-97064 Würzburg
Germany

George W. McDonald, Pulping Group Leader
Research & Development Division
Union Camp Corporation
P.O. Box 3301
Princeton, NJ 08543
609 844-7271
fax: 609 844-7323

Momtaz Monsour, President
MTCI Inc.
P.O. Box 21
Columbus, MD 21045

Michael Morris
TPS, Termiska Processer AB
Studsvik
611 82 Nyköping, Sweden
46 155-221372
fax: 46 155-263052

Tom Mullen, Technology Segment Lead
Pulp and Paper
Air Products and Chemicals, Inc.
7201 Hamilton Blvd.
Allentown, PA 18195-1501

Bo Oscarsson, Technical Director
Jaakko Pöyry Fluor Daniel
100 Fluor Daniel Drive
Greenville, SC 29607-2762
864 281-5010 or -5733
fax: 864 676-7630

William Parks
U.S. DOE, EE-22
Energy Efficiency and Renewables

1000 Independence Ave., SW
Washington, DC 20585-0121
202 586-2093
fax: 202 586-3180
william.parks@hq.doe.gov

Jim Patel, President
Carbona Corp.
4501 Circle 75 Parkway
Suite E5300
Atlanta, GA 30339
770 956-0601
fax: 770 956-0063

Allen Pfeffer, Vice President
Research and Technology BA Boilers
ABB Power Plant Laboratories
ABB-Combustion Engineering
P.O. Box 500
2000 Day Hill Road
Windsor, CT 06095-0500
860 285-5639
fax: 860 285-2565
email: allen.m.pfeffer@usppl.mail.abb.com

Jon Pietruszkiewicz, Manager
Advanced Power Technology & Consulting
Bechtel Power Corp.
9801 Washingtonian Blvd.
Gaithersburg, MD 20878-5356
301 417-3755
fax: 301 869-5770
jpietrus@bechtel.com

Delmar R. Raymond, Director
Strategic Energy Alternatives
Weyerhaeuser Company
Mailstop CCII-103
Federal Way, WA 98477-001
206 924-6850
fax: 206 924-6812
raymond@wdni.com

Larry Ritter, Energy Manager
Boise Cascade Corp.
1111 West Jefferson Street (83702)
P.O. Box 50
Boise, Idaho 83728-0001
208 384-4804
fax: 208 384-7637

John W. Rohrer, Vice President, Manager, Operations
Zurn-NEPCO
133 Pope Ave.
South Portland, ME 04106
207 791-5100
fax: 207 791-5156

Dave Ruprecht, Senior Development Manager
Corporate Science and Technology
Air Products and Chemicals, Inc.
7201 Hamilton Blvd.
Allentown, PA 18195-1501
610 481-8149
fax: 610 481-6670

Robert W. Swindeman, Mechanical Properties Group
Metals & Ceramics Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6155
423 574-5108
fax: 423 574-5118

Frank Tenore, President
Stonechem
245 Summer Street
Boston, MA 02210
617 589 1083
fax: 617 589-1372

Chris Verrill
Babcock & Wilcox
Alliance Research Center
1562 Beeson St.
Alliance, OH 44601-2196
330 821-9110, ext. 7859
fax: 330-829-7283
chris.l.verrill@mcdermott.com

Bjorn Warnqvist
ÅF-IPK
Fleminggatan 7
Box 8309
104 20 Stockholm, Sweden
46-8-657-1302
Fax 46-8-653-9136

Victor F. White, Program Manager
Gasification Systems
Noell, Inc.
2411 Dulles Corner Park, Suite 410
Herndon, VA 22071
703 793-6500
Fax 703 793-4974

Robert Williams, Senior Research Scientist
Center for Energy and Environmental Studies
Princeton University
Princeton, NJ 08544
609 258-5276
fax: 609 258-3661
email: rwilliam@arundel.princeton.edu

Wenrui Yang
Research & Development Division
Union Camp Corporation
P.O. Box 3301
Princeton, NJ 08543
609 896-1200
fax: 609 896-7323

4. PERSPECTIVES OF THE ORGANIZERS

4.1. Background

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

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

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

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

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

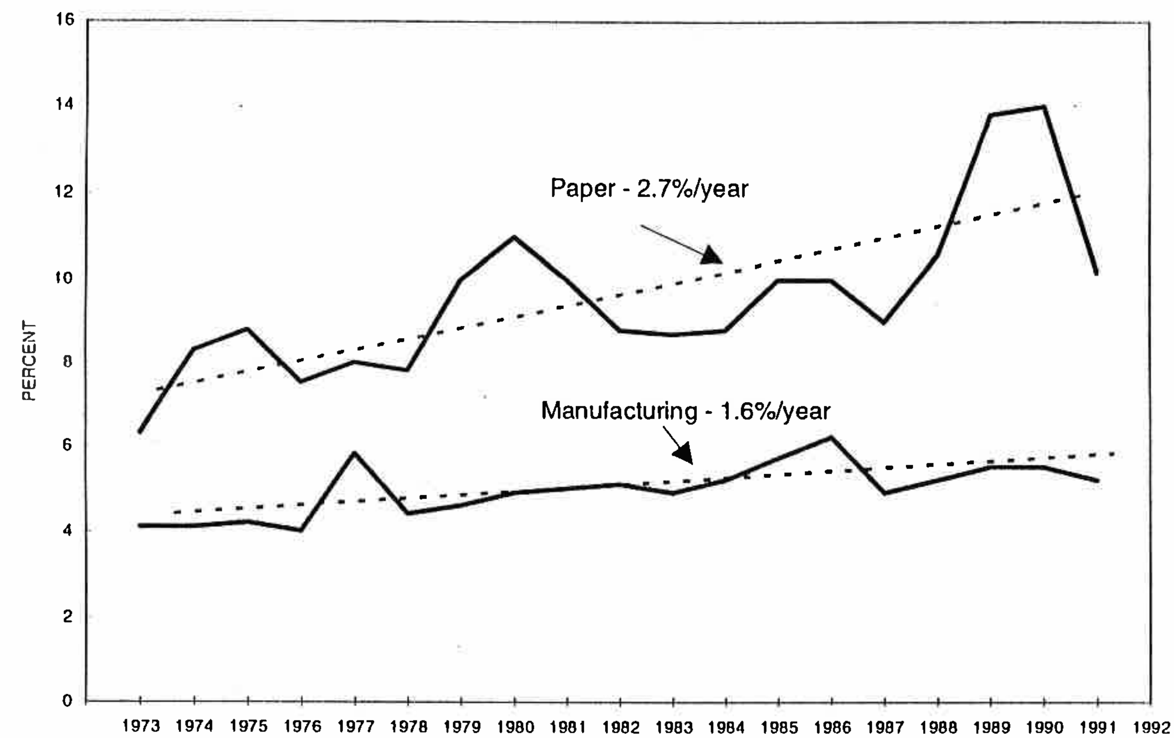


Fig. 1: Capital expenditures as percent of sales. Source: Dept. of Commerce, API. (See Annex 1.)

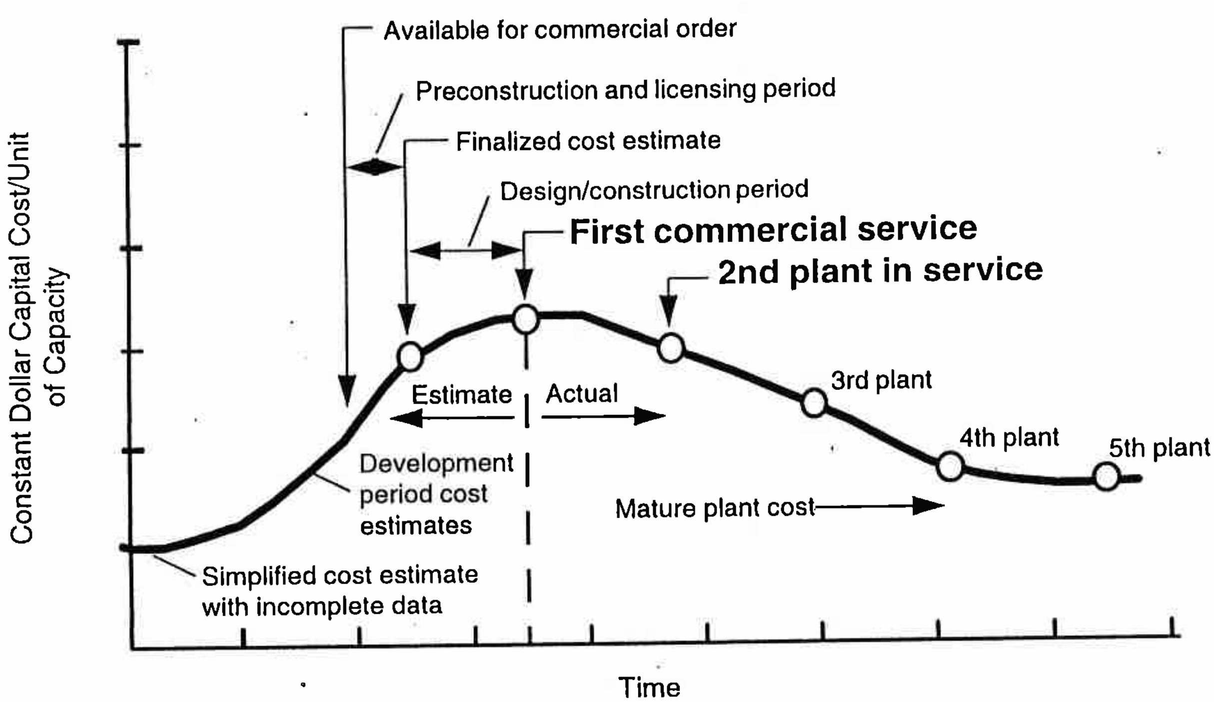


Fig. 2: Generic capital cost trend for early commercial units of a new powerplant technology, based on Technical Assessment Guide of the Electric Power Research Institute [2].

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

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

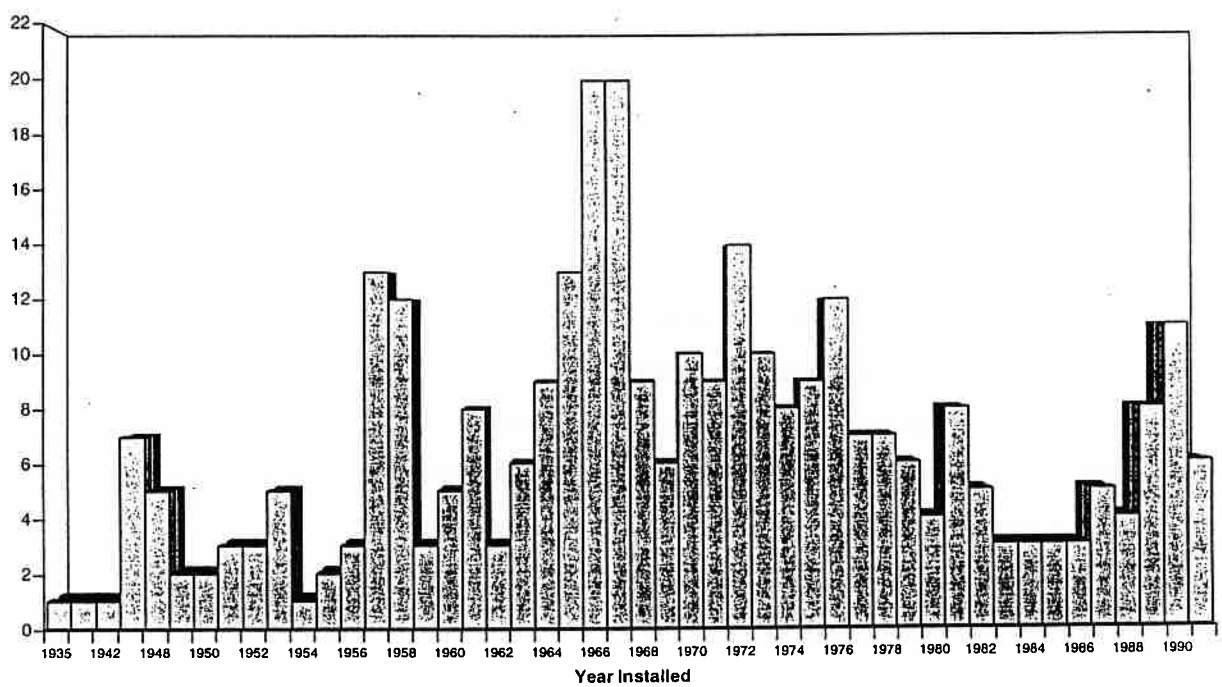


Fig. 3: In service kraft recovery boilers in North America, by year installed. Source: Annex 1.

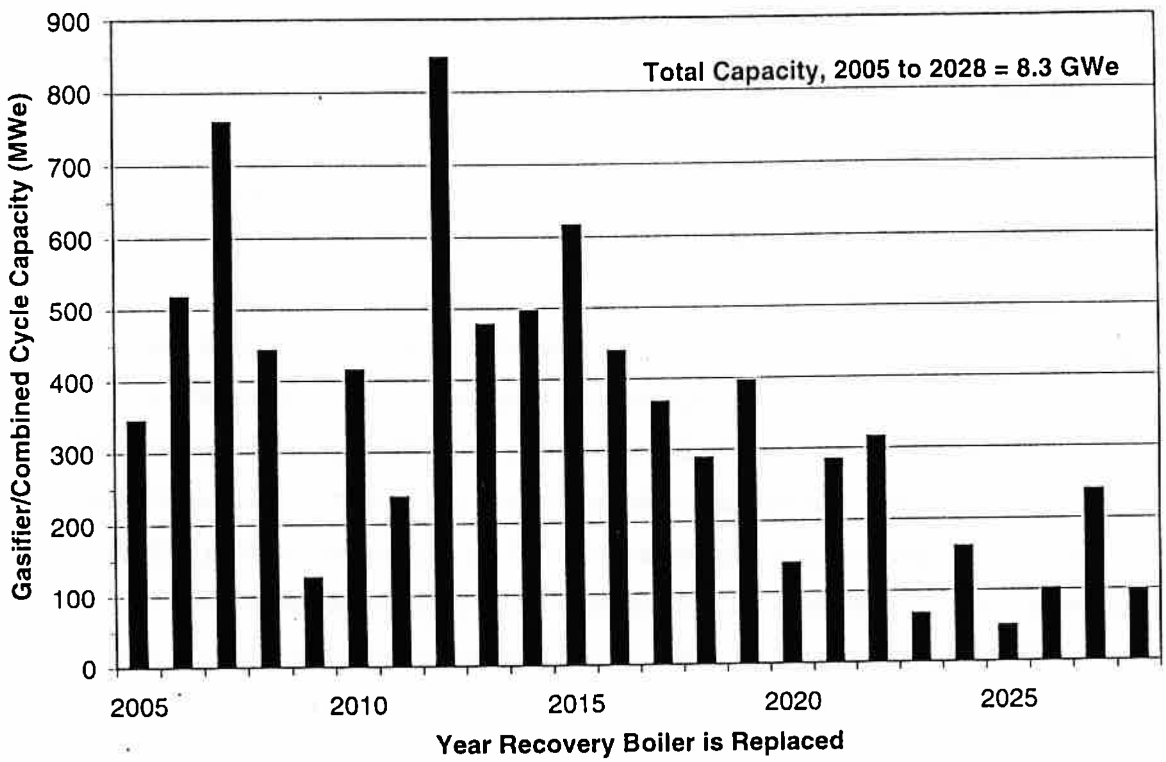


Fig. 4: Potential market for black liquor gasifier/combined cycles in North American pulp and paper mills, based on annual recovery boiler capacities installed starting in 1965 and assuming replacement of this capacity after 40-year unit lifetimes with BLGCC cogeneration (25% electric efficiency).

4.2. Why BGCC and BLGCC Technologies?

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

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

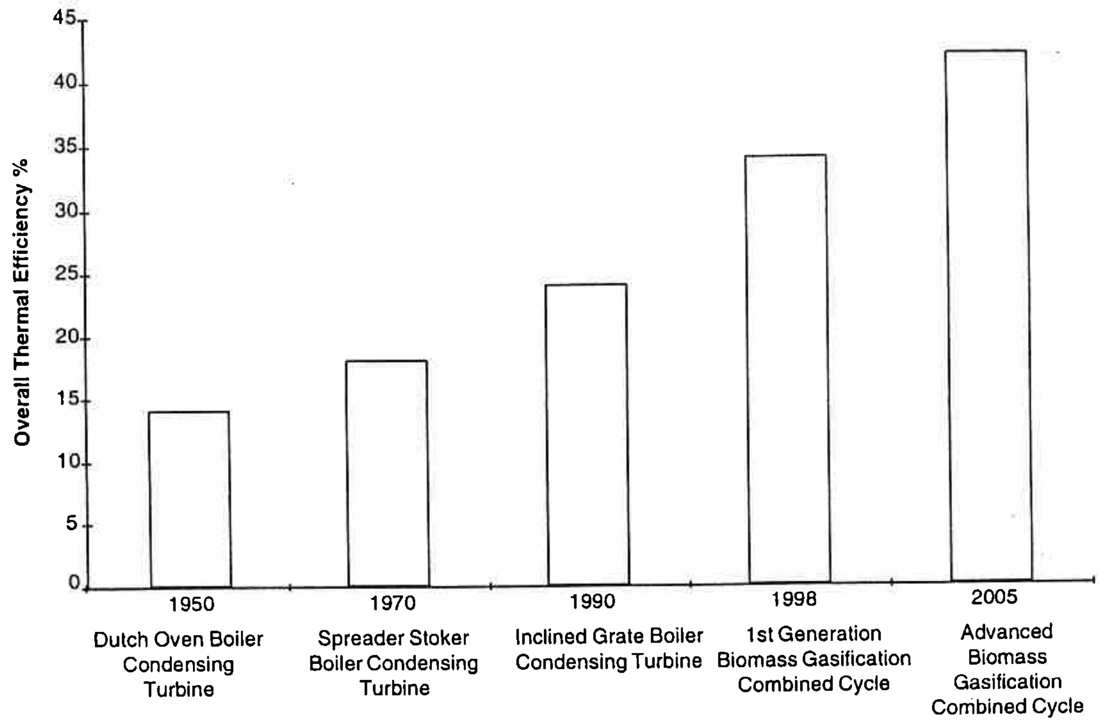


Fig. 5: Power-recovery island of 2010--power generation efficiency comparison [2].

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

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

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

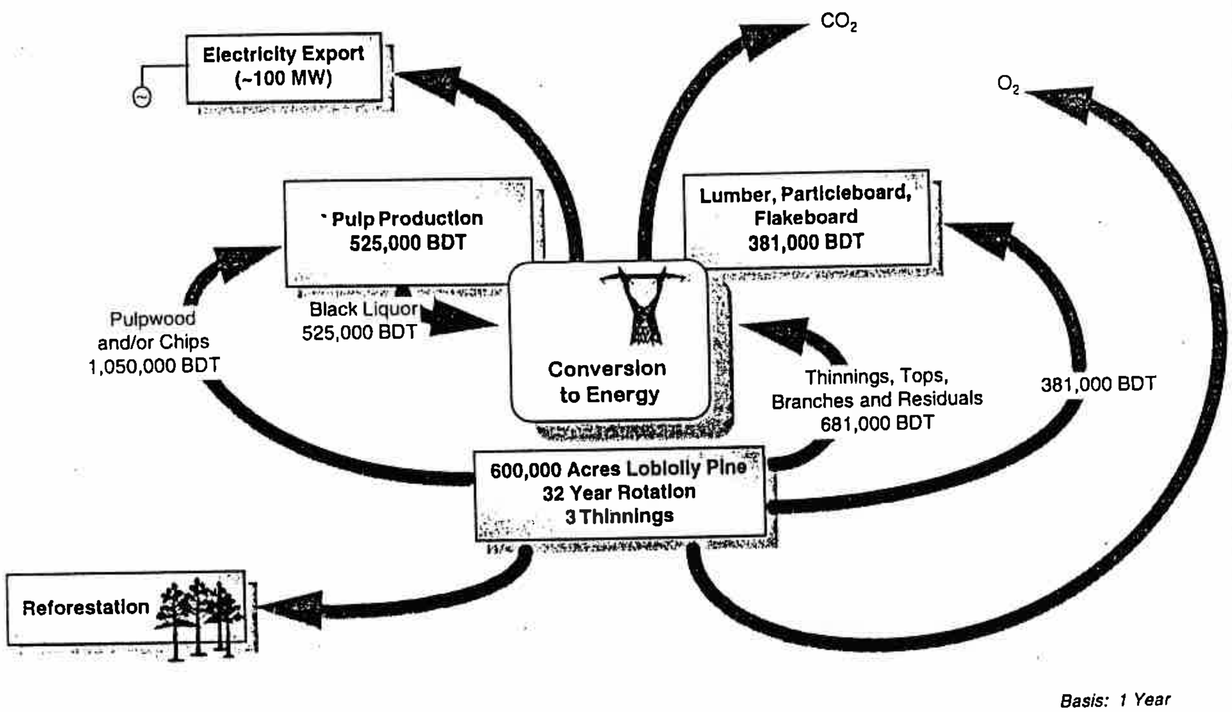


Fig. 6: Schematic representation of electricity export potential with BLGCC/BGCC at one Weyerhaeuser location.

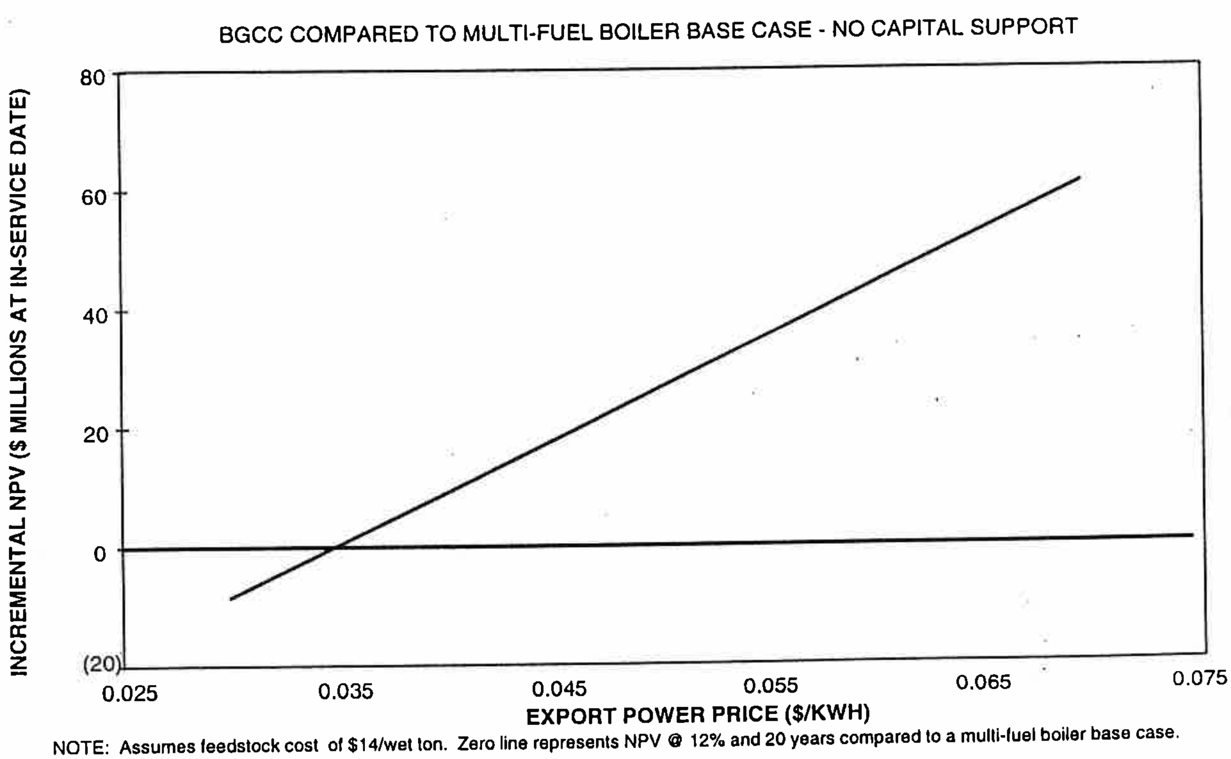


Fig. 7: Net present value of a BGCC project at a Weyerhaeuser mill as a function of export-electricity sale price [5].

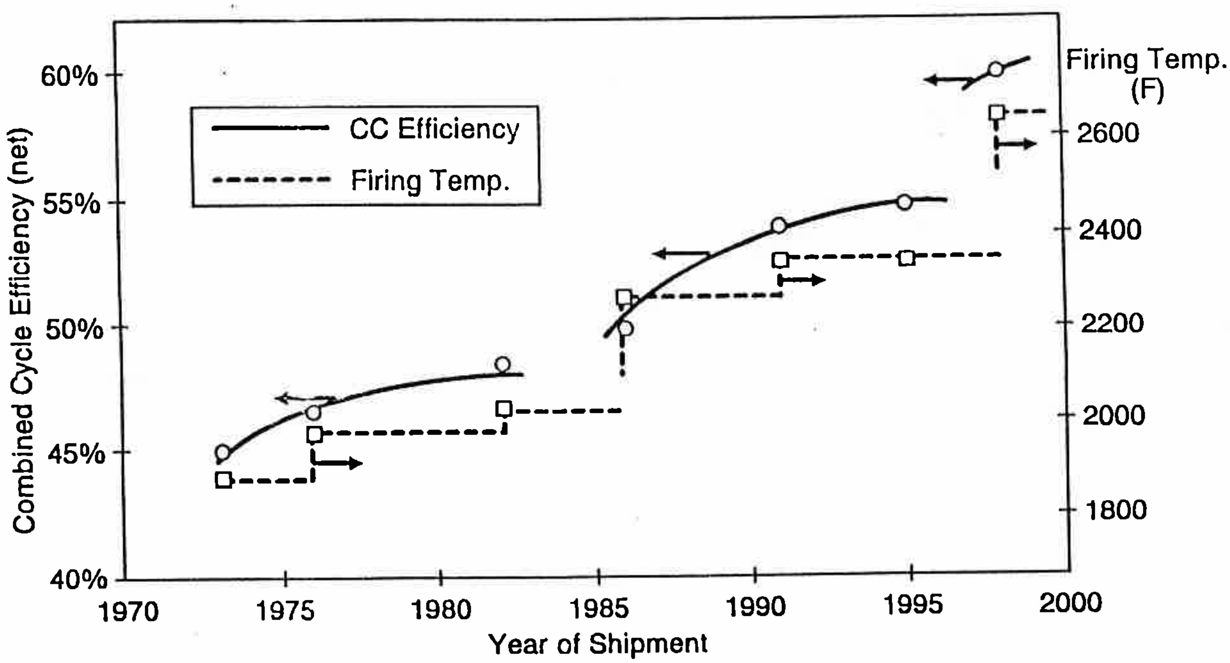


Fig. 8: Natural gas combined cycle efficiencies and firing temperatures for General Electric machines [6].

4.3. What Will Commercialization Cost?

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

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

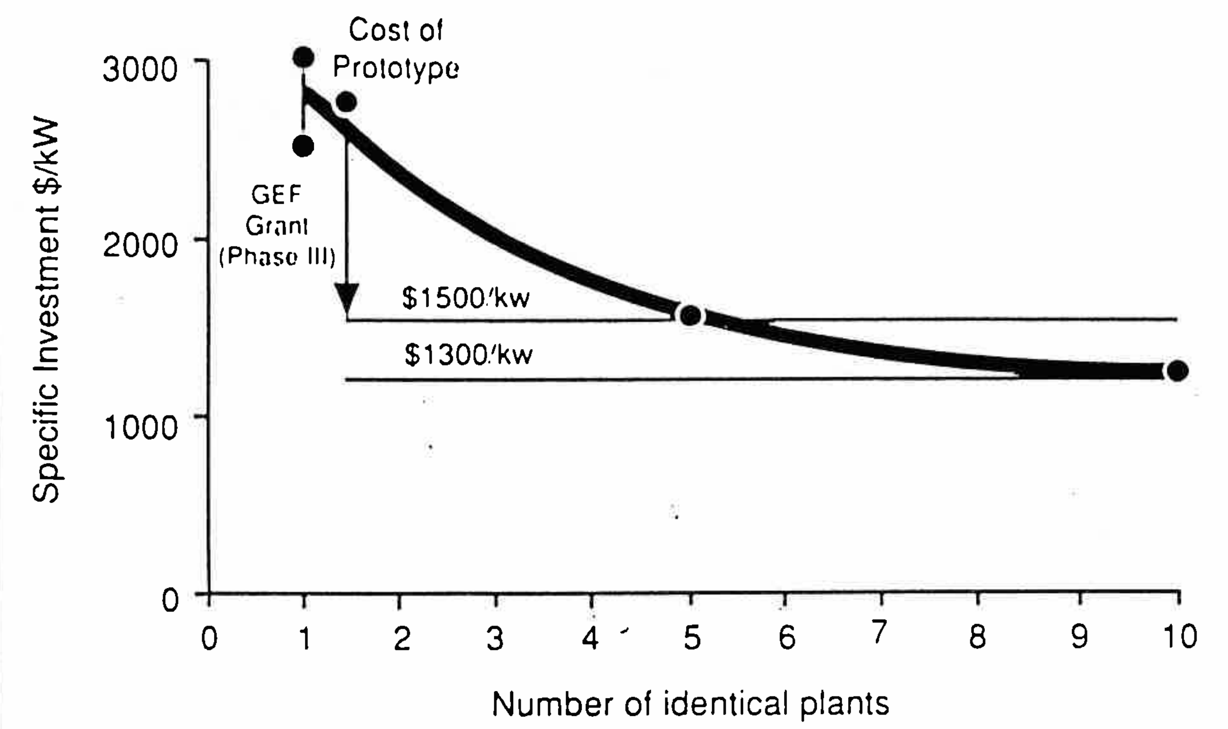


Fig. 9: Learning curve projected by Shell International Petroleum Company for BGCC technology [7].

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

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

4.4. References

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

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

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

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

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

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

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

5. WORKSHOP SUMMARY

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

5.1. Setting the Context

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

5.2. Technology Background and Issues

Eric Larson and Stefano Consonni (who collaborates with Princeton University researchers) then presented overviews of biomass and black liquor gasification technologies and issues relating to their application with gas turbines. Larson highlighted the large increase in power generation that could be realized with gasifier/gas turbine systems at pulp mills compared to existing steam-turbine based systems and noted other prospective benefits of BGCC and BLGCC systems, including an improved environmental profile for the powerhouse at lower capital investment. Additionally with BLGCC, powerhouse safety might be improved, there might be added flexibility in preparing pulping chemicals, and there may be opportunities for reconstituting pulping chemicals directly out of the gasifier (direct causticization) rather than by the capital- and energy-intensive lime-based recovery process used today.

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

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

5.3. Gasifier Supplier Perspectives

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

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

Black Liquor Gasifier Suppliers

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

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

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

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

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

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

Biomass Gasifier Suppliers

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

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

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

A number of areas were pointed out by the speakers where additional development work would be beneficial, especially to reduce capital costs and improve confidence in future performance of BGCC facilities. One speaker emphasized the need for improved equipment designs rather than better integrated-facility designs to reduce capital costs for the N^{th} plant, as well as modularity and factory-over-field fabrication. In the gasification area, there exist operating data for only a limited set of fuels; an expansion of this database is needed. Better refractory materials might reduce gasification costs. Improved biomass drying and feeding systems (especially into pressurized reactors) need to be demonstrated under commercial operating conditions. Hot gas cleanup has been demonstrated at pilot scales, but requires further demonstration under commercial operating conditions. Quench/cold-gas cleanup has been demonstrated to be effective and relatively inexpensive in a wide range of other applications, though there is some associated efficiency penalty. Integration of the gasifier/gas cleanup system with the gas turbine requires further demonstration and operating experience. It was noted that there are several demonstration facilities worldwide (e.g., Värnamo, Tampere, Hawaii, Vermont) which might be used to advantage, if an international cooperative effort were launched to commercialize BGCC technology. The need for cooperation was emphasized by one speaker, e.g. to insure appropriate sequencing of demonstration projects and exchange of information among projects to maximize the learning from each.

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

5.4. Steps to Timely Commercialization of BGCC and BLGCC Technology

After a summary of the Day-1 activities, the final (half) day of the workshop was devoted to discussion to identify steps to achieving timely commercialization of BGCC and BLGCC technology. Weyerhaeuser is pursuing a number of relevant activities, which Del Raymond outlined in an opening presentation. A detailed assessment of BGCC opportunities at their New Bern, North Carolina mill helped convince Weyerhaeuser to pursue commercialization of BGCC technology. Present activity is focussed on positioning a Weyerhaeuser mill for commercial implementation of a BGCC system (most likley to be based on the indirectly-heated Battelle Columbus Laboratory gasifier) in the 1999-2001 timeframe. If a suitable Weyerhaeuser mill cannot be identified, a non-Weyerhaeuser location will be sought, so that momentum toward BGCC commercialization can be maintained.

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

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

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

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

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

ANNEX 1

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

Financial support provided by
The Office of Industrial Technologies, U.S. Department of Energy
The Weyerhaeuser Company
and
The Energy Foundation
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

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

Black Liquor Technical Breakout Session, Day 1

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

Biomass Technical Breakout Session, Day 1

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

Review of Princeton's Research, Day 1

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

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

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

Context and Technology Overviews, Day 1

Delmar Raymond
Weyerhaeuser Company

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

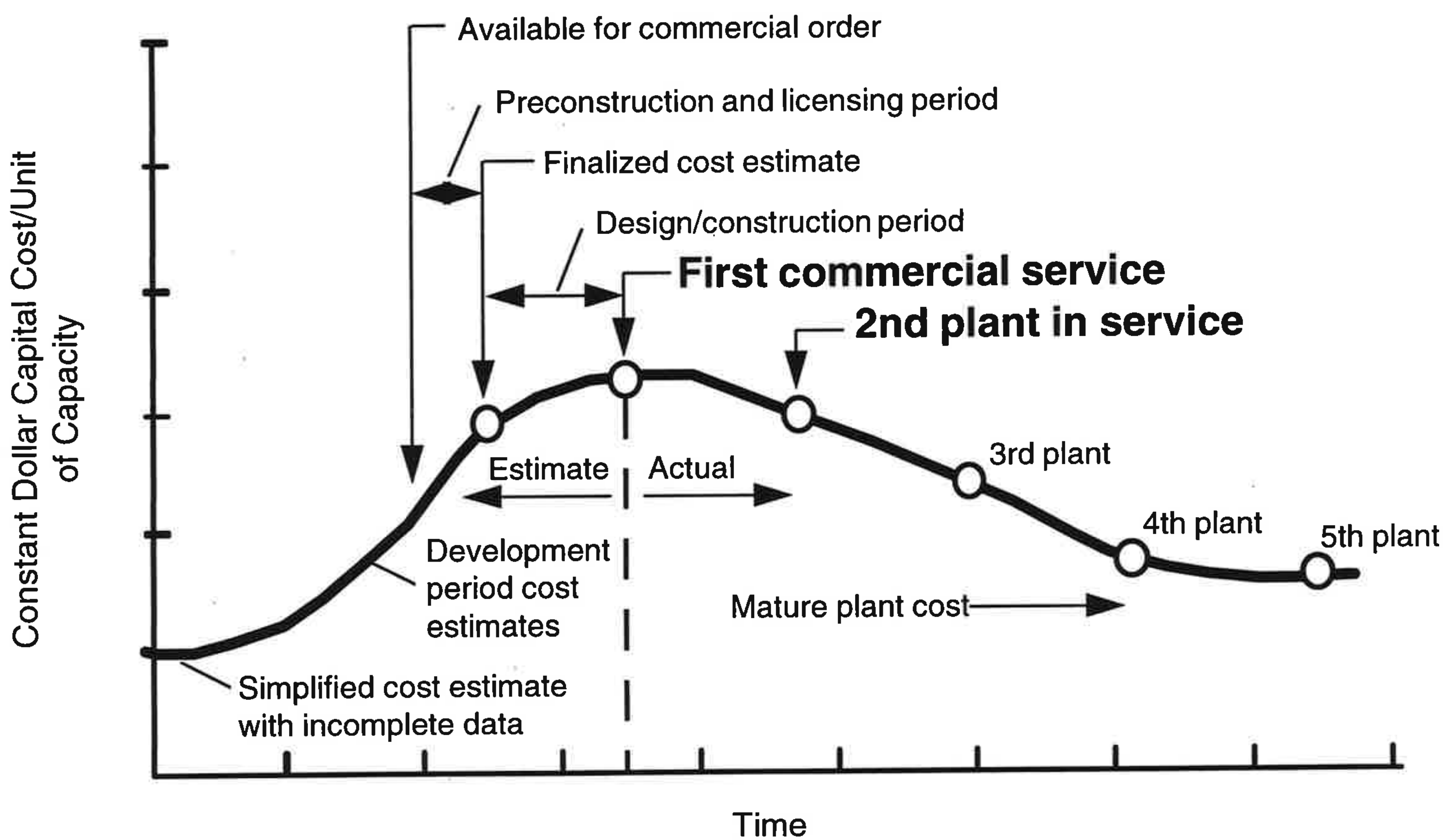
Biomass & Black Liquor Gasification Combined Cycle

An Industry Priority

Princeton University

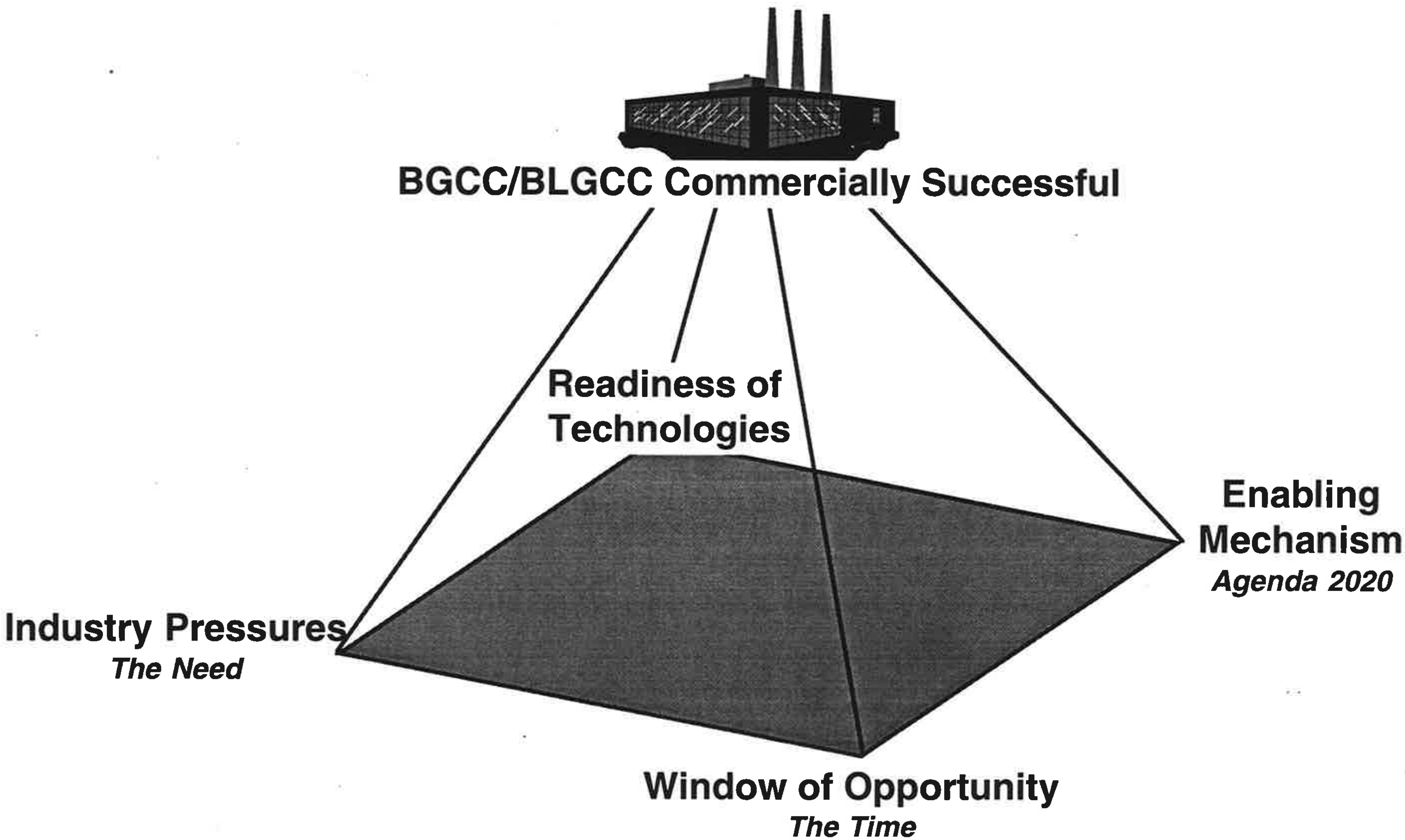
January 16, 1997

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

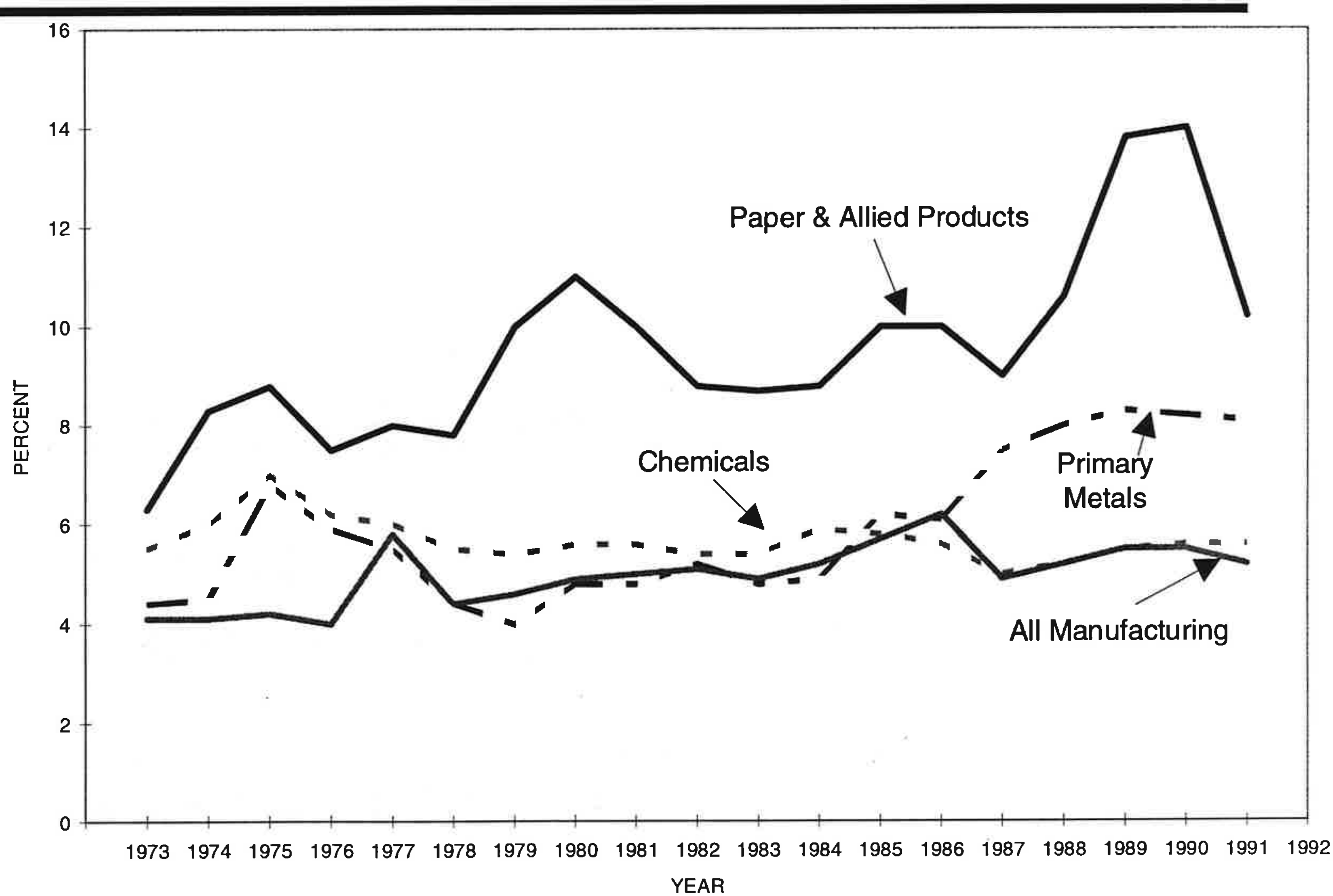
Government Response to Greenhouse Gas Issues

- 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

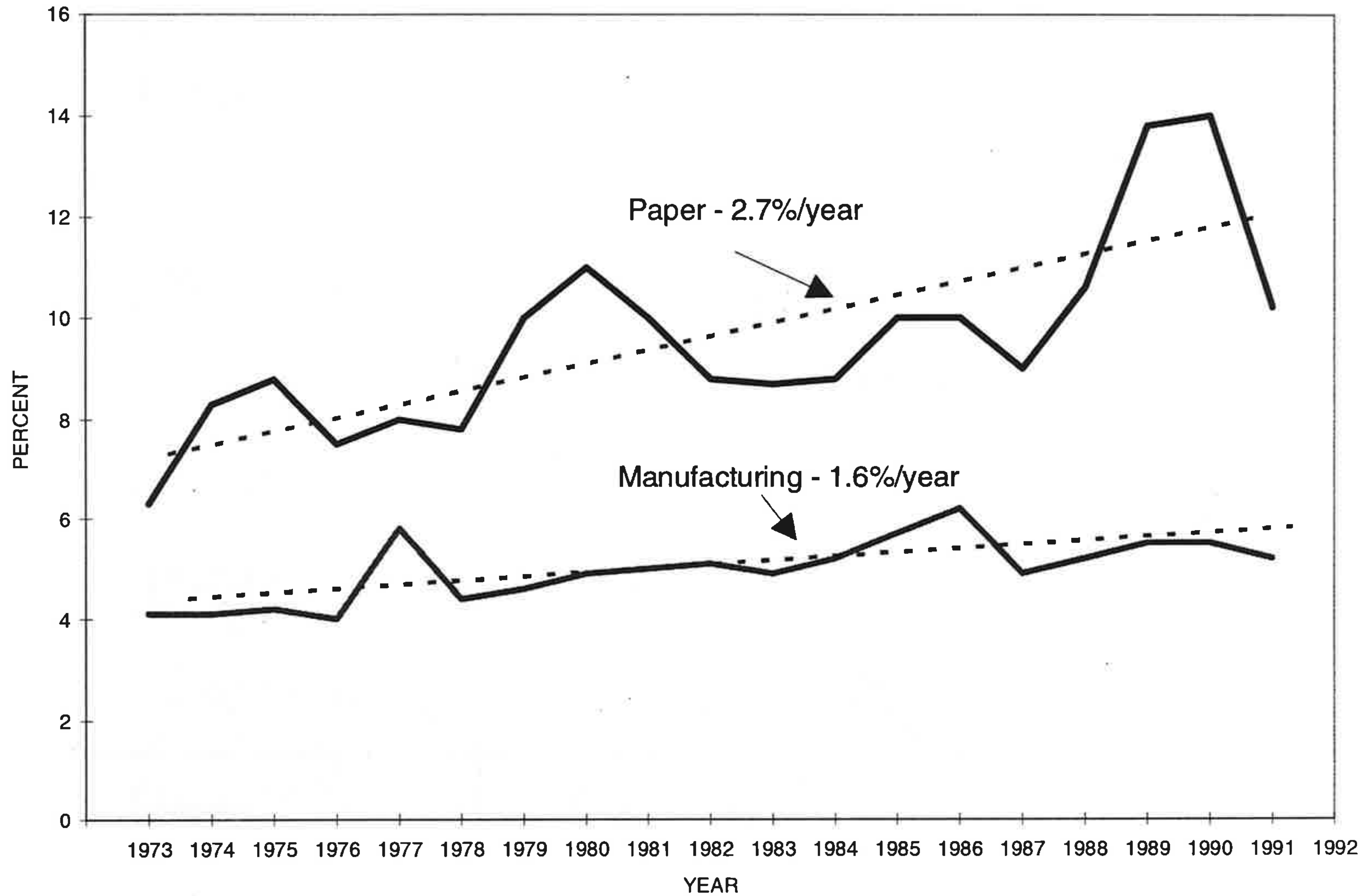
- Capital intensity compared to other industries
- Rate of increasing capital intensity

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

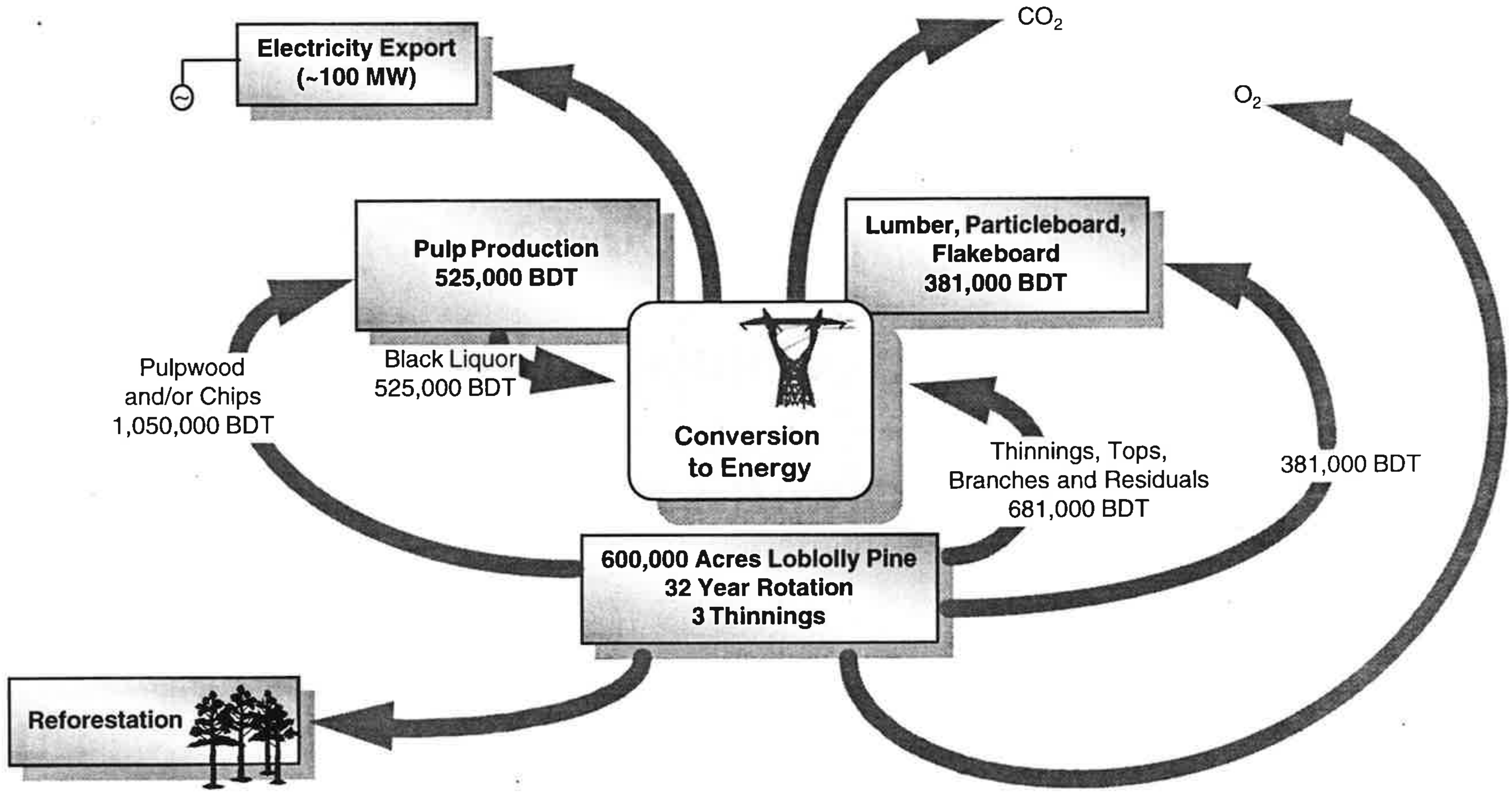
What BGCC & BLGCC Offer

- 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

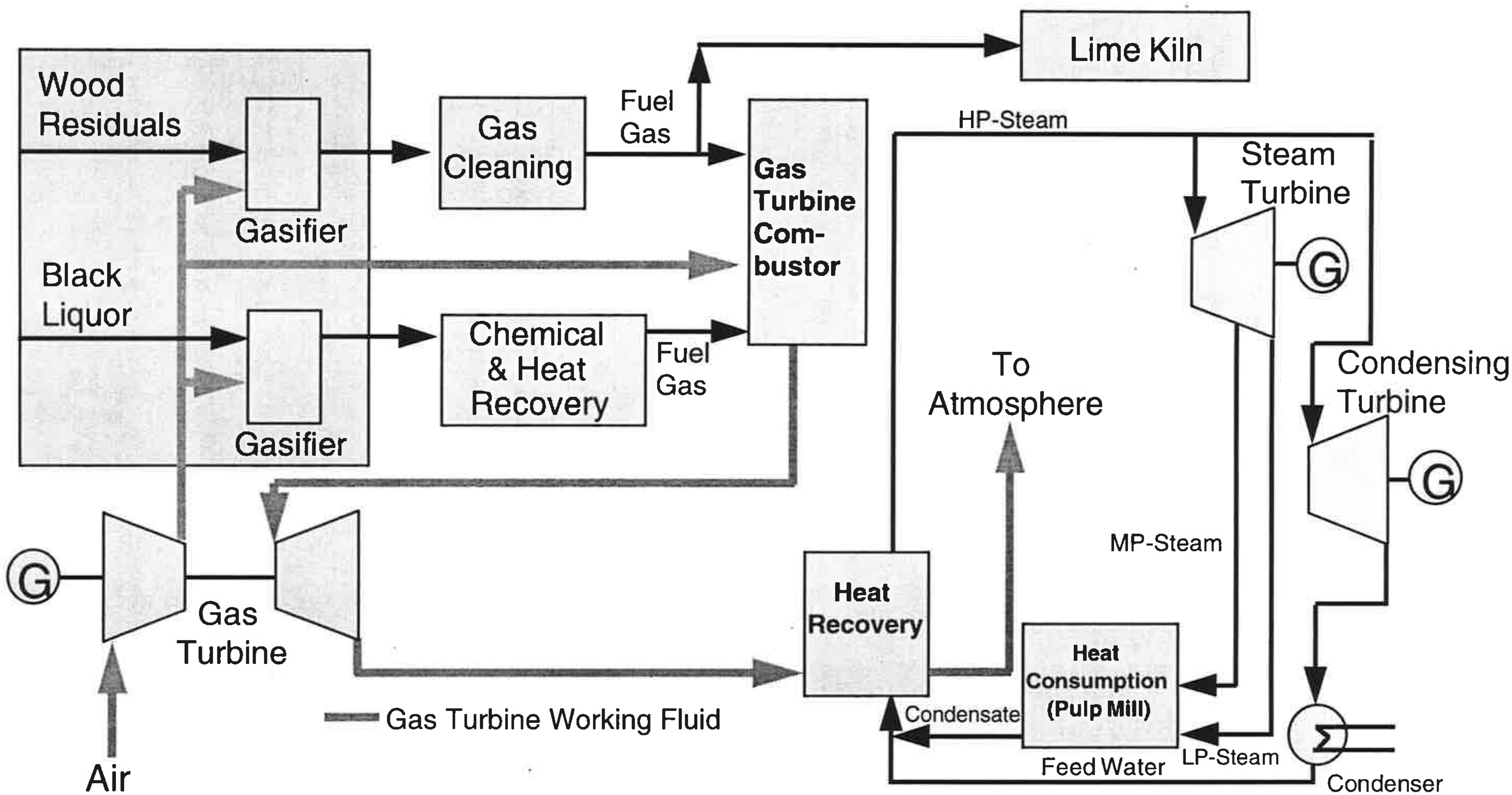
- Fuel from biomass model - an example
- A possible powerhouse configuration
- The efficiency potential

Alternative Fuel Options - A Plausible Model



Basis: 1 Year

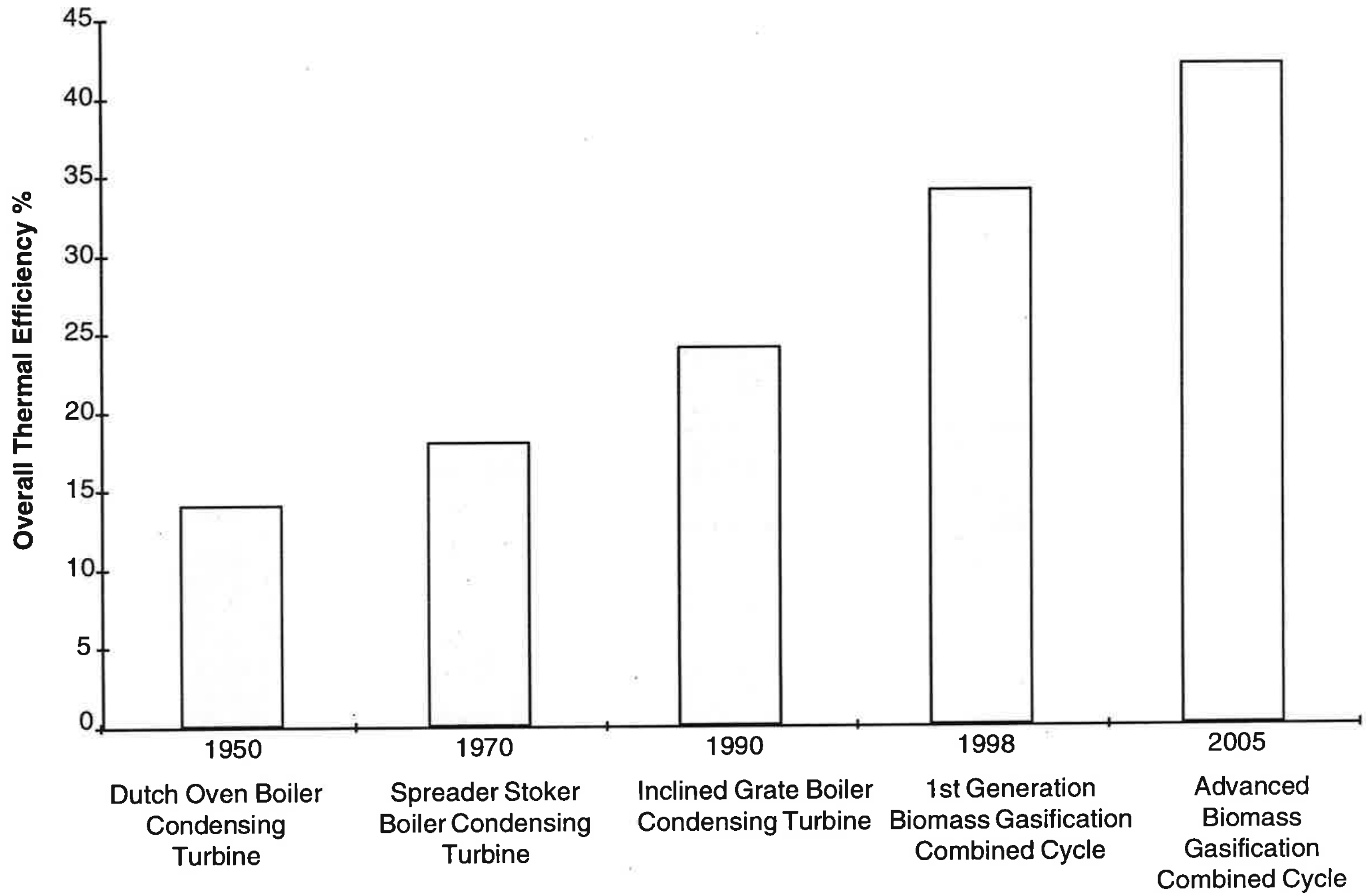
Power Recovery Island of 2010 Possible Configuration



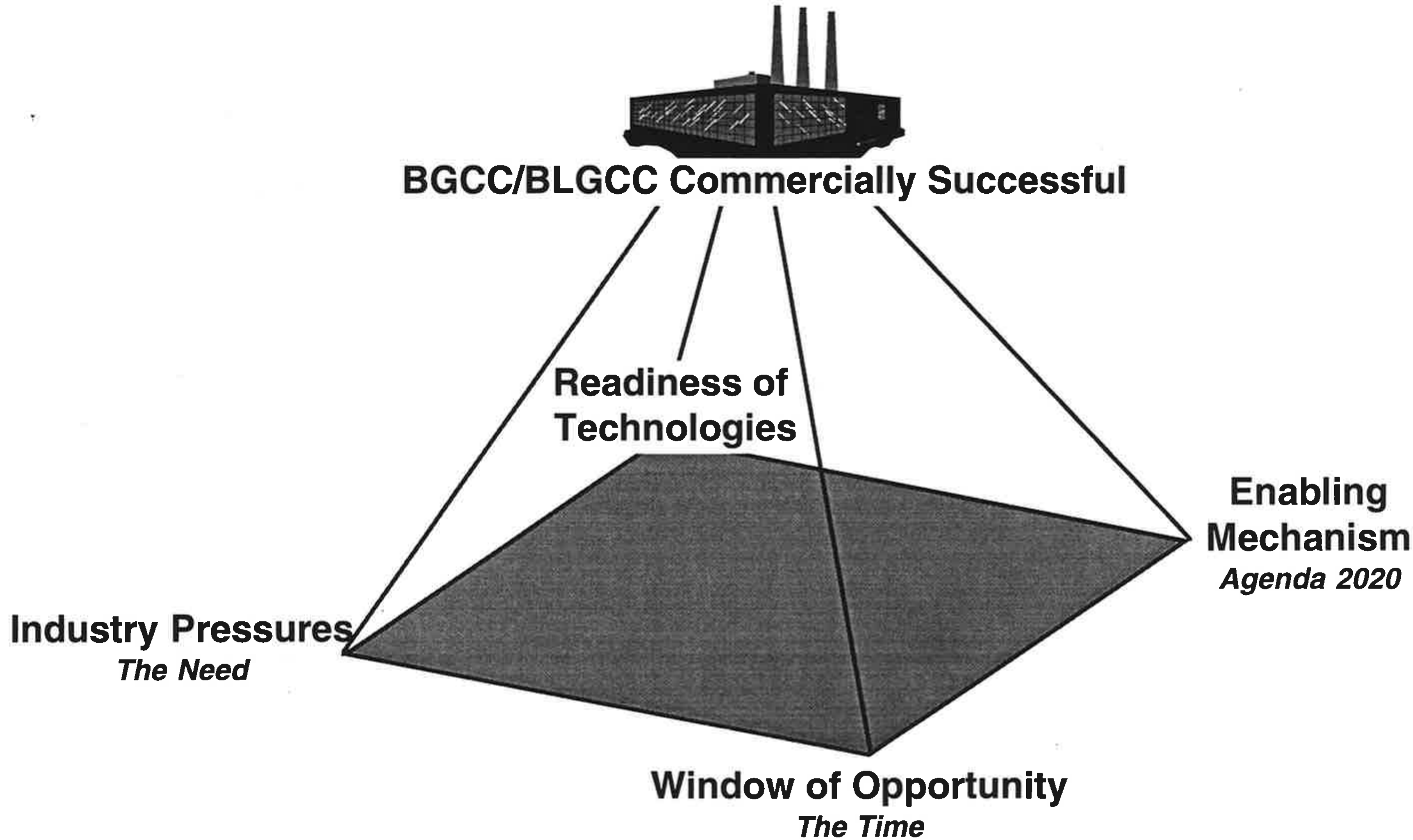
Source: Adapted from data provided by the Swedish National Board for Industrial & Technical Development

Power-Recovery Island of 2010

Power Generation Efficiency Comparison



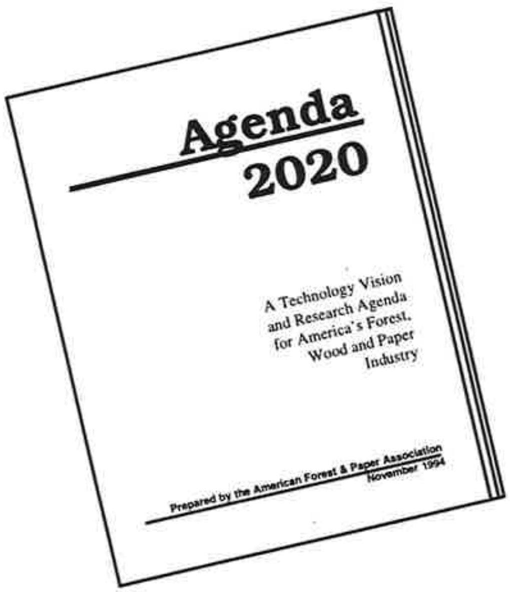
Commercialization of BGCC & BLGCC Technologies - *Why Now?*



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

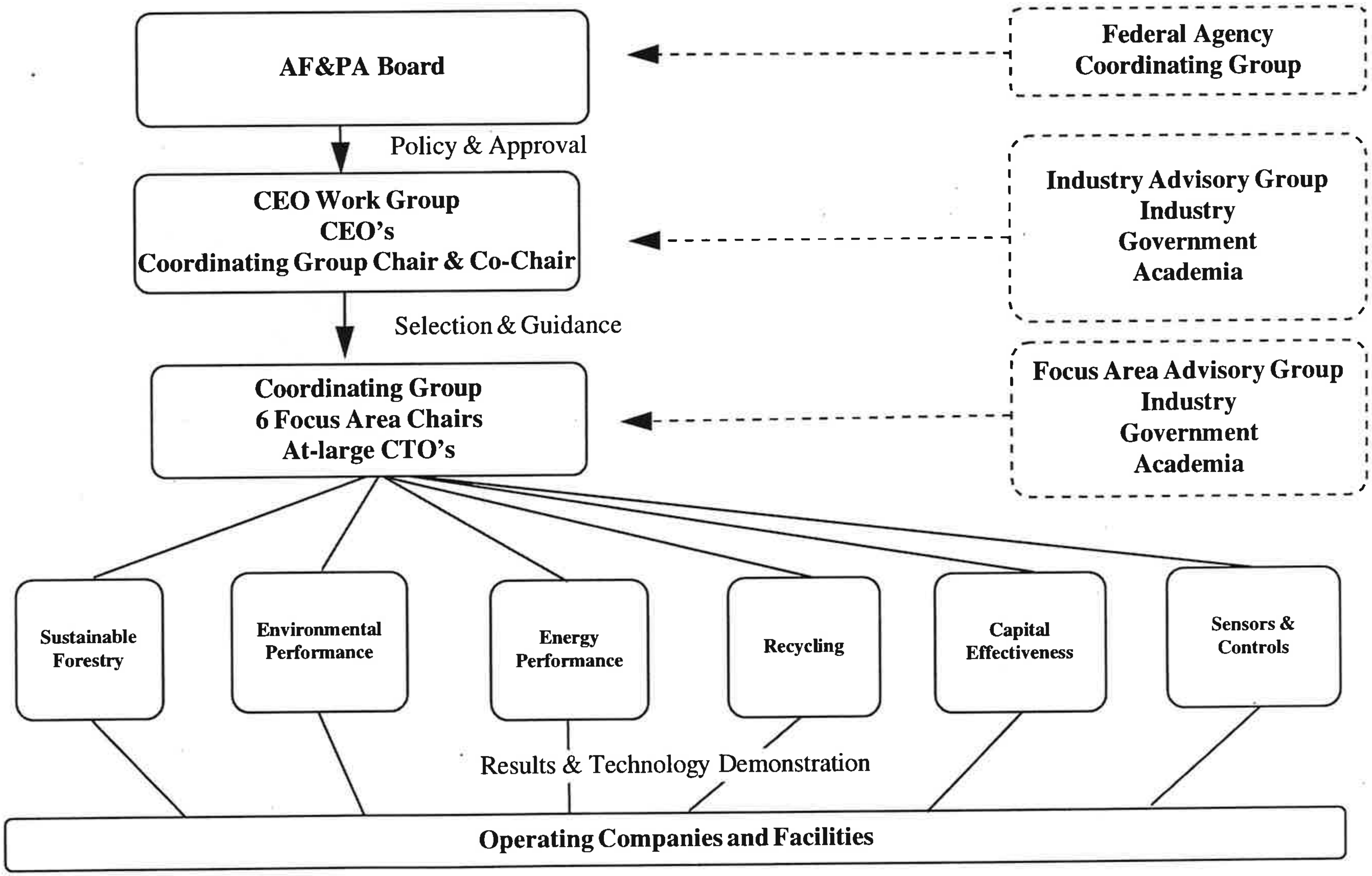
Agenda 2020 Execution Principles

- 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



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

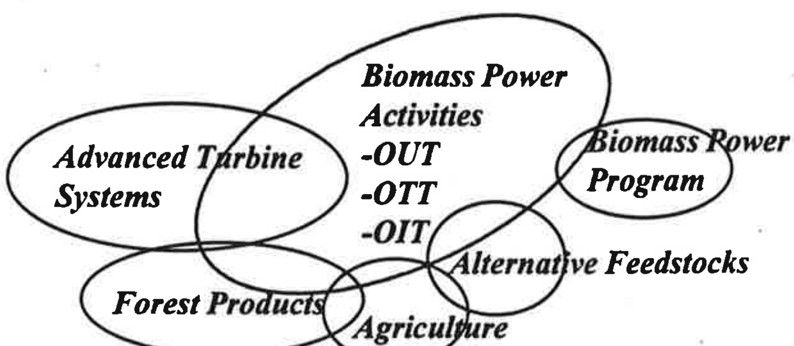
"DOE Initiatives in Gasification/Biomass Power"

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.

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

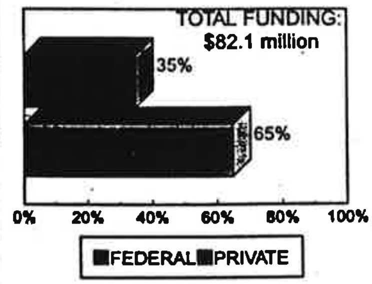
Biomass Power Program

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*

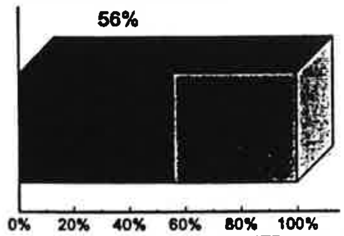
Hawaii Gasifier Plant

PROJECT COST-SHARING



PROJECT DURATION

% DURATION COMPLETED



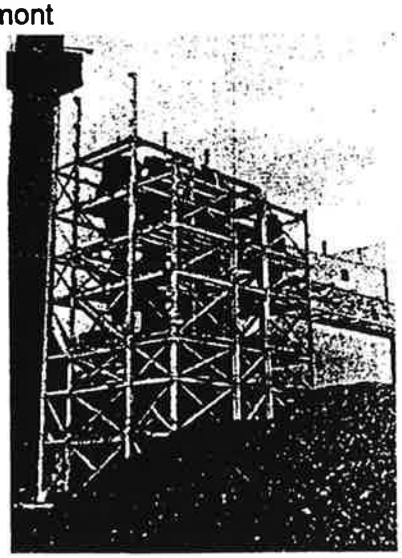
START DATE: 09/30/91 ; END DATE: 09/29/00

Program Operational Details:
MAJOR PROGRAM PROJECTS

Biomass Power Program

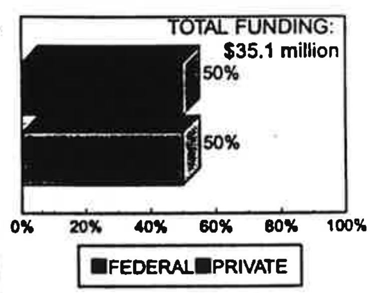
Vermont IGCC Scale-up Project

- 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)*



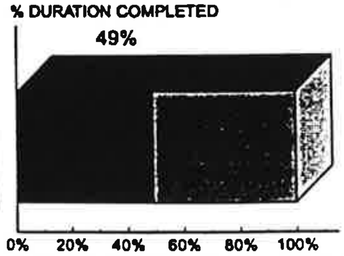
Gasifier Construction

PROJECT COST-SHARING



PROJECT DURATION

% DURATION COMPLETED



START DATE: 10/01/94 ; END DATE: 10/31/98

Biomass Power Program

Program Operational Details:
MAJOR PROGRAM PROJECTS

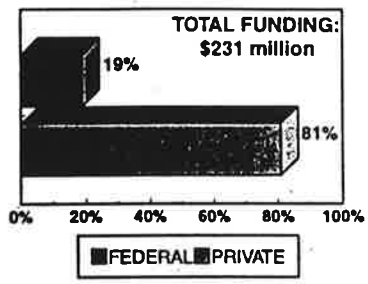
Minnesota Agri-Power Project (MnVAP)

- **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*

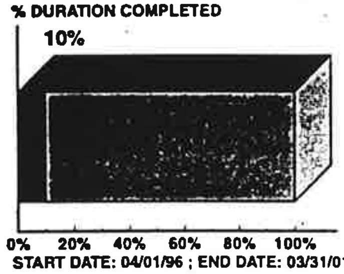
Alfalfa Harvester

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

PROJECT COST-SHARING



PROJECT DURATION



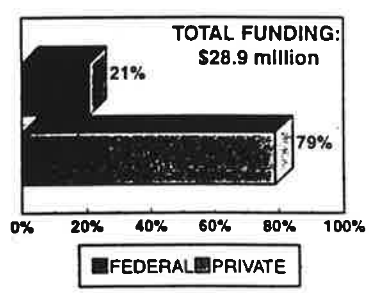
Biomass Power Program

Program Operational Details:
MAJOR PROGRAM PROJECTS

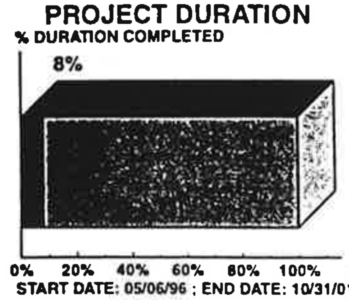
Chariton Valley Gasification/Co-firing Project

- **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.*
  - *ABB/CES (Asea Brown Boveri/Combustion Engineering Systems)*
  - *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)*

PROJECT COST-SHARING



PROJECT DURATION



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

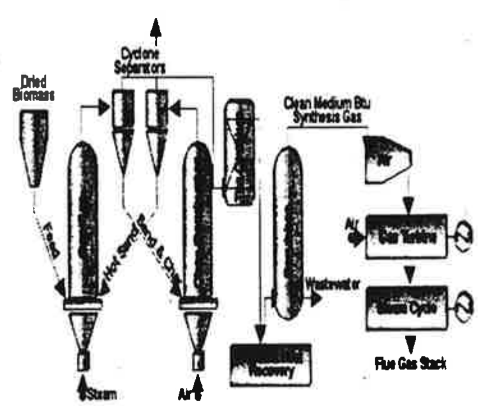
Location: New Bern or Plymouth, North Carolina

Partners:

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

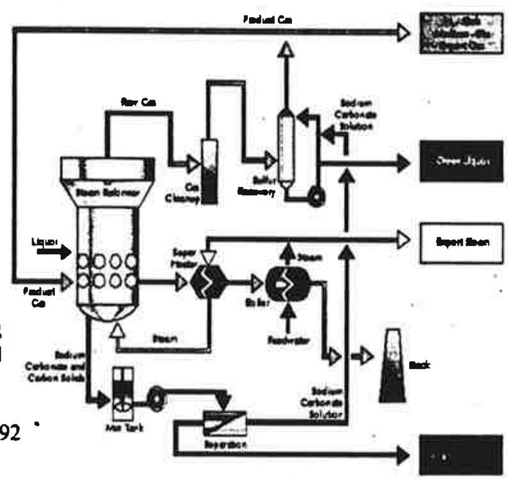
Project Details:

-Asses 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:
-PulseEnhanced 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

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

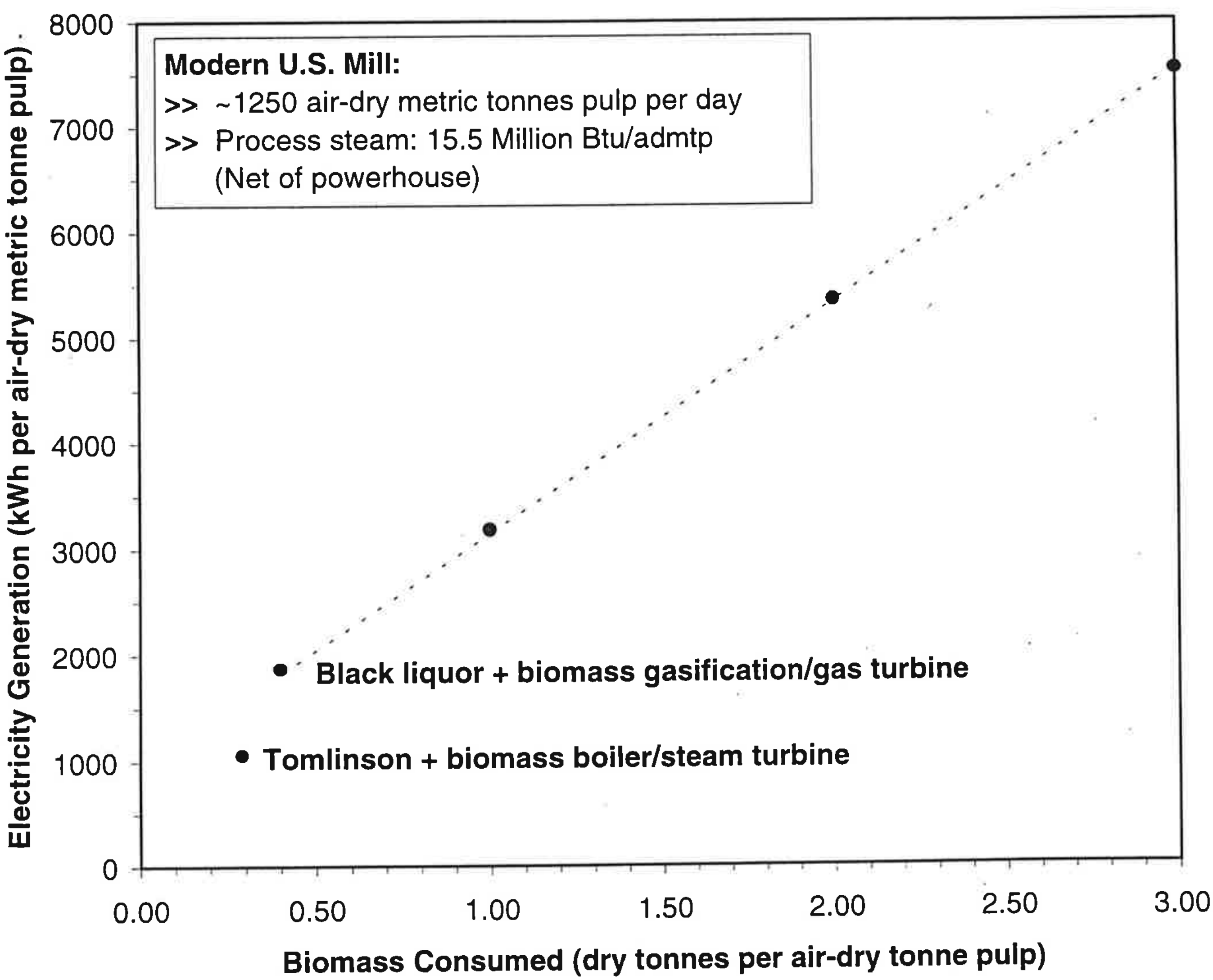
Workshop on Commercialization of Black
Liquor and Biomass Gasification for Gas Turbine
Applications in the Pulp and Paper Industry
Princeton University, Princeton, NJ
16-17 January 1997

Prospective Benefits of Gasifier/Gas Turbines vs. Boiler/Steam Cycles

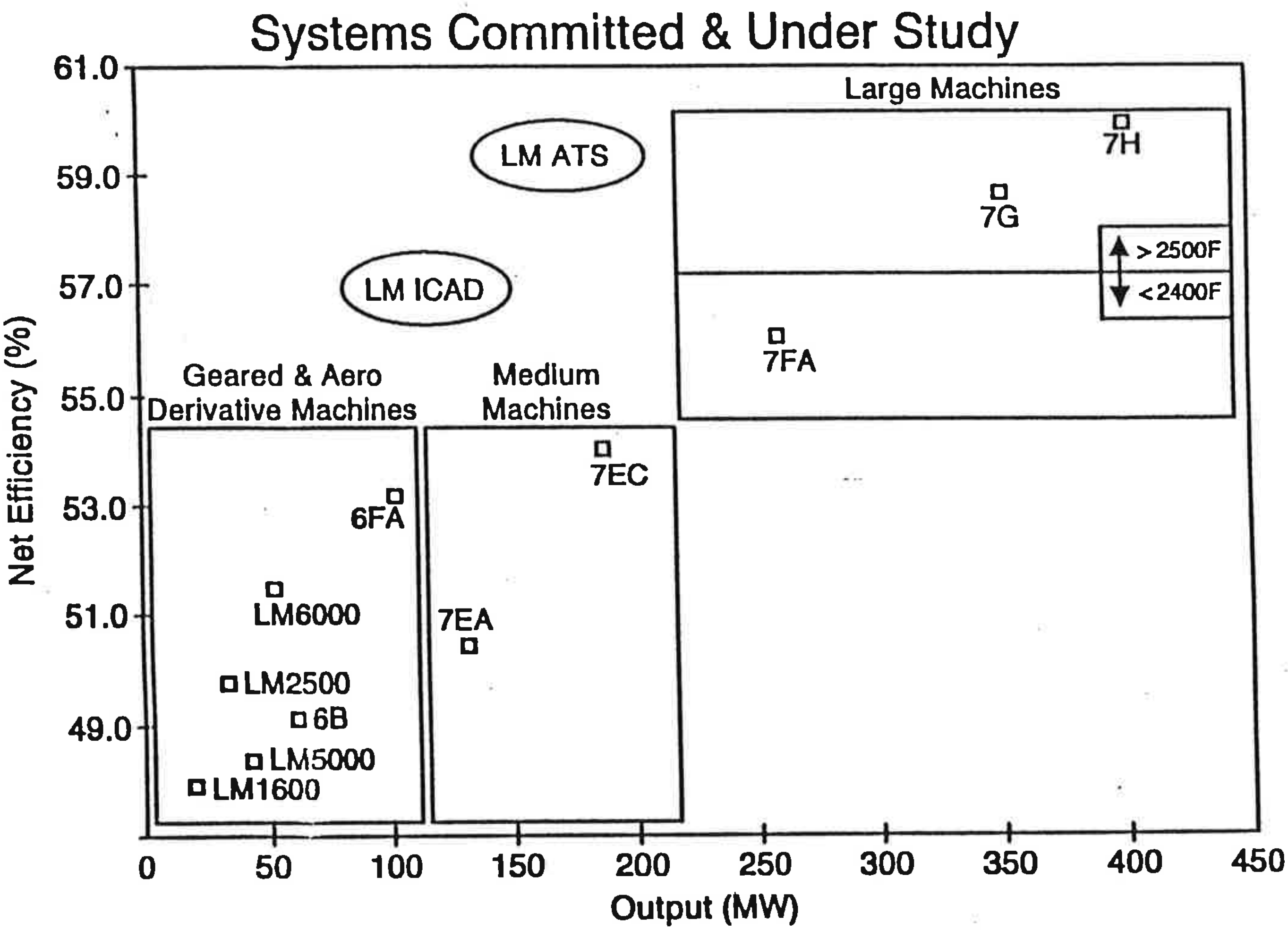
- For biomass and black liquor:
  - » Higher overall efficiency; large increase in electrical efficiency.
  - » Reduced environmental impact.
  - » Reduced capital costs.
  - » Improved availability.
- For black liquor:
  - » Improved safety
  - » Added flexibility in preparing pulping chemicals.
  - » Opportunity for direct causticizing.

Potential Power Generation at a Bleached Market Kraft Pulp Mill

(preliminary estimates)



Efficiency vs. Power Output for Gas Turbines Burning Natural Gas (GE)

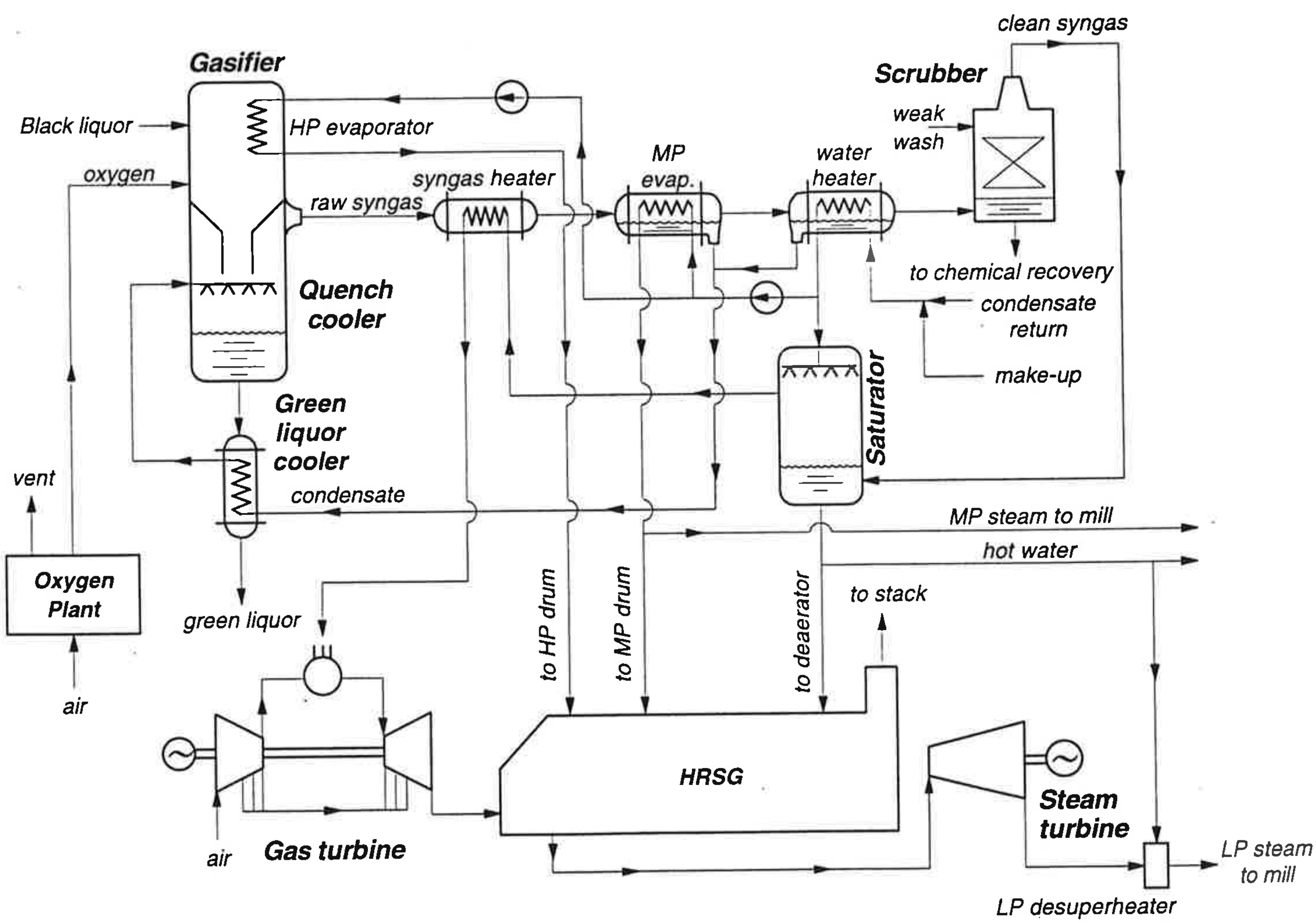


Novel Bottoming Cycle - Kalina
- Aeroderivative - Adds Up to 4 Pts.
- Large Utility - Adds 2 to 3 Pts.

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 O_2
  - » **Noell**: Oxygen-blown
  - » **Tampella and Ahlstrom**: not active

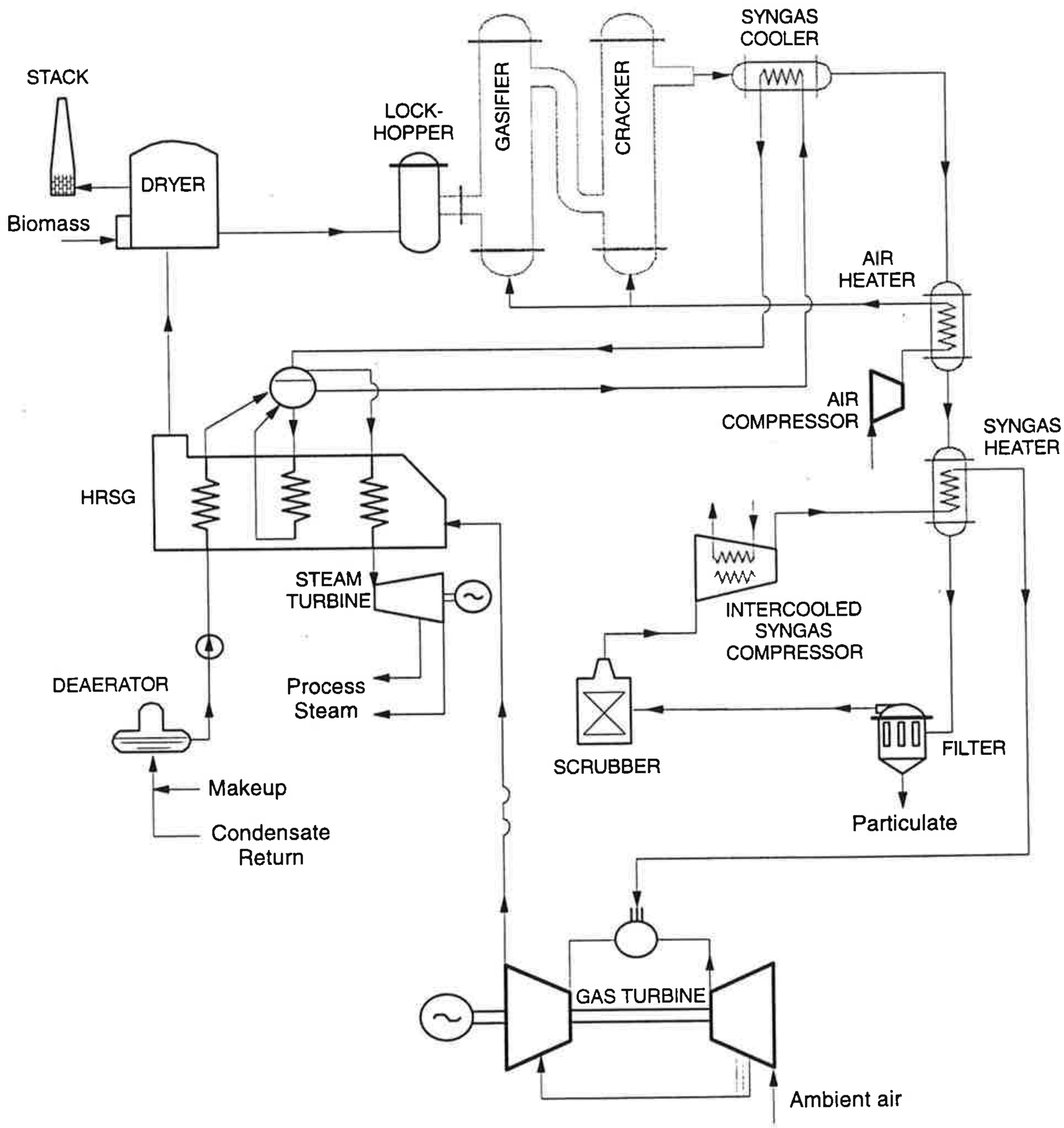
Black Liquor Gasifier/Gas Turbine Cogeneration System (Noell Gasifier)



Biomass Gasifiers Under Developement

- 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

Contaminant	Concern	Limit
Particulate Matter	Erosion	All particles less than 10 micrometers diameter, with 90 percent less than 5 micrometers.
	Deposition	Less than 100 ppmw.
	Environmental	.03 lb/MMBtu, HHV[1].
Alkali	Corrosion	Total alkali (sodium plus potassium) less than 20 ppbw.
Sulfur	Corrosion of Heat Recovery Equipment	No specific limit. Adjust temperatures to prevent acid condensation.
	Environmental	1.2 lb SO_2/MMBtu, HHV and 90% reduction[1].

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

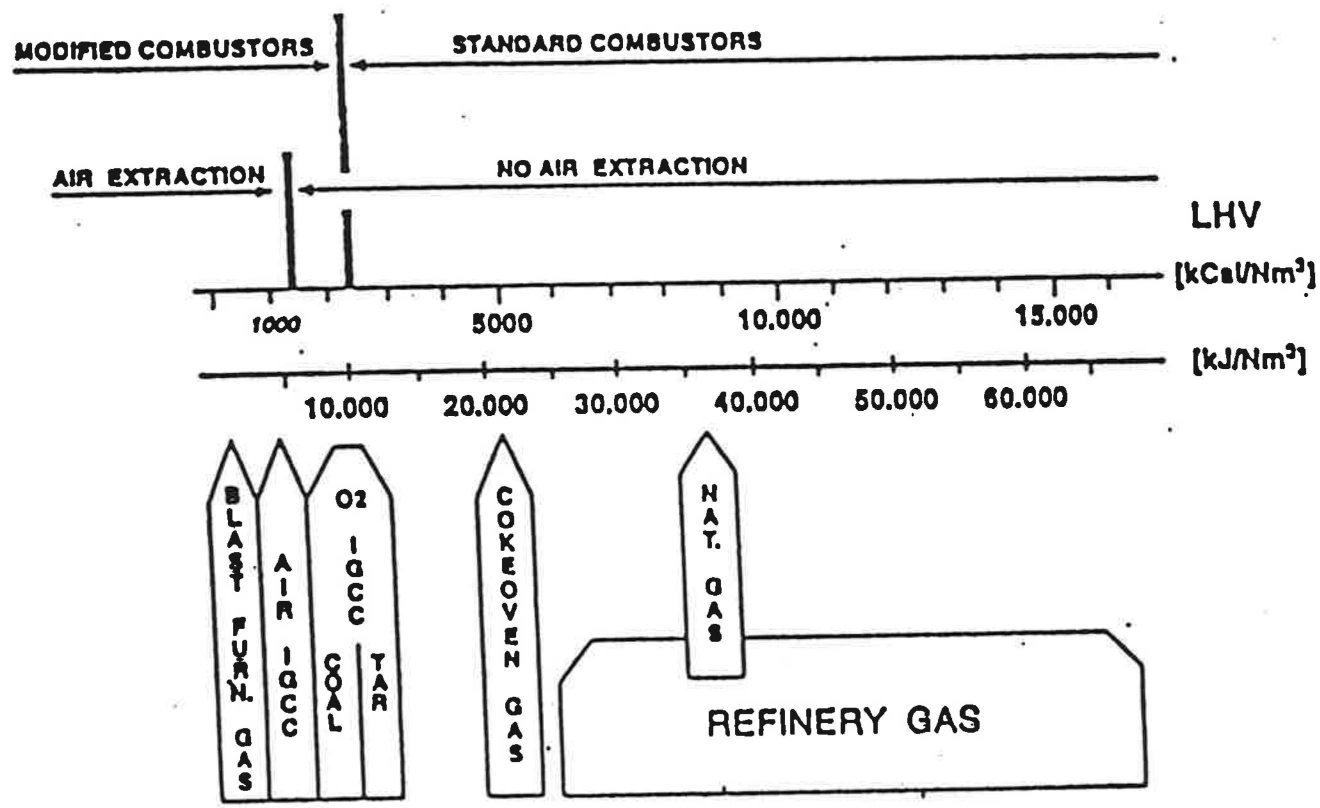
b) bleed air at compressor exit (or along the compressor)

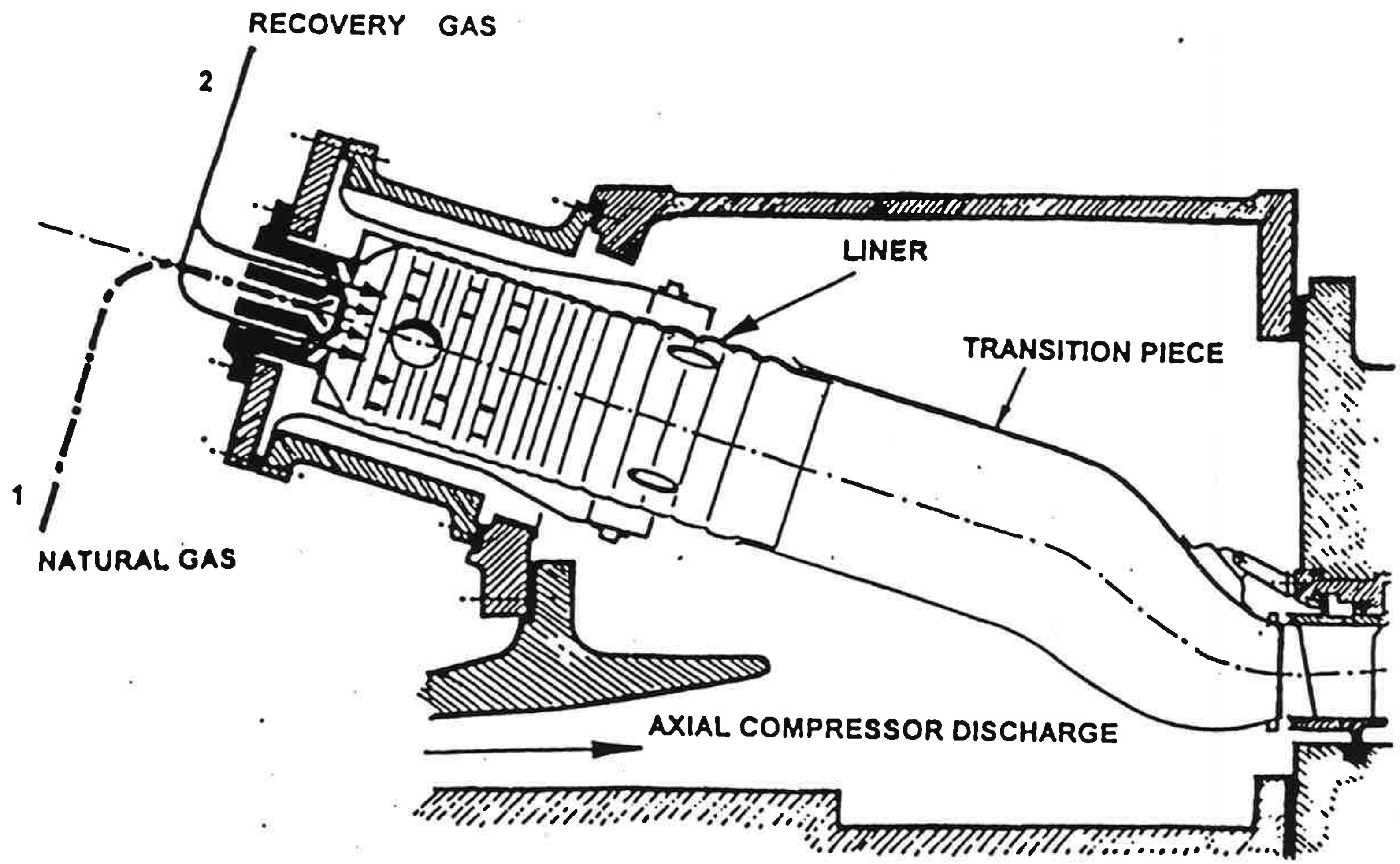
c) modify turbine
   - increase height of turbine blades
   - modify stagger angle of turbine blades

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





RECOVERY GAS
2
LINER
TRANSITION PIECE
1
NATURAL GAS
AXIAL COMPRESSOR DISCHARGE

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.

BLACK LIQUOR GASIFICATION COMMERCIALIZATION WORKSHOP

Princeton University

January 1997

NOELL, INC.

A Member of the
Preussag Group

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

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	Preussag AG
• Annual Sales ('94-'95)	$1.5 billion
• Group Companies	~15 worldwide
• Employees	~~~3,400~~ worldwide 8,000

NOELL, INC.

A Member of the
Preussag Group

PREUSSAG NOELL GmbH

- Systems and Mechanical Engineering
- Power and Environmental Engineering
- Process Engineering
- Services

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
BLACK LIQUOR GASIFICATION PROGRAM OVERVIEW

- Application Assessment 6/95 - 12/96
- Technology Development 1/97 - 6/97
- Technology Demonstration 6/97 - 6/00

TECHNOLOGY ASSESSMENT
(Jun '95 - Dec '96)

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

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.

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

FUTURE WORK (1/97 - 6/97)

- 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

COMMERCIALIZATION ISSUES

- Confirmation of key process objectives to assure involvement of all relevent 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

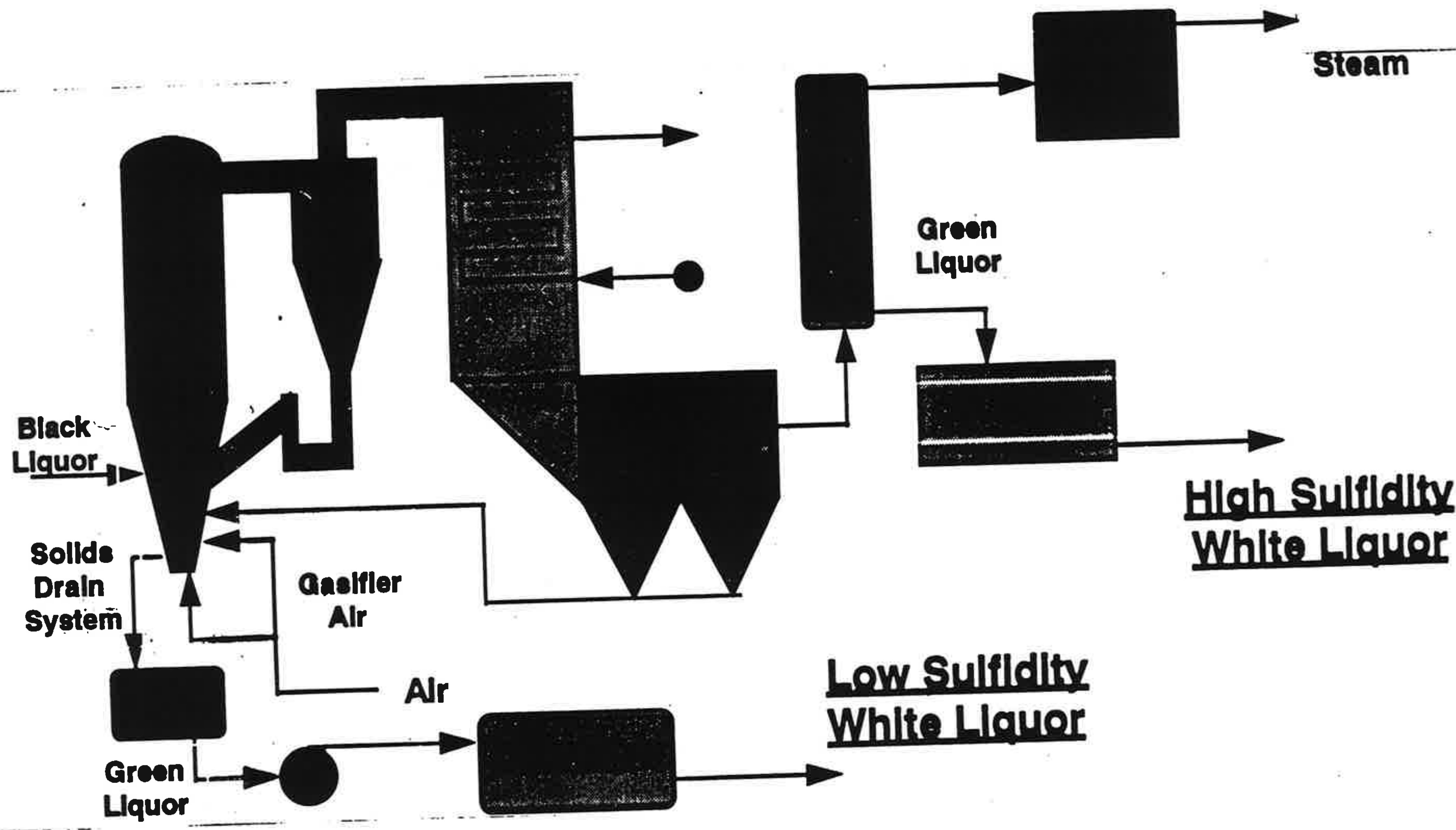
- ABB BLG Technology
- Key Drivers Required to Replace the Tomlinson CRU
- Major Technology Uncertainties
- Critical Path for Development
- How Can the P&P Industry Help
- Summary

ABB/CE BLG Process Description

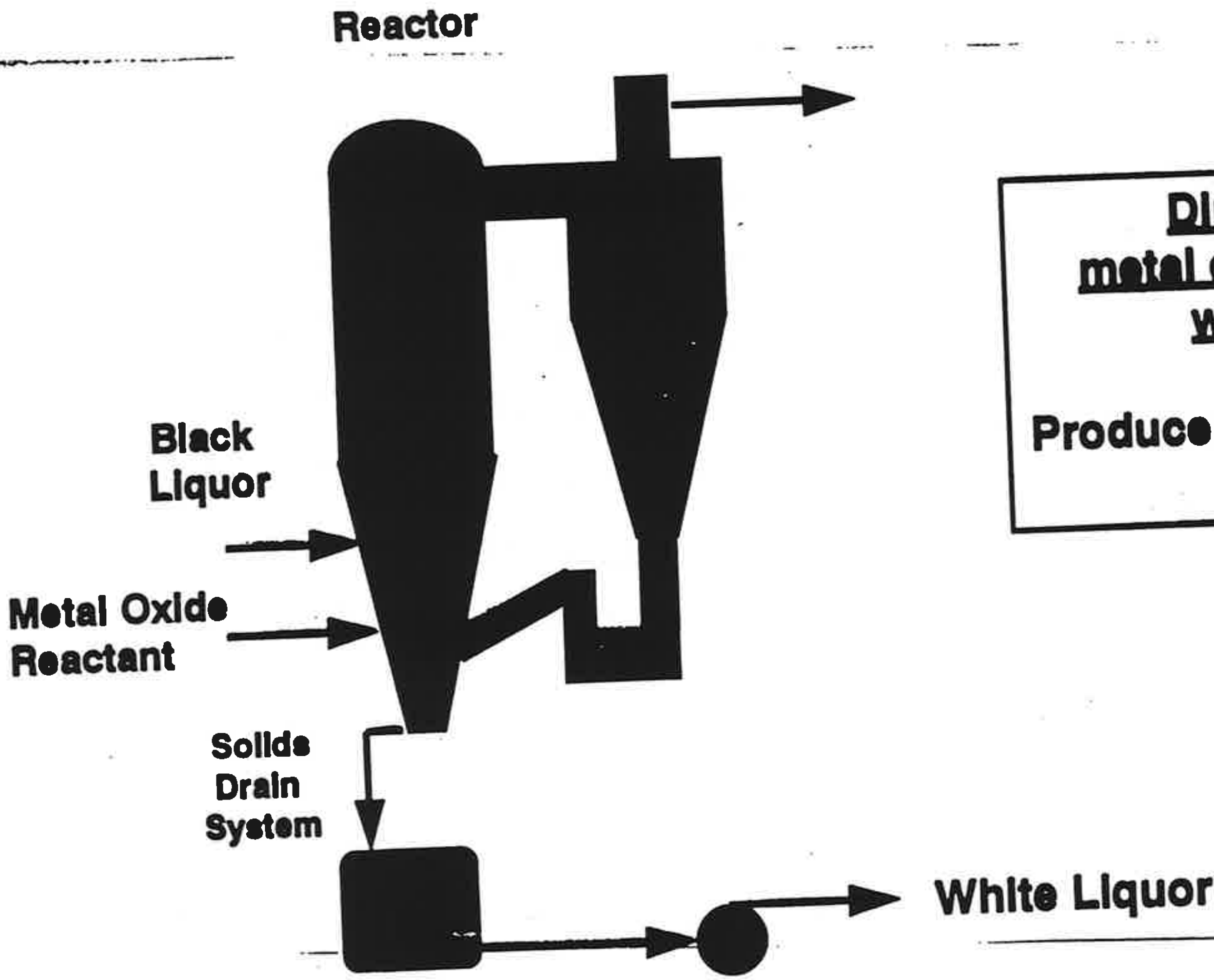
- **Non-Smelting Process**
  - Low Temperature Operation: 1300 - 1380°F (700 - 750°C)
- **Air Blown Gasification**
- **Gasifies With Circulating Fluid Bed Technology**
  - Reactor, cyclone, seal pot & solids return line
- **Incorporates Equipment Proven In Other Processes**

ABB

Original BLG CRU Process



Direct Causticization Of Sodium Will Simplify Pulp Mill Operations



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

Produce NaOH directly from bed solids
No $NaCO_3$ Formed

ABB

C/NEWPRS/AVN/BLGASBW

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

ABB

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
      - H_2S/CO_2 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

ABB

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?
  - Direct Causticizing
    - Major economic impact \$5-\$10/Tonne pulp possible savings
    - ABB process well suited
    - Promising demonstrations with TiO_2 have been conducted
    - Recovery of TiO_2 has major influence on economics
  - Lower carbon loss
    - May be major challenge
  - Higher reduction efficiency
    - Surprisingly low economic impact

ABB

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

ABB

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

ABB

Major Technology Uncertainties

- **Direct Causticizing - ABB Process**
  - TiO_2 recovery/recycle
  - NaO/TiO_2 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

ABB

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
    - [redacted]
    - 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

ABB

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

ABB

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

Presentation Outline

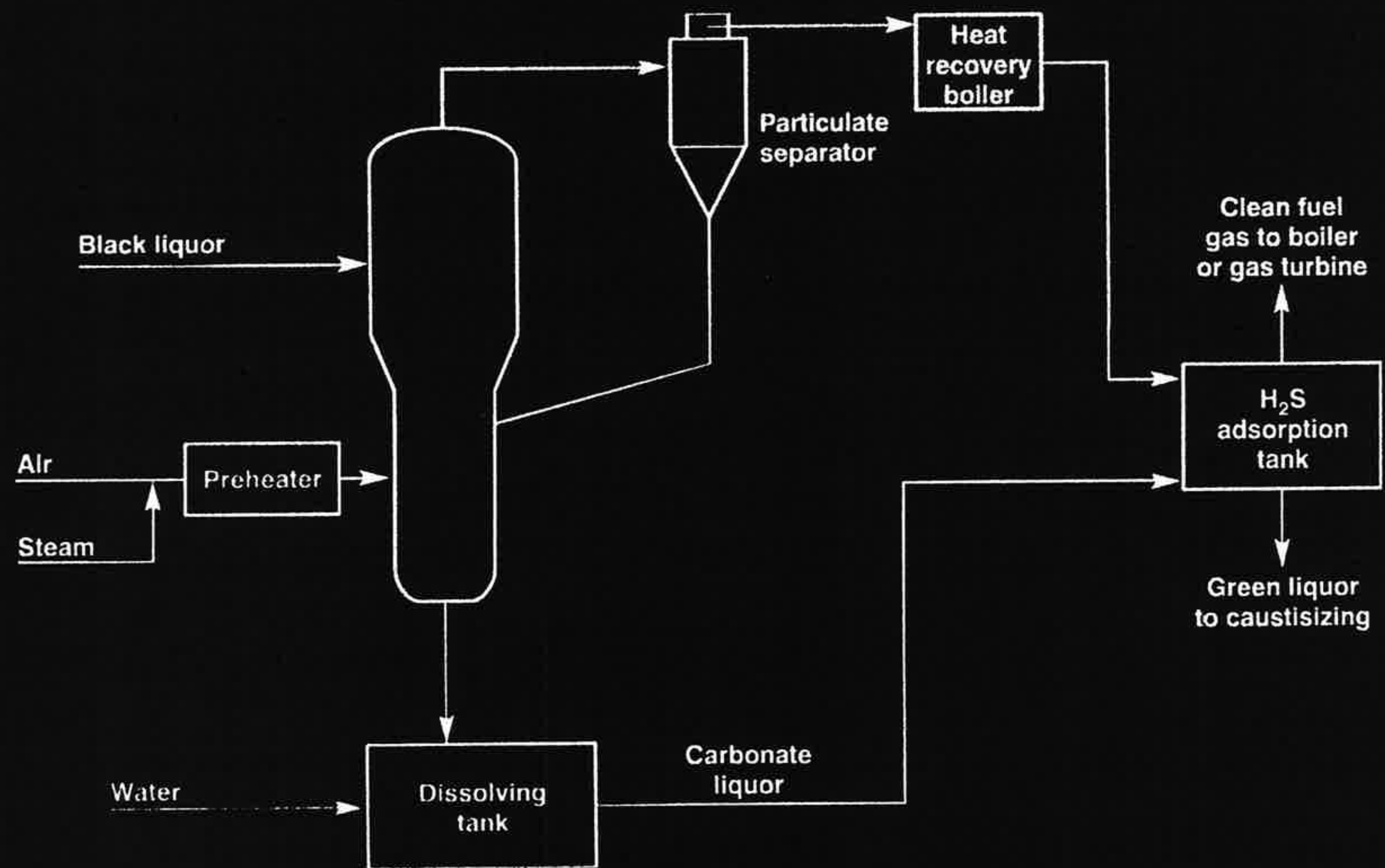
- B&W Development Program
- Obstacles to Commercialization
- Successful Demonstration of BLG

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

B&W Development Program

Low-Temperature Gasifier Design



Results of Bench-Scale Tests

- Low-Temperature Gasification Feasible
  - Low HHV gas produced at 1200°F (650°C)
- Tar Formation was Observed
  - Small quantity & most condensed at low temperature
- Incomplete Char Conversion
  - Char accumulation noted at 1000-1200°F (550-650°C)
- Bed Material Free-Flowing when Fluidized
- More Testing Required
  - Must address char and tar control

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)

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

Low-Temperature Processes:

- Slow Gasification Kinetics
- Incomplete Conversion of Tars
- More H_2S in Product Gas

- Development Costs, esp. Tar Control

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

Energy Penalties (MBtu/ADTP)*

	High-Temp Air, 1 atm	*Low-Temp Air, 1 atm*	*Conv. Boiler*
Hot water	5.92	0.53	~ 0
Causticizing	2.38	2.93	1.8

* 3000 lb BLS/ADTP (Bleached)

Causticizing Requirements

- H_2S and CO_2 absorption forms $NaHCO_3$
  - CO_2 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

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 $NaHCO_3$ formation during product gas scrubbing

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

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 & turbomachinary partners
- Validated modeling to support commercial designs

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 gasfication systems

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

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

CHEMREC®

Format	◆ A venture company in the Kværner Pulp & Paper business area
Area of activity	◆ Kraft chemicals recovery and power generation based on black liquor gasification
Business mission	◆ Commercialize basic proprietary technologies Develop expanded and stepout technologies Prepare and implement plant projects based on new technologies
Organization	◆ * Executive management * Control and administration * Contracts and negotiations * Technology * Studies and commercial configurations * Projects and plants

CHEMREC® Recovery
Two major applications

Kværn
Image Libr

CHEMREC Recovery capacity booster

- Relieve overloaded recovery boilers
- Capacity expansion projects

CHEMREC IGCC (Integrated Gasification Combined Cycle)

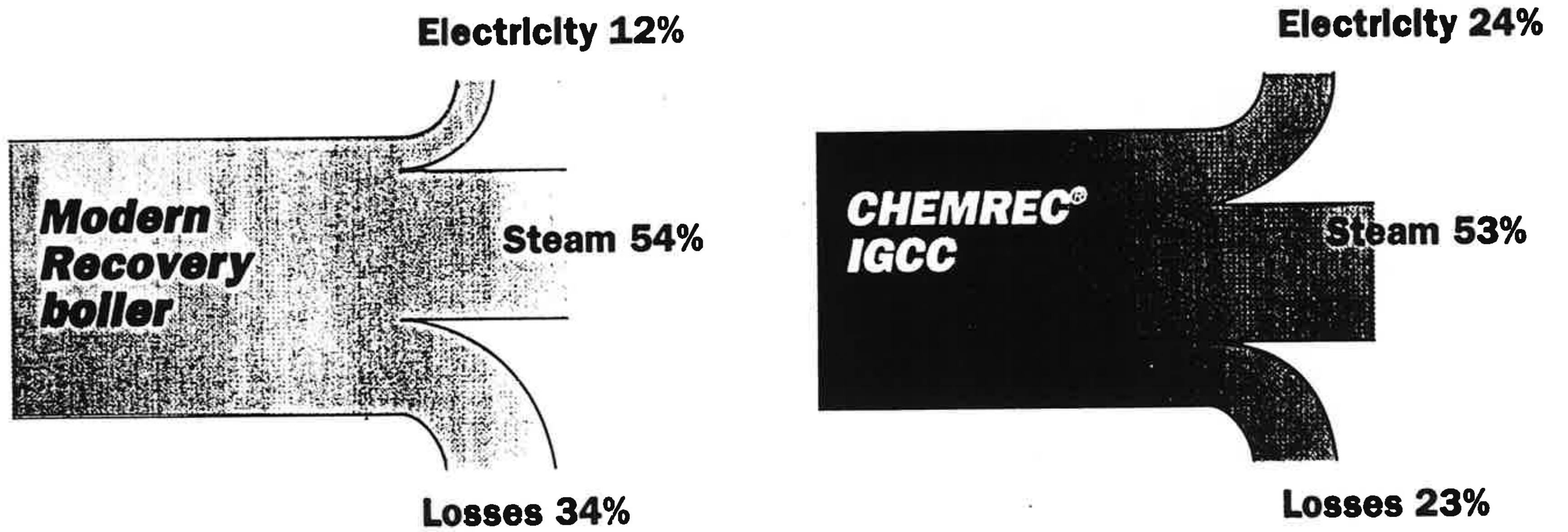
- Replace old recovery systems
- Recovery technology for greenfield mills

CHEMREC® Recovery
Milestones

Pilot plant	3 TDS/24 h	SKF Hofors	1987–1990
Demonstration plant	100 TDS/24 h	AssiDomän	1992–
Pressurized pilot plant	6 TDS/24 h	STORA	1994–
Commercial plant	350 TDS/24 h	Weyerhaeuser	1996–
Financing and engineering, pressurized demo plant			1996–

CHEMREC® vs Recovery boiler
Energy flows Cogeneration

HHV-basis



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

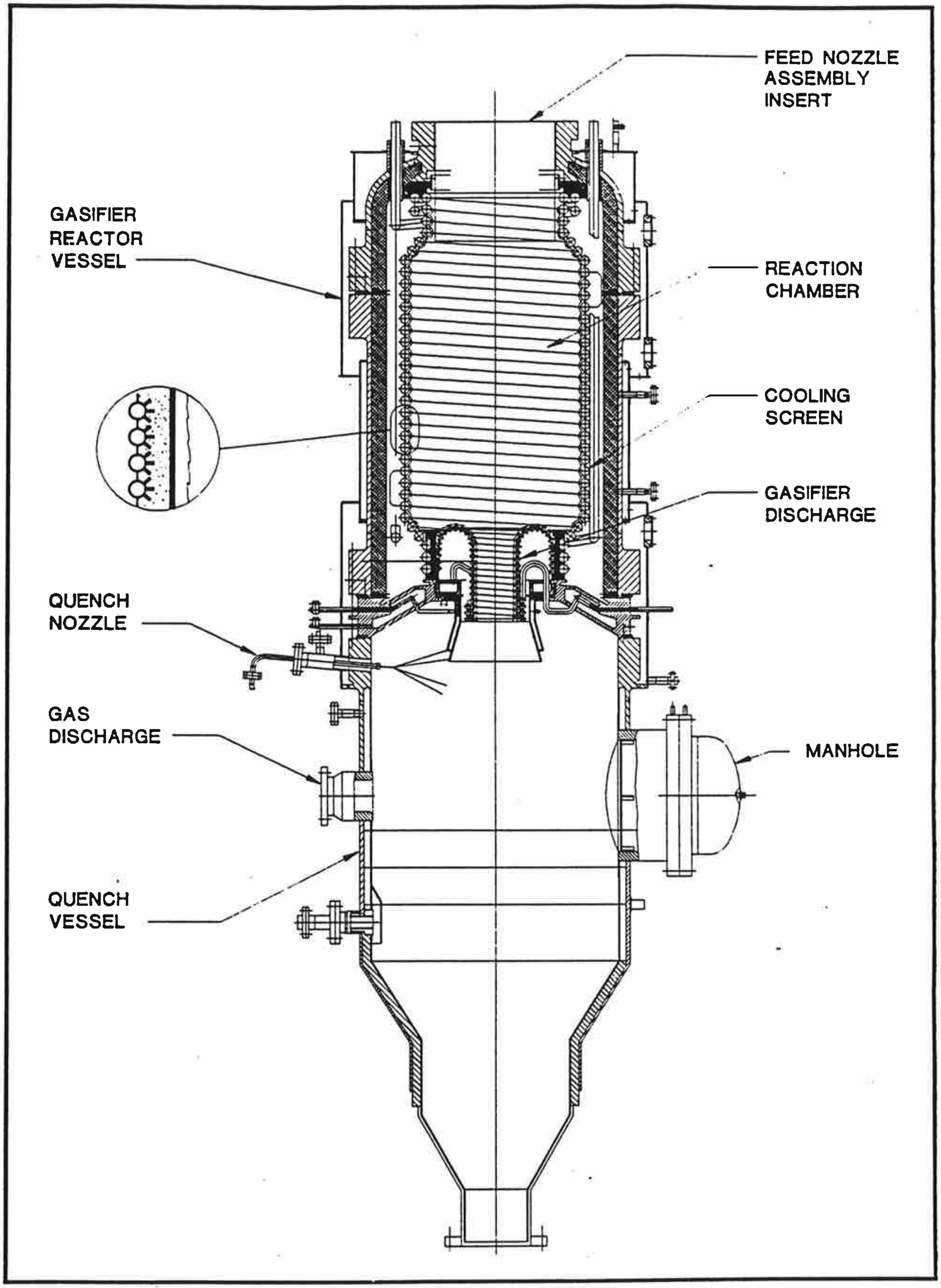
- Bankability/Stand-alone Financing

- The Commercial Proposition

4) Cellulose Industry Facilitating Actions

- Long Term Replacement Strategy for CR Boilers

- IPP Alliances or Analogues



NOELL

Figure 1
Gasifier / Quench Assembly

Biomass Technical Breakout Session, Day 1

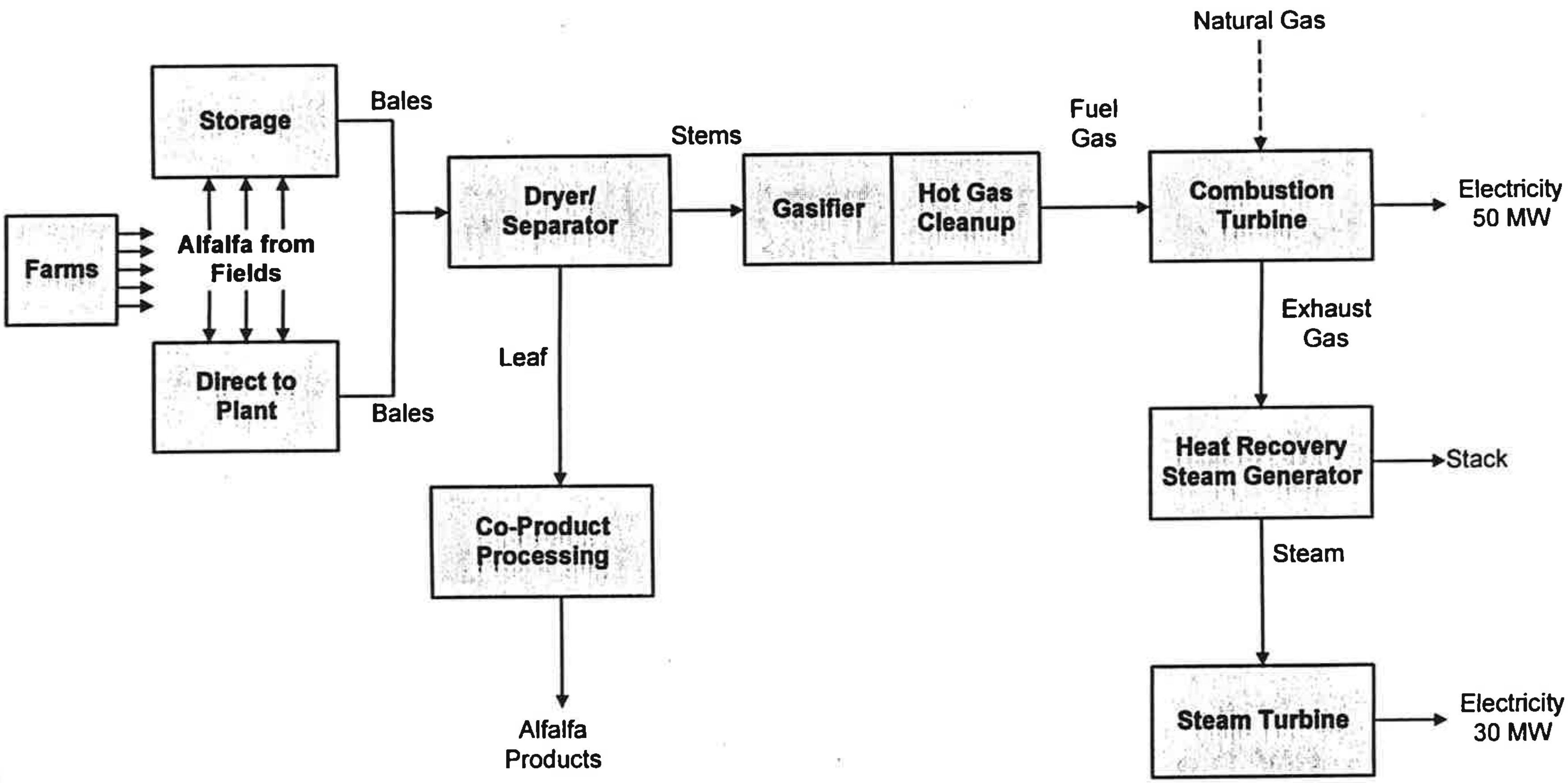
Jim Patel
Carbona Corporation

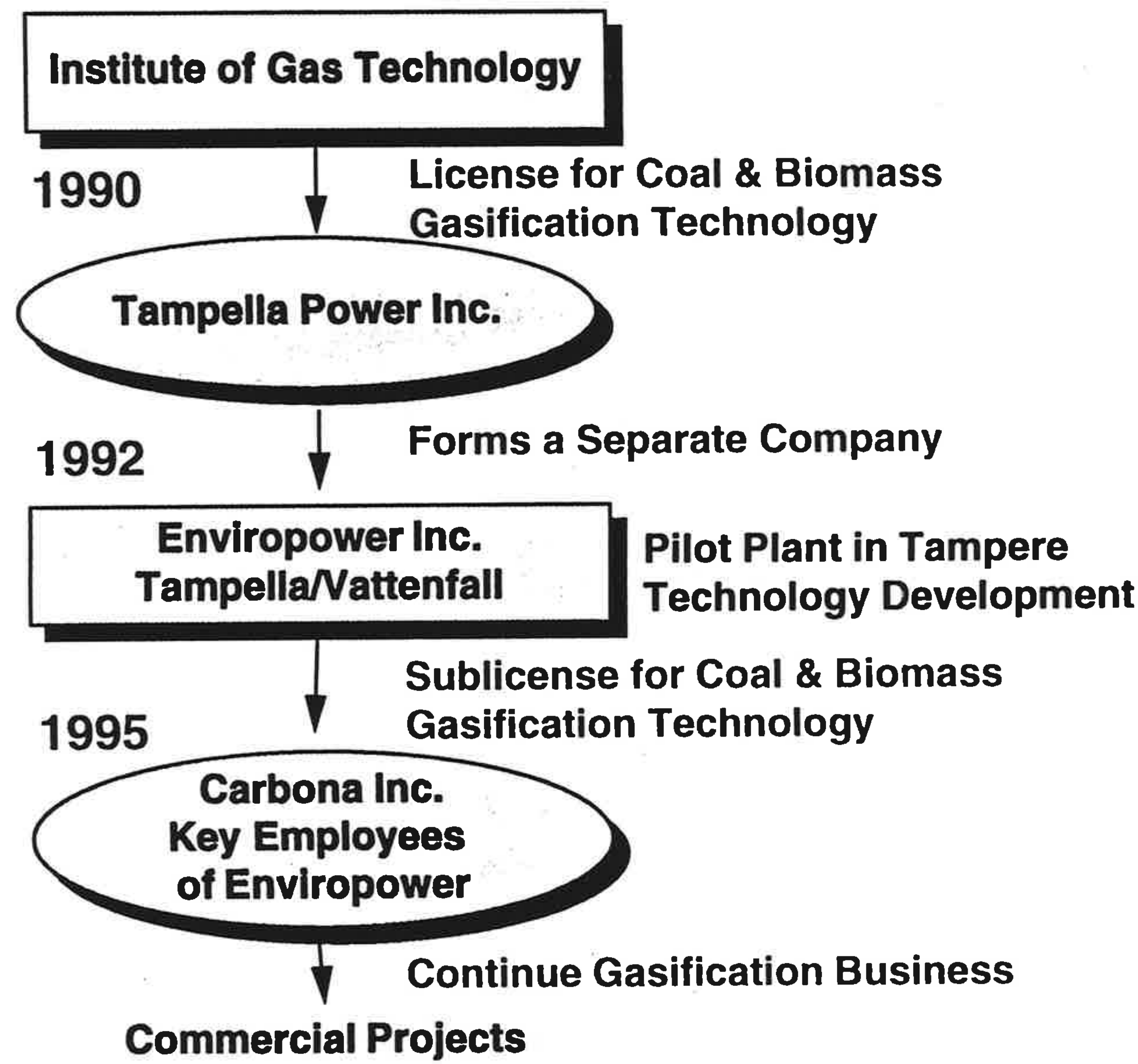
Workshop on Commercialization of Biomass Gasification in Pulp and Paper Industry

by J. G. Patel
CARBONA CORPORATION
Atlanta, GA

January 16-17, 1997
Princeton, NJ

Minnesota Agri-Power Project

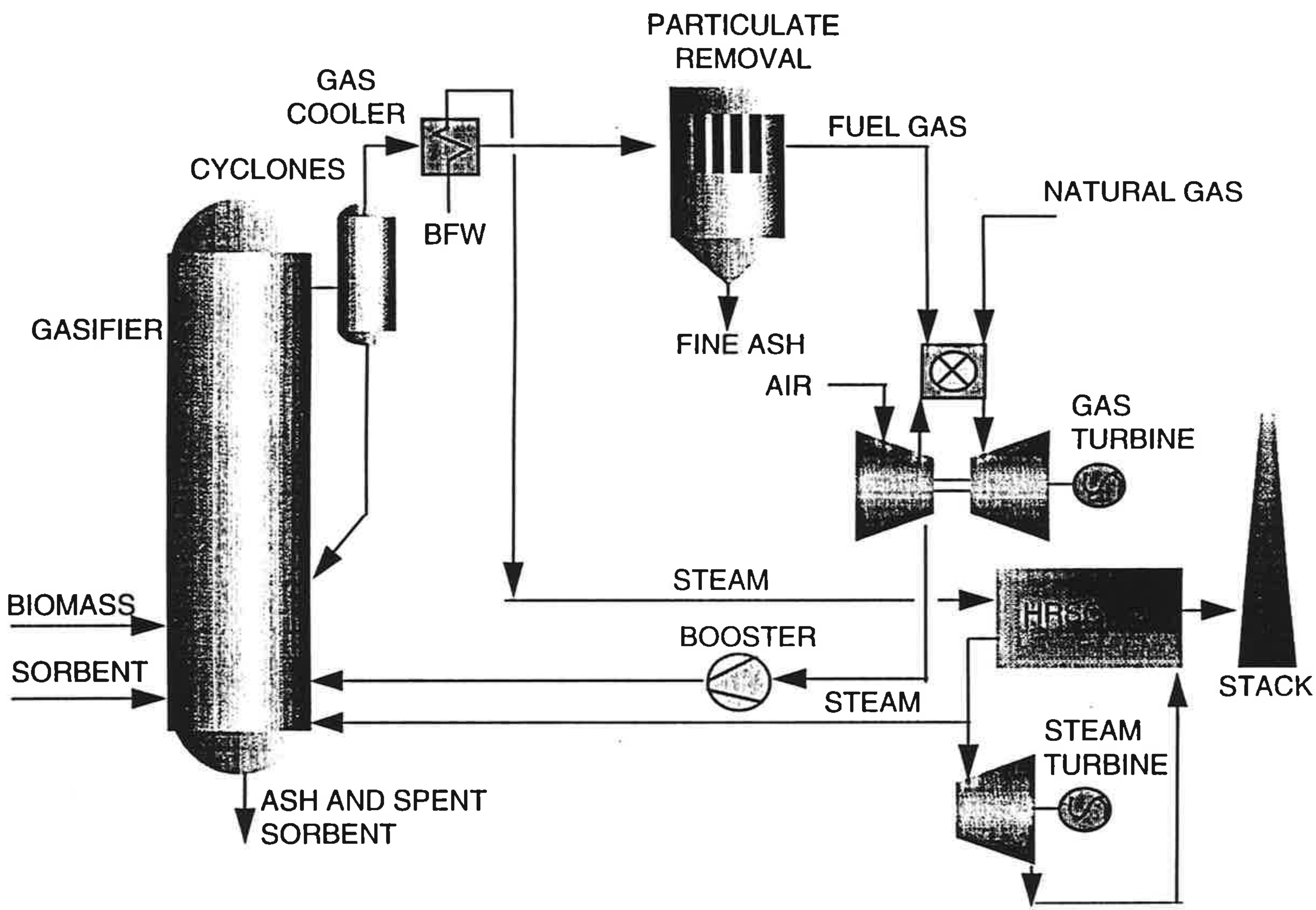



Institute of Gas Technology
1990
License for Coal & Biomass
Gasification Technology
Tampella Power Inc.
1992
Forms a Separate Company
Enviropower Inc.
Tampella/Vattenfall
Pilot Plant in Tampere
Technology Development
1995
Sublicense for Coal & Biomass
Gasification Technology
Carbona Inc.
Key Employees
of Enviropower
Continue Gasification Business
Commercial Projects

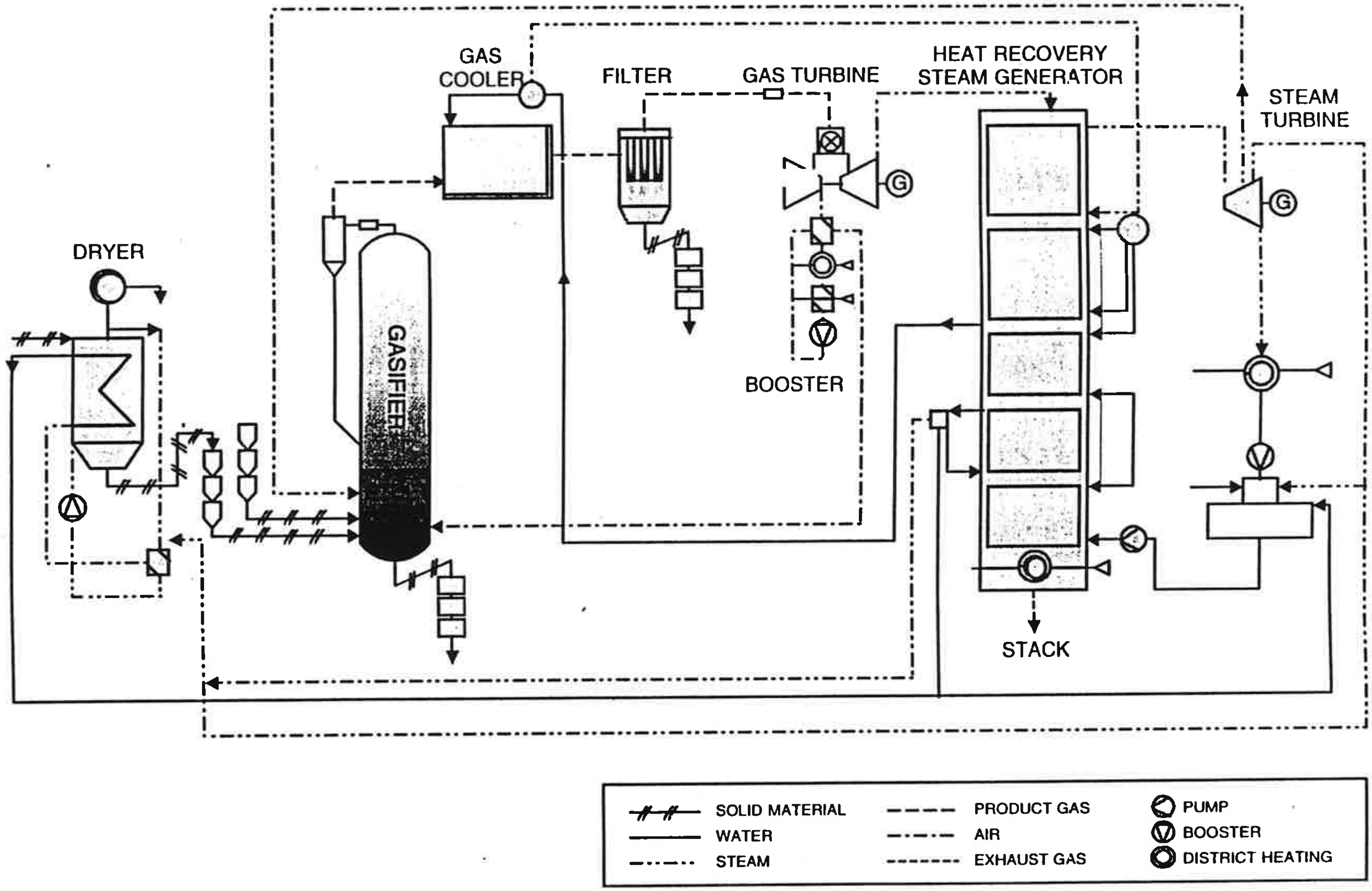
CARBONA INC.

- 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



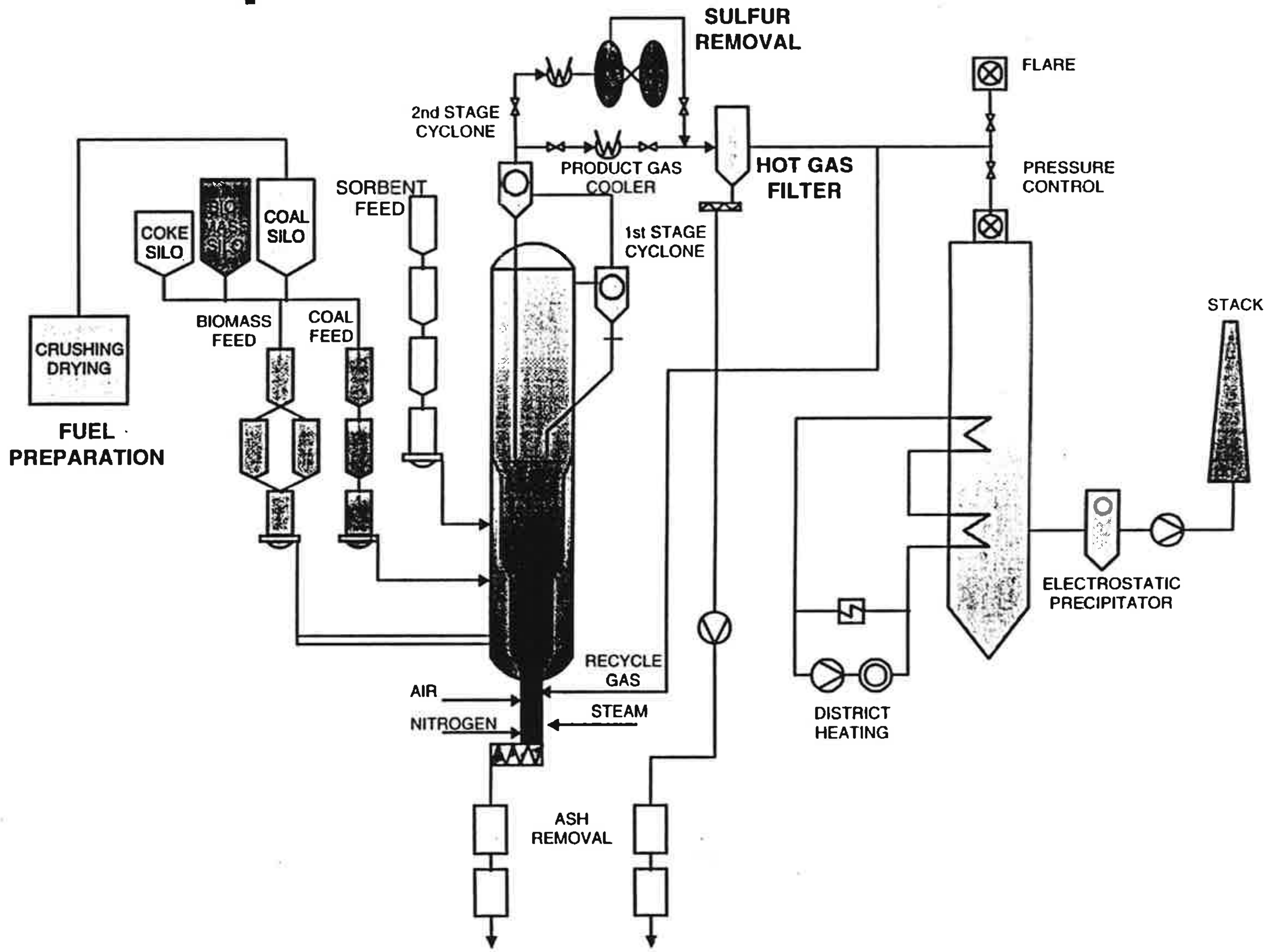
Enviropower's IGCC Concept

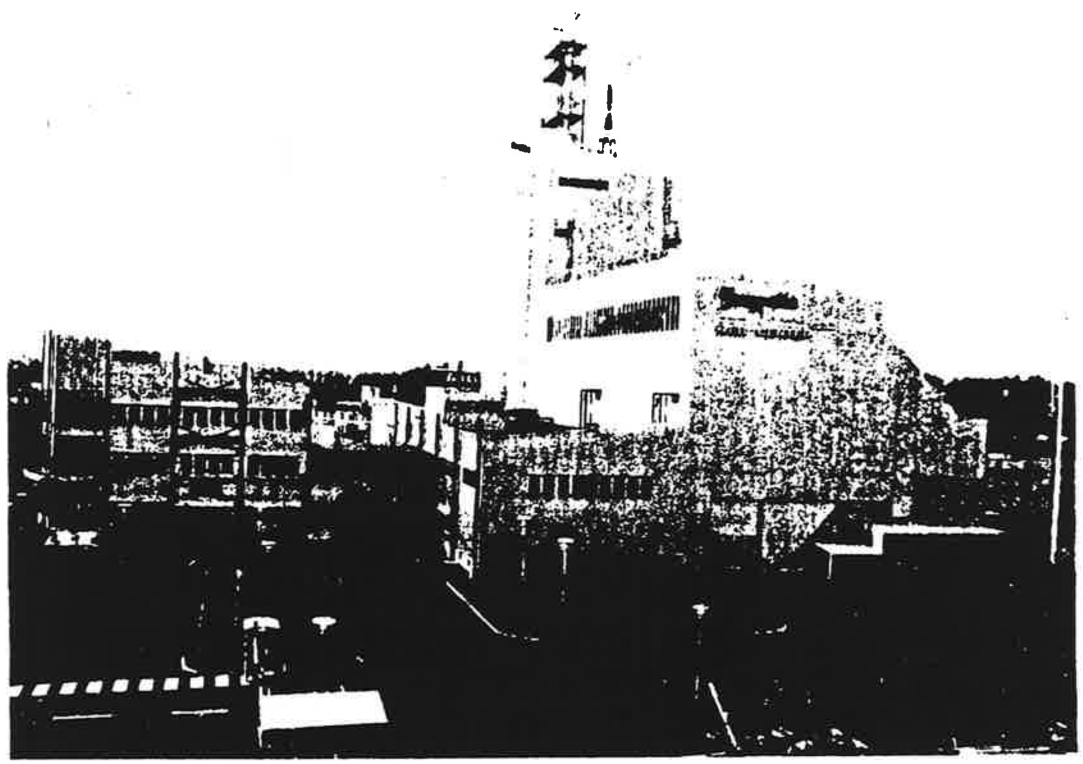


Process Development

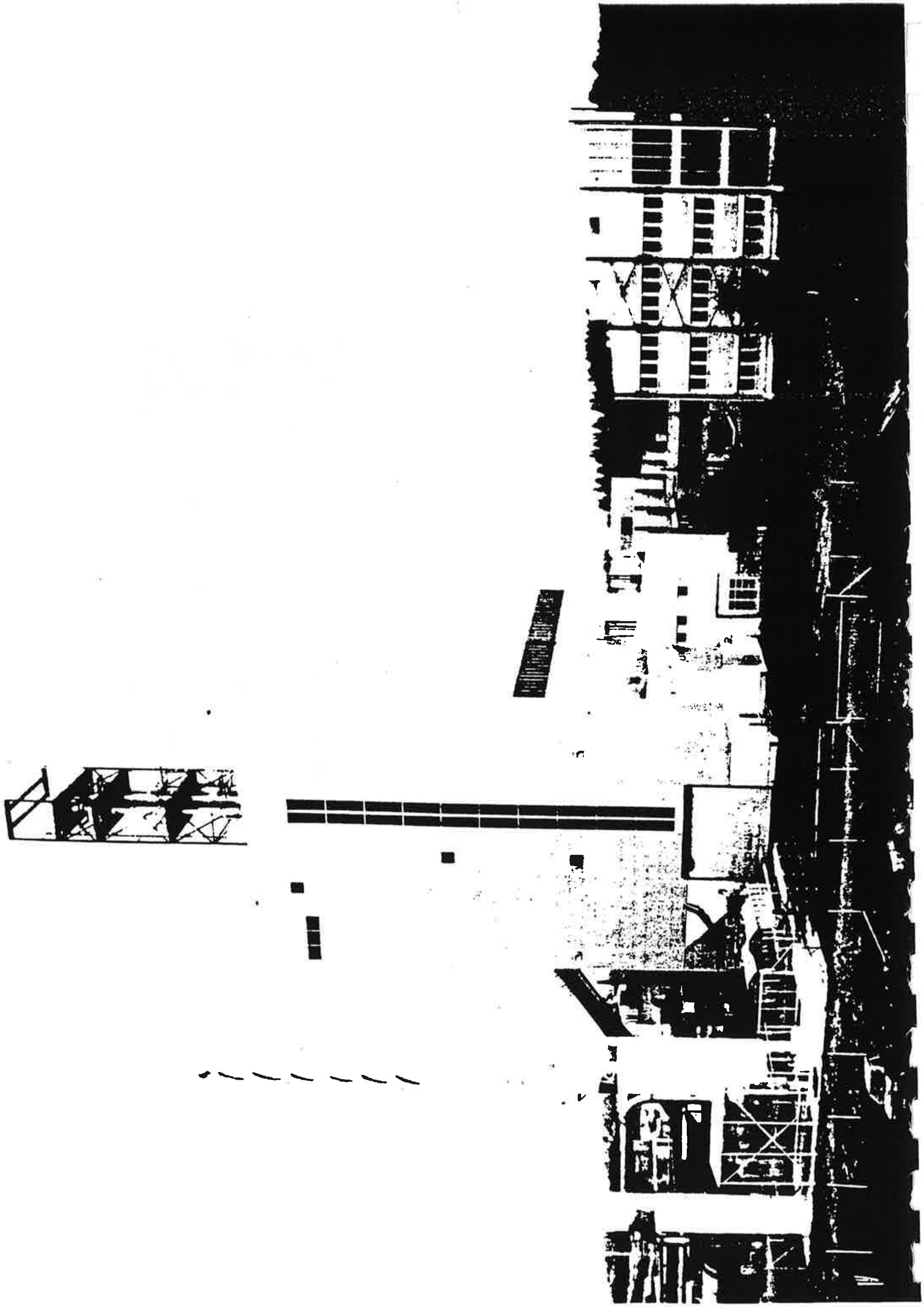
- Biomass feed system
- Drying
- Gasification
- Gas clean-up
- Gas combustion
- Biomass and coal
- 1991 to 1995
- Support for 2 demonstration plants

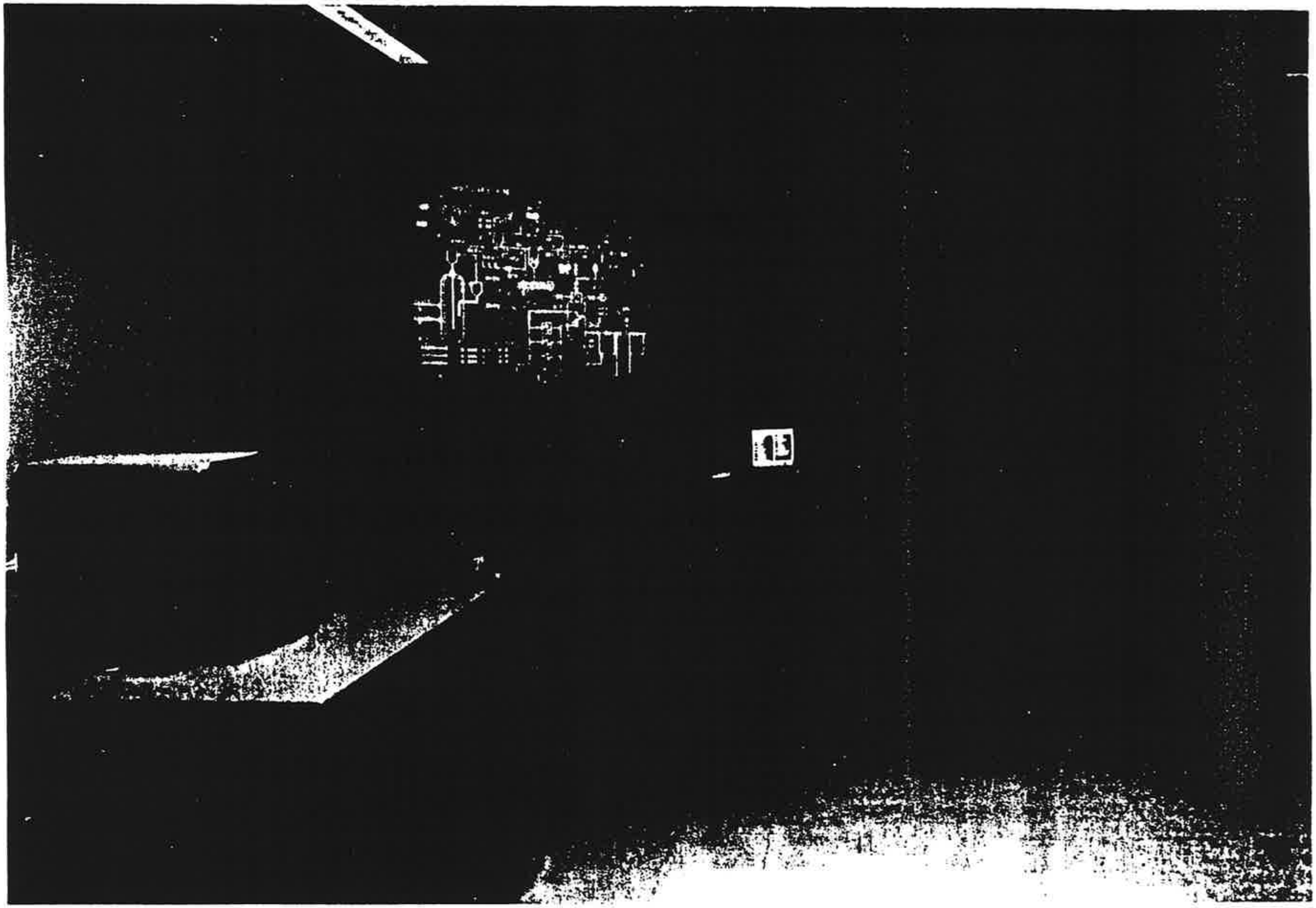
Enviropower's Gasification Pilot Plant





Tampella power





R & D CENTER, Control room

Tampella power

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

Ultimate analysis wt%, dry	
C	49.7 - 52.0
H	5.5 - 5.9
N	0.5 - 0.7
S	< 0.1
As	2.7 - 5.4
Moisture (as fed), wt%	18 - 42
Fuel LHV (dry) MJ/kg	18.6 - 19.3
Btu/lb	8000 - 8300

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)

	Amount/tn
Wood Chips	1630
Forest Residue	1750
Paper Mill Waste (bark, paper, sludge)	1180
Willow	400
Straw with Coal	20 (+120 tn coal)

The Range of Main Operating Parameters

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

Biomass Gasification
Pilot Test Program/Test Results

Pilot plant fuel input	MJ/s	15	15
Product gas LHV (dry)	MJ/m^3	4.5 - 5.6	4.5 - 5.6
Fuel conversion	%	97 - 99	97 - 99
Product gas dust content after ceramic filter	mg/m^3N	< 5	< 5
Alkalines (K + Na)	ppm(w)	0.01	0.01
Product gas H_2S content	mg/m^3N	15 - 50	-200
Product gas NH_3 content	mg/m^3N	500 - 1500	-2200

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 & napthalene 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 NH3. 40-55% converted.

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)

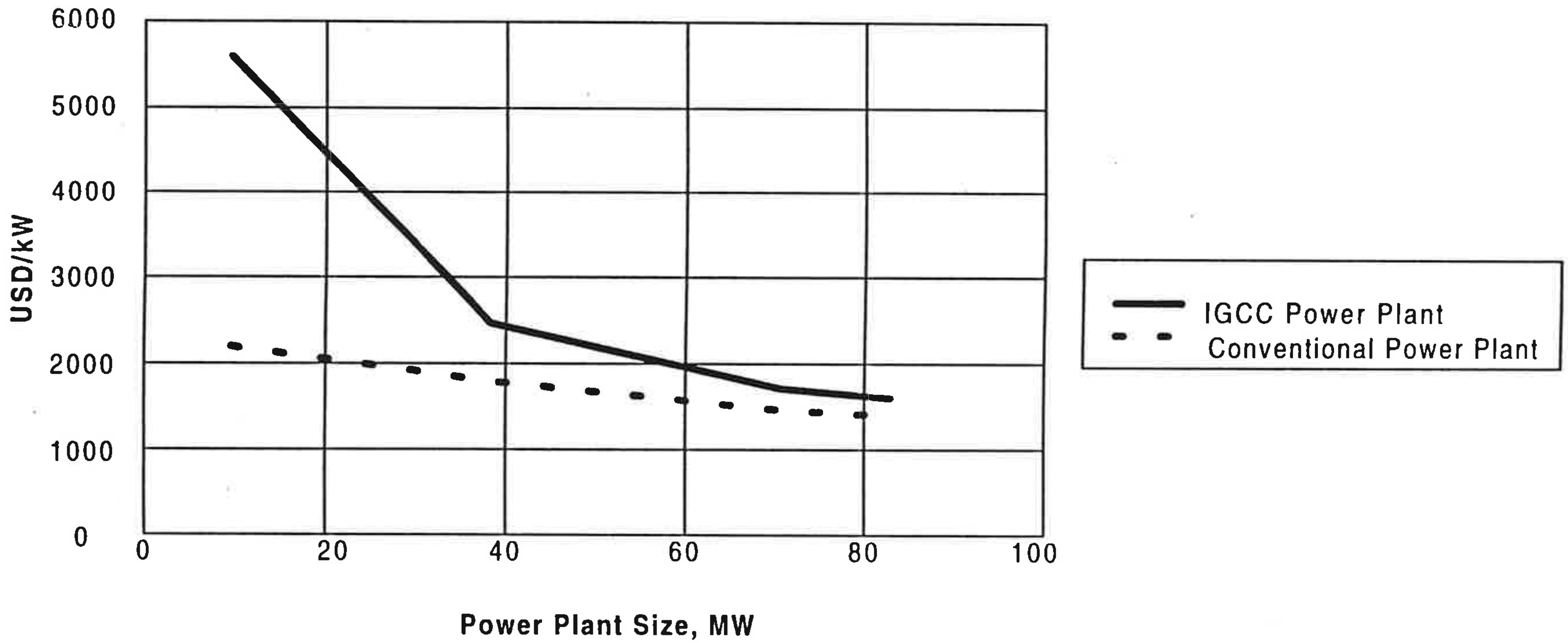
	Amount/tn
Wood Chips	1630
Forest Residue	1750
Paper Mill Waste (bark, paper, sludge)	1180
Willow	400
Straw with Coal	20 (+120 tn coal)

Gas Turbines for Biomass IGCC

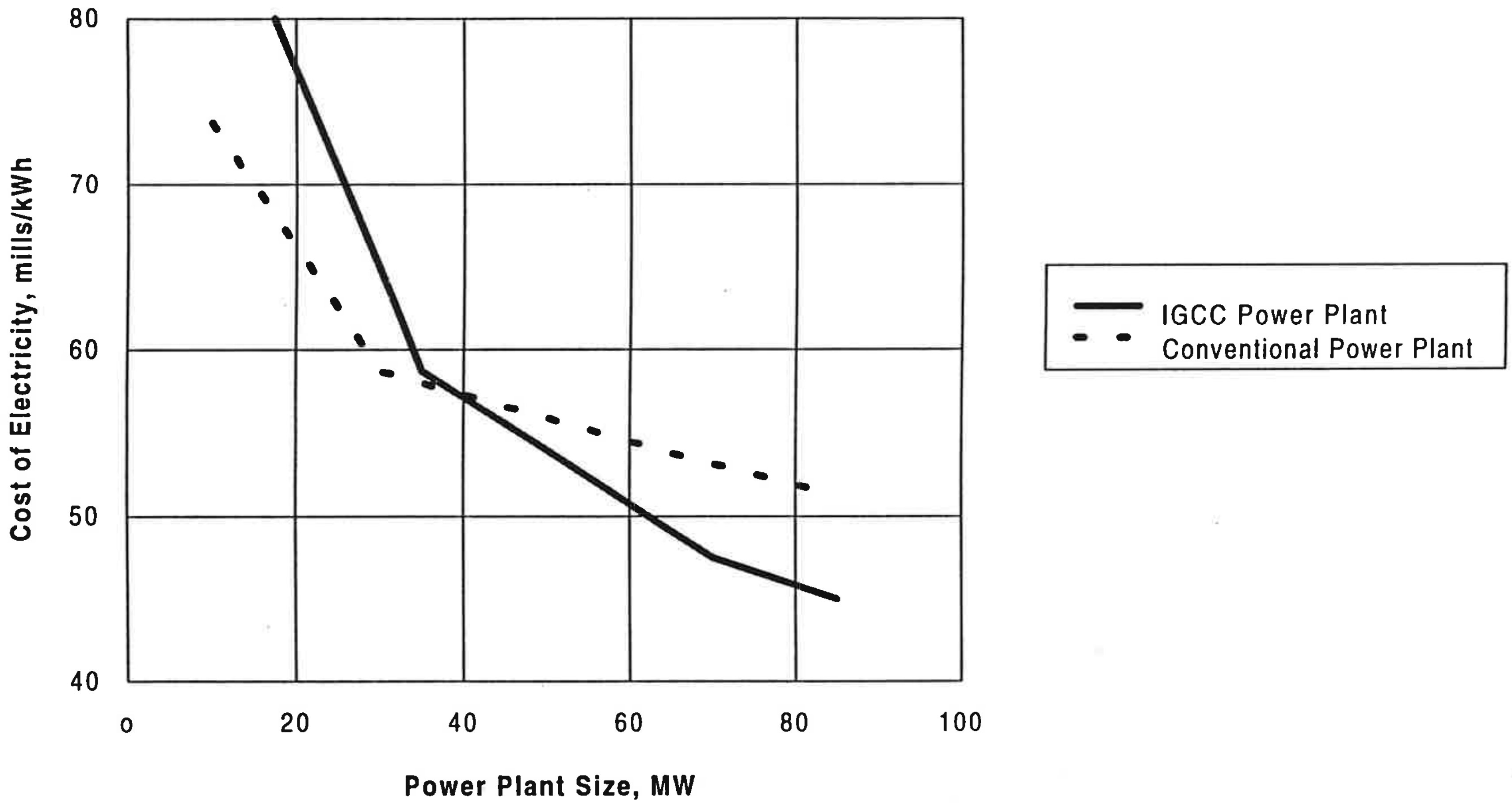
EGT, Typhoon	7.5	42	64000	200000
Mitsubishi, MW151	39	45	300000	940000
GE, F6B	62	48	465000	1.5 million
Westinghouse, CW251	72	48	540000	1.7 million
Siemens, V64.3	97	48	865000	2.7 million
GE, F6FA	110	49	921000	2.9 million

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

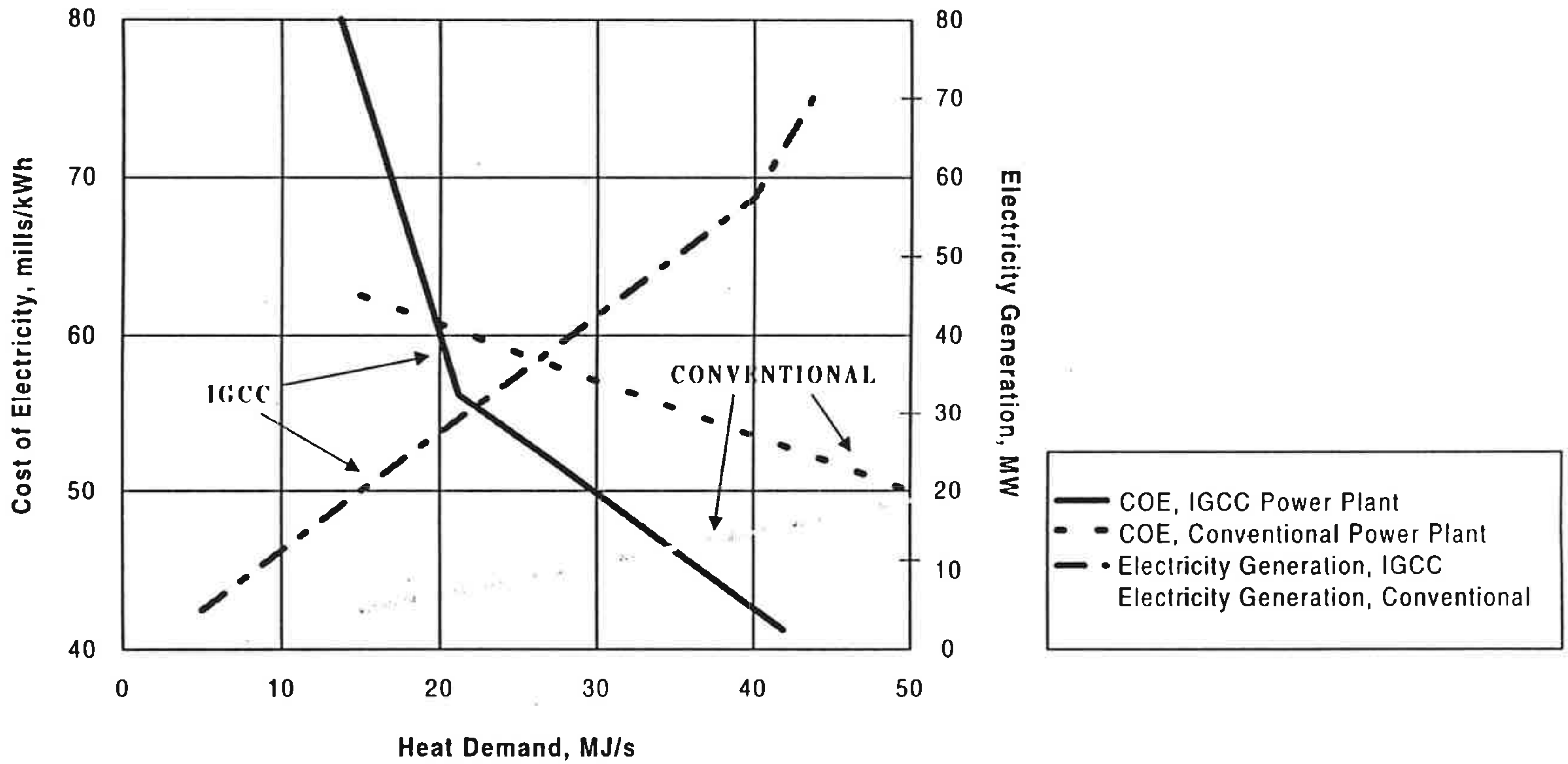
Specific Investment Cost



Cost of Electricity



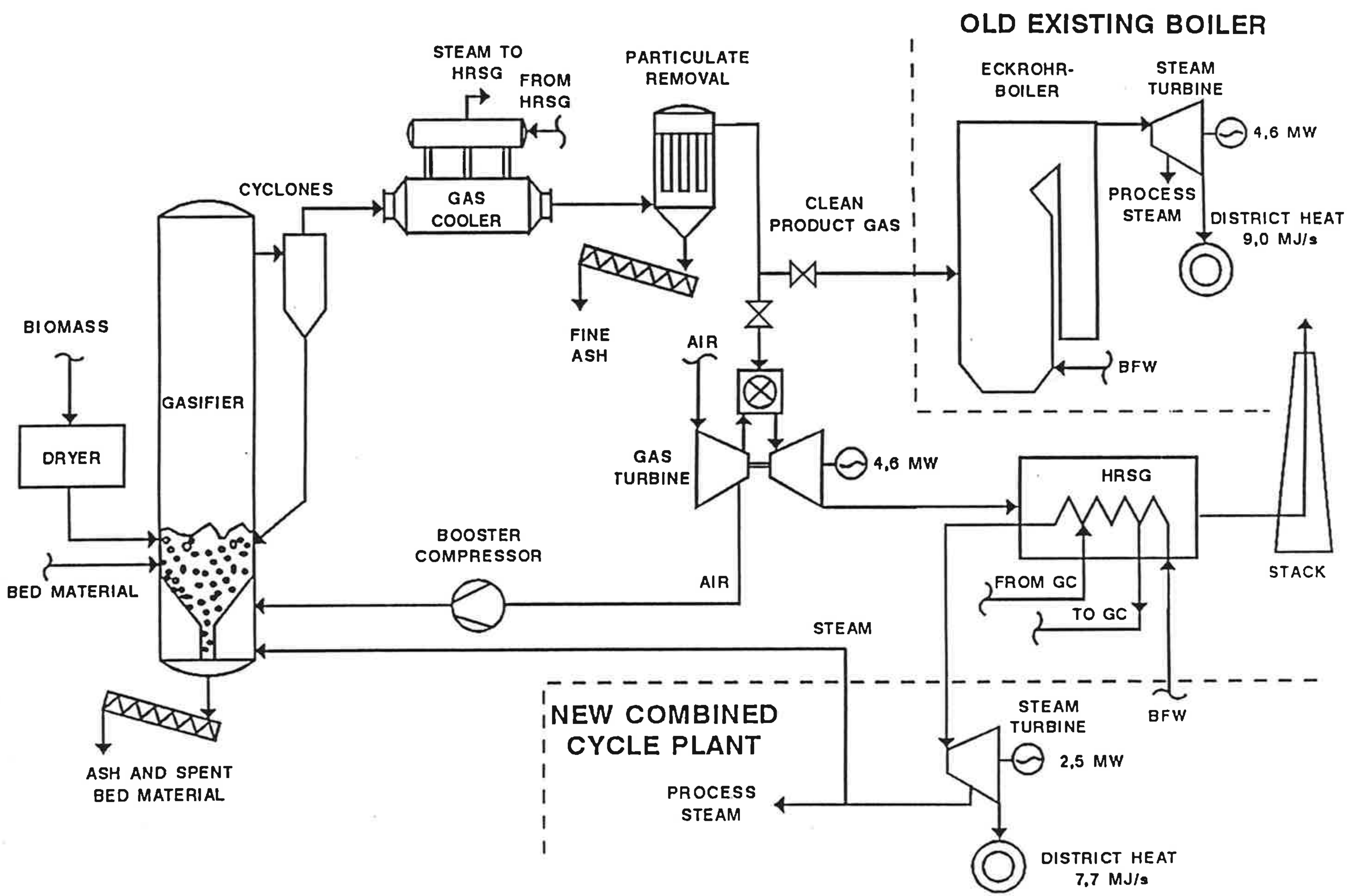
Process Heat for Pulp and Paper Industry



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

IGCC Process of Kotkan Energia Oy
Air Blown Fluidized Bed Gasifier and Hot Gas Clean-Up



HK 9/4/96

Plant Performance

Parameter	Biomass Gas	Natural Gas
Dried biomass feed rate, lb/h (9.4% moisture)	91,300	0
Gasifier heat input (hhv), MMBtu/h	669	0
Combustion turbine firing rate (hhv), MMBtu/h	614*	574
Heat export to leaf processing plant, MMBtu/h		
- Steam @ 4,100 lb/h	5	0
- Flue gas @ 310,000 lb/h	20	0
Power production, MW		
Gas turbine	50.1	53.3
Steam turbine	29.3	19.8
Gross	79.4	73.1
Auxiliary use	-4.3	-2.7
Net	75.1	70.4
Heating rate (hhv), Btu/kWh	8,910	8,155
Overall efficiency, %	38.3	41.9

* Biomass gas temperature 1,020 F, HHV = 155 Btu/SCF

Technology

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

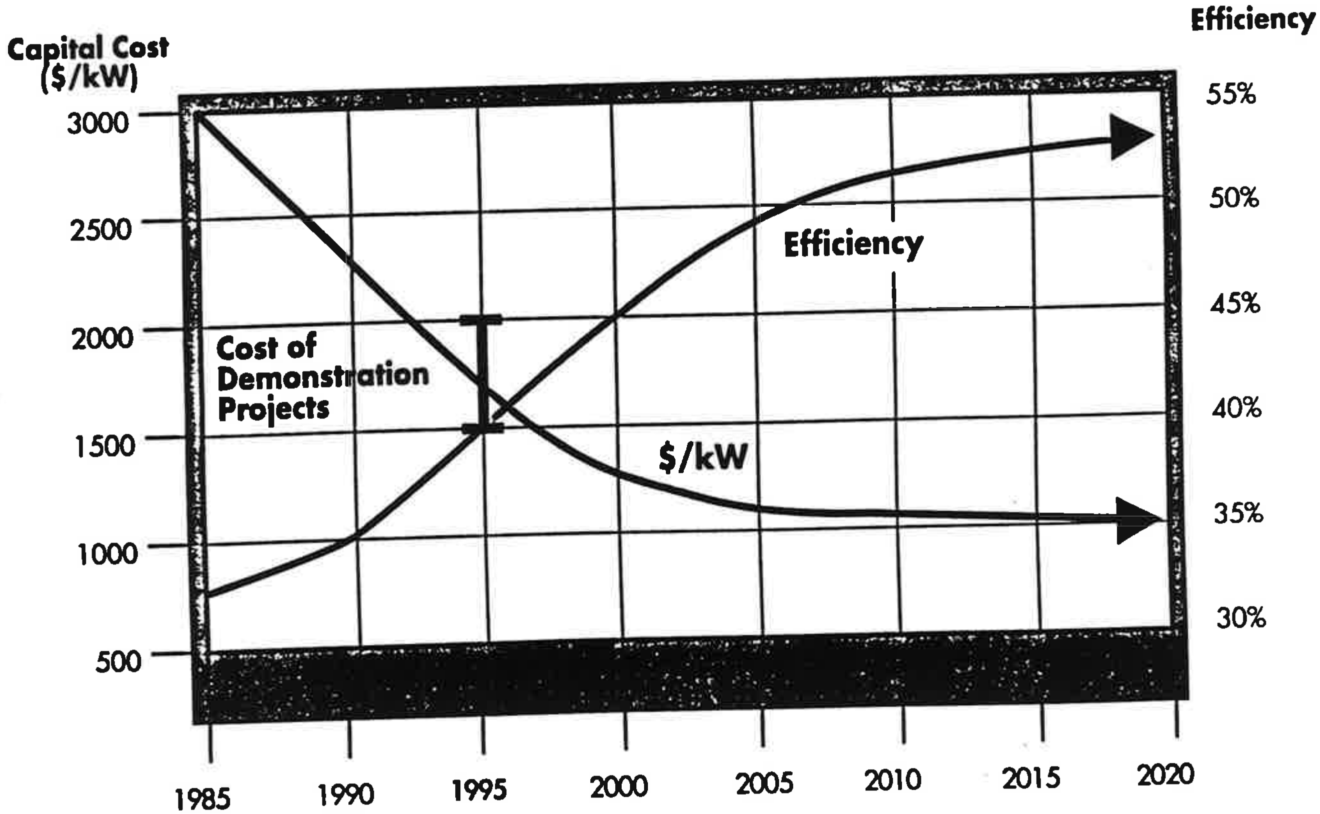
Operating Experience

- 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

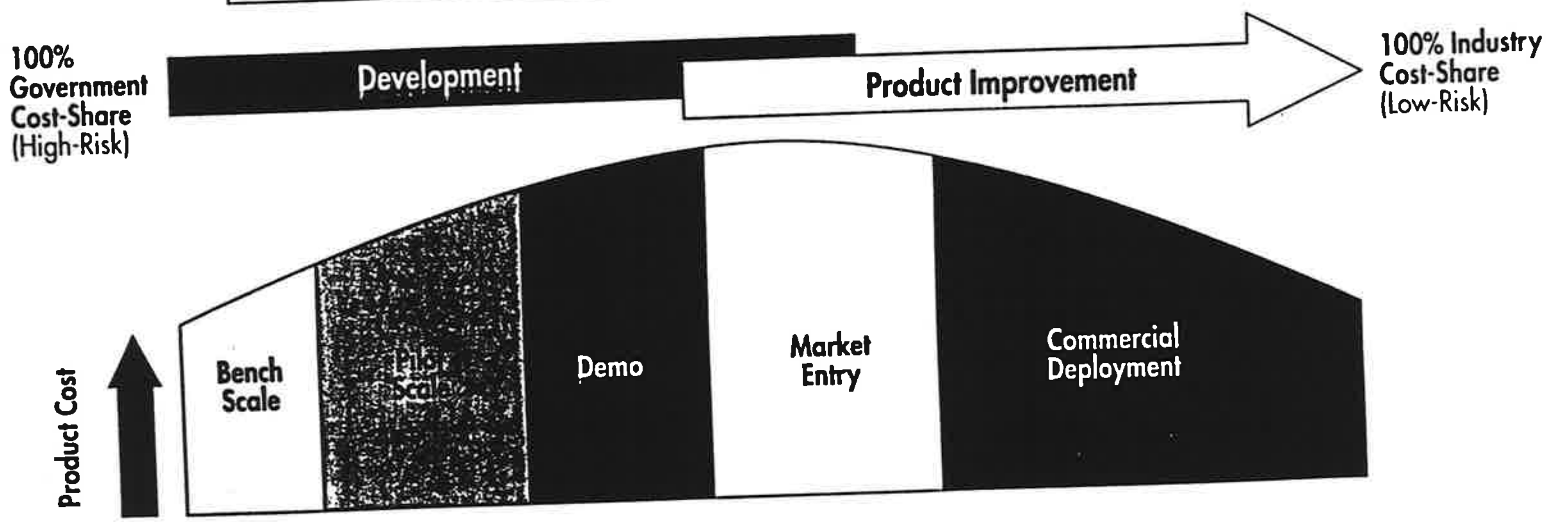
Pulp & Paper Industry

- 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 technolgy owners from future profits

Increasing Efficiency and Decreasing Costs in IGCC Development



Costs in Relation to Product Maturity



Clean Coal Programs

- 3 IGCC Coal Projects
  - Wabash River, Indiana, PSI
    GE7FA turbine; 192 MW
  - Polk, Florida, TECO
    GE 7FA turbine; 196 MW
  - Pinon Pine, Nevada, Sierra Pacific
    GE6FA turbine; 61 MW
- Will provide valuable data & information for application to biomass gasification.

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

Fiscal Year	1986–87	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Total[d]
Adjusted Appropriations[a]												
P.L. 99-190	248,500	149,100										397,600
P.L. 100-202		50,000	190,000	135,000	199,997							574,997
P.L. 101-446				419,000	155,998							574,998
P.L. 101-121[b]					35,000	315,000	0	100,000	18,000	100,000	32,000	600,000
P.L. 101-121[b]						100,000	0	125,000	19,121	100,000	255,879	600,000
Total	248,500	199,100	190,000	554,000	390,995	415,000	0	225,000	37,121	200,000	287,879	2,747,595

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 construction 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 3¢ to 4¢ power (producable 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/MMBtu), biomass feeds are available at very low costs and perhaps negative cost (-$2 to +$1/MMBtu), 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/MMBtu natural gas or $4/MMBtu 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 50¢ 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 gulf states and western Canada), you have -25¢ 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 50¢ 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

J. Rohrer
Zurn/IEP
1/16/97

Biomass Gasification Feedstock Costs
(Shredded and Delivered)

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

J. Rohrer
Zurn/IEP
1/16/97

Equipment vs. Facility Development

- **"Its the equipment stupid"**
- **Integrated plant design plays lesser role**
- **Modularization and factory assembly packaging will lower cost**

J. Rohrer
Zurn/IEP
1/16/97

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 <u>cost more than gasifier vessels</u>

- 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**

J. Rohrer
Zurn/IEP
1/16/97

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

J. Rohrer
Zurn/IEP
1/16/97

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

J. Rohrer
Zurn/IEP
1/16/97

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**

J. Rohrer
Zurn/IEP
1/16/97

Biomass Technical Breakout Session, Day 1

Michael Morris
TPS

tps

Engineering Services:

- Licensing of CFB Combustion Technology
- Licensing of CFB Combustion Technology
- Special Flow Measurement Devices
- Engineering Consultancy and Services

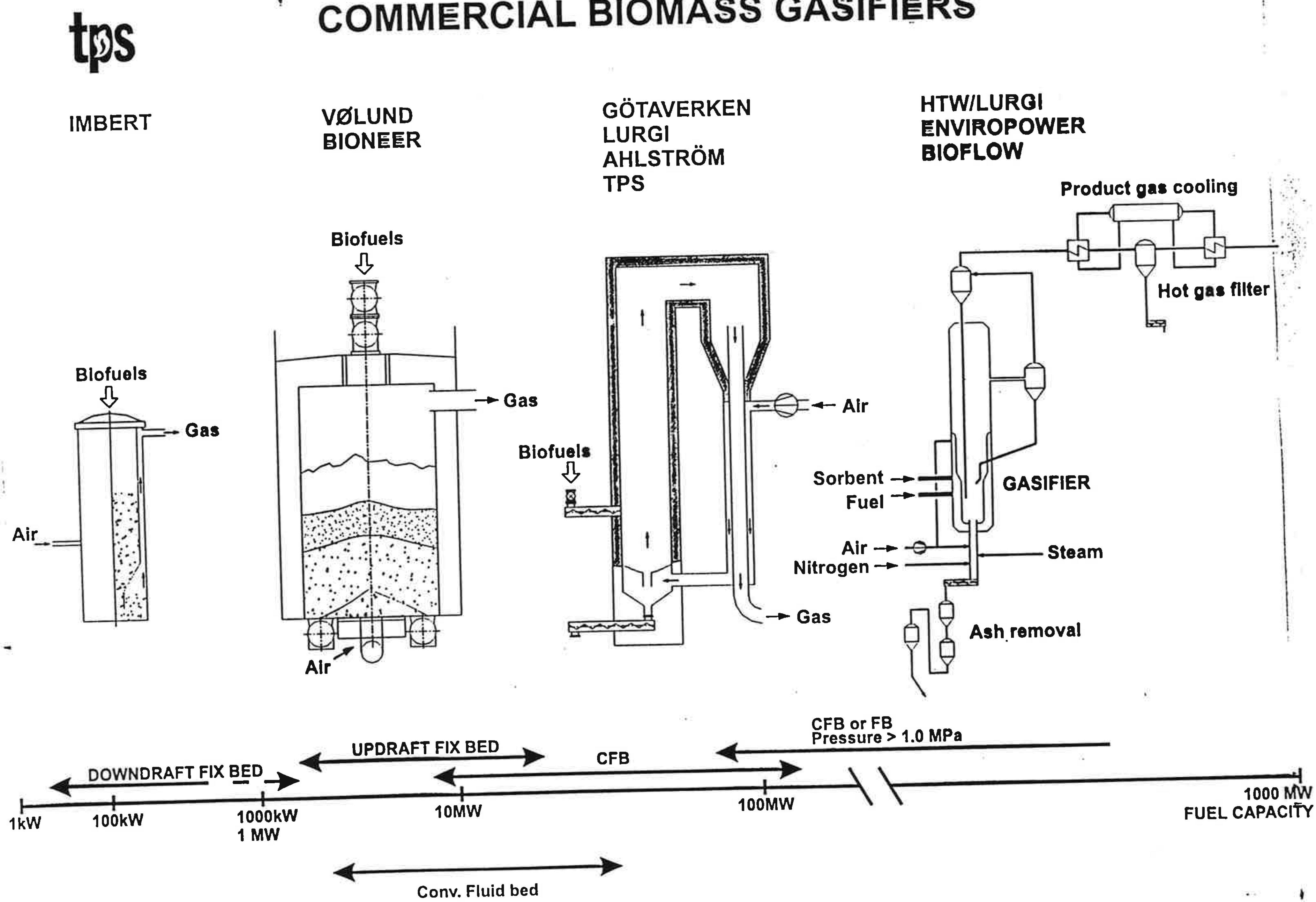
Energy Related Contract R&D with Emphasis on:

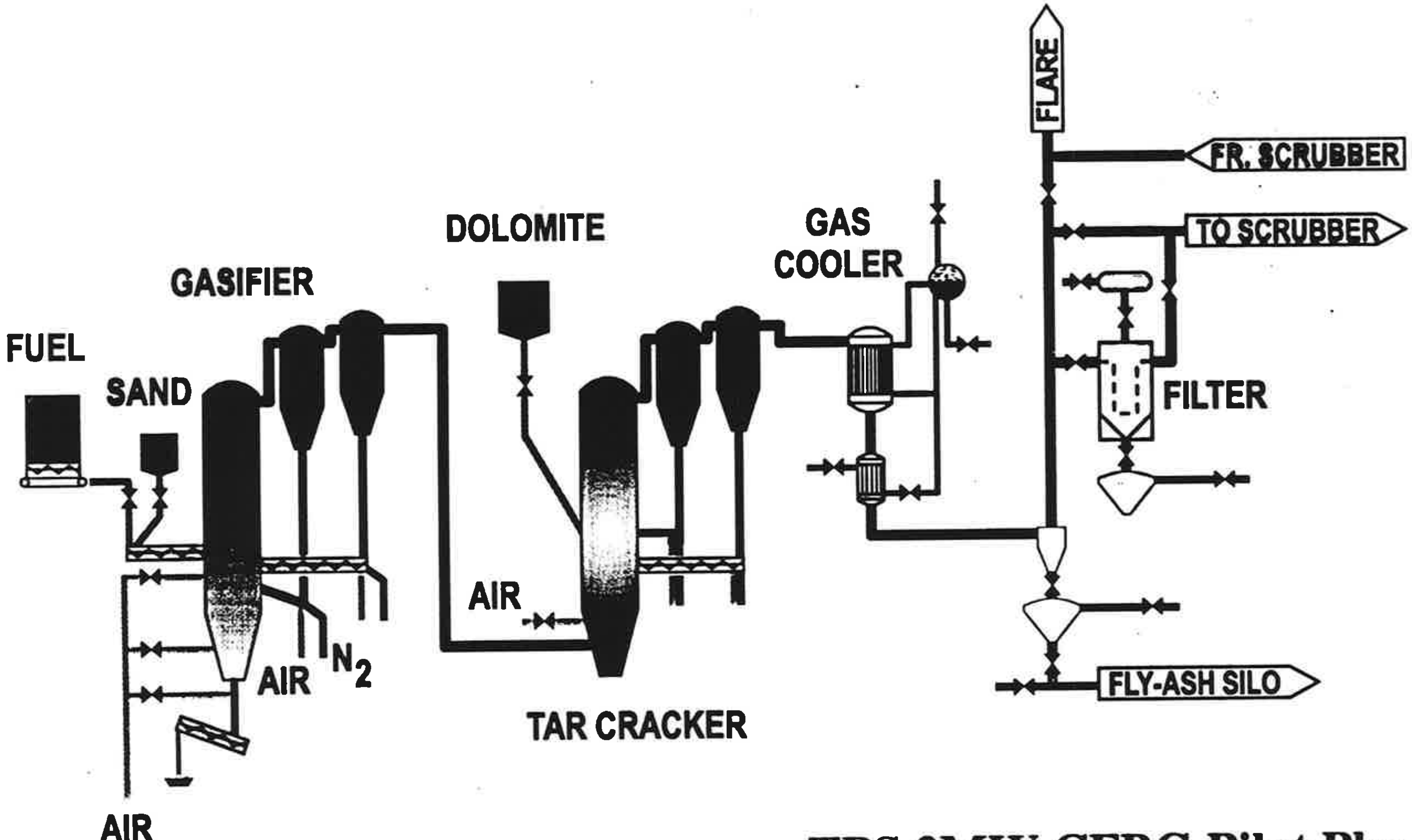
- Environment
- Combustion and Gasification
- Electricity and Heat Generation

No. of Personnel: 45 (1994)

Turnover: 45 million SEK (1994)

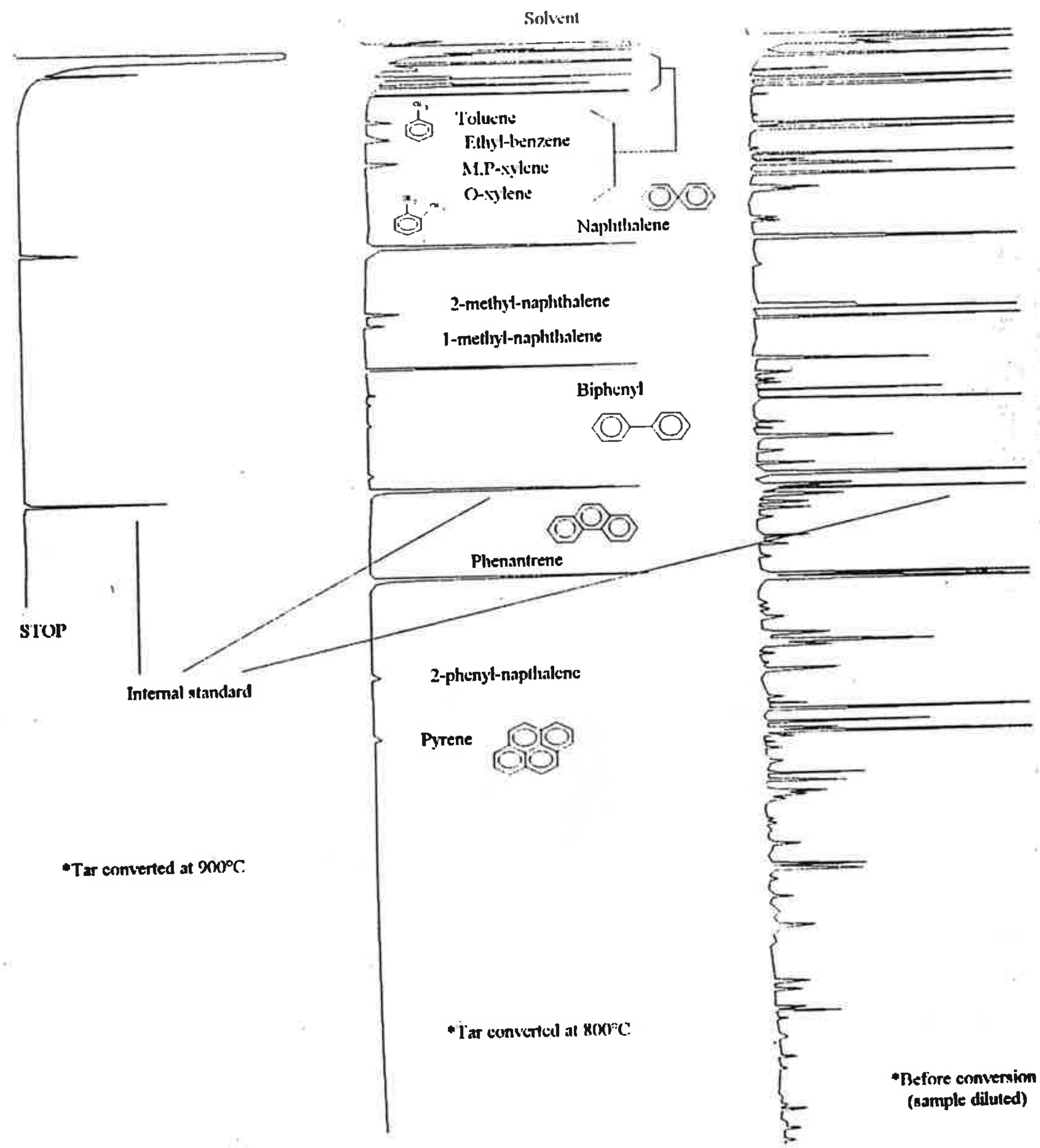
COMMERCIAL BIOMASS GASIFIERS





TPS 2MW CFBG Pilot Plant

Termiska Processer AB



Gas chromatograph values recorded before and after the dolomite cracker (laboratory experiments)

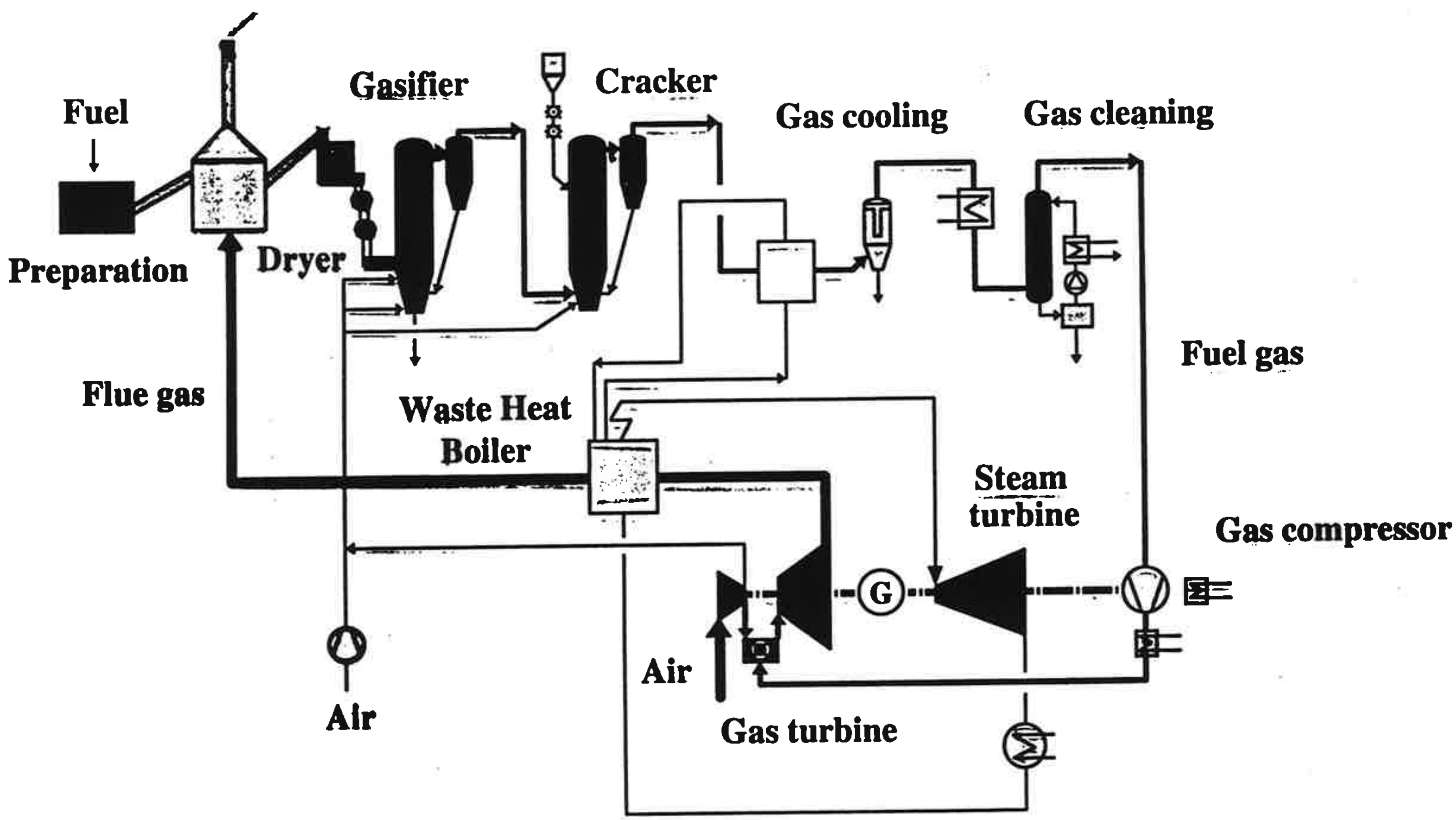
tps

<u>Fuels Tested in Laboratory or Bench-scale Apparatus:</u>

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

<u>Fuels Tested in TPS's 2MW CFB Gasification Pilot Plant:</u>

- Wood chips (e.g. Swedish, Spanish, Brazilian, English)
- Bark
- Wood pellets
- Pelletised Industrial Waste
- Pelletised RDF (Refuse Derived Fuel)
- Lignite



CFBG Combined-cycle Scheme

Termiska Processer AB

1997-01-13 – 6

tps

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

tps

2 Gasifiers, 15 MW_t each
Gas Boiler and Flue Gas Cleaning
Power from 6.7 MW_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

BILANCIO GLOBALE IMPIANTO DI TESTI

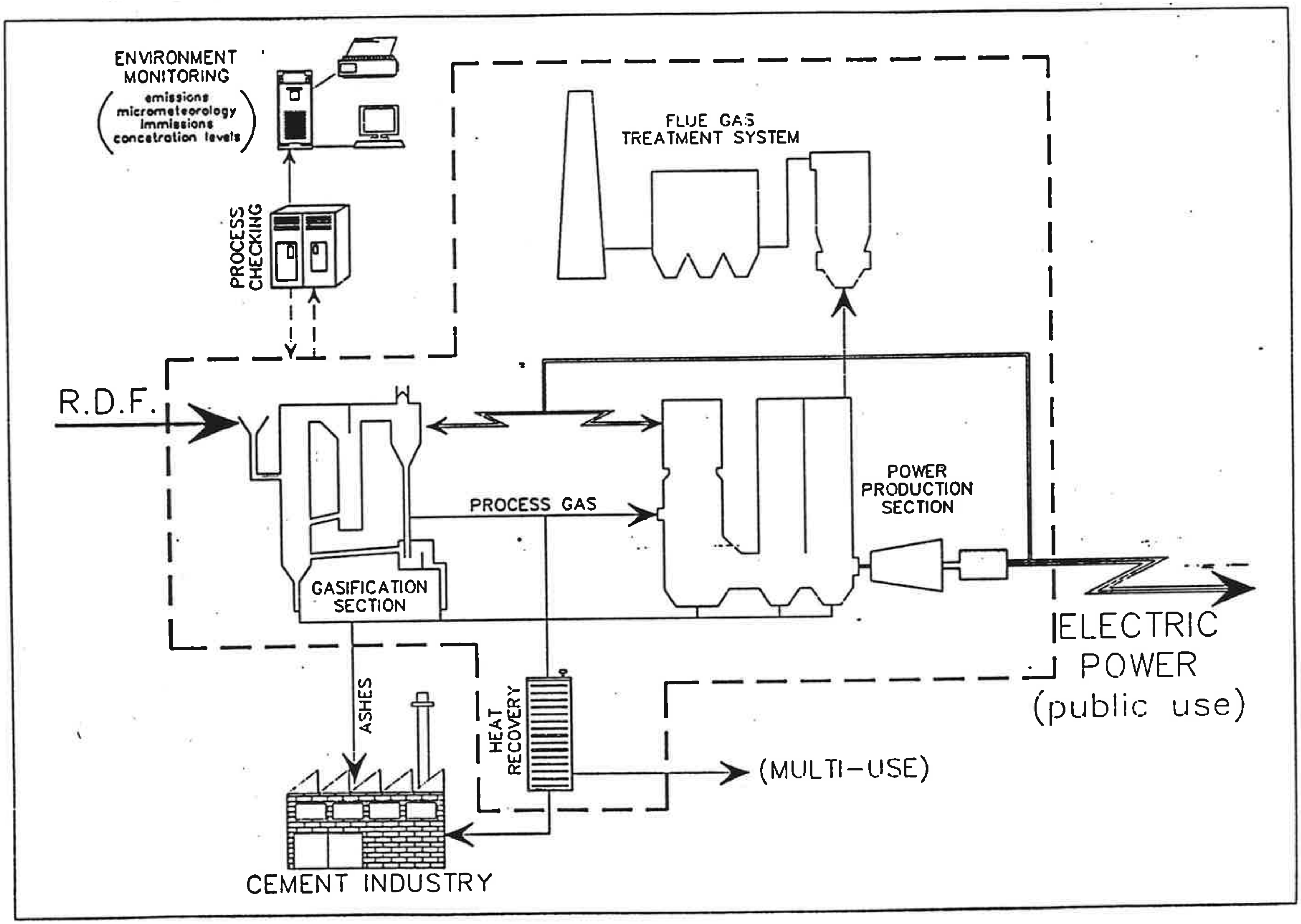
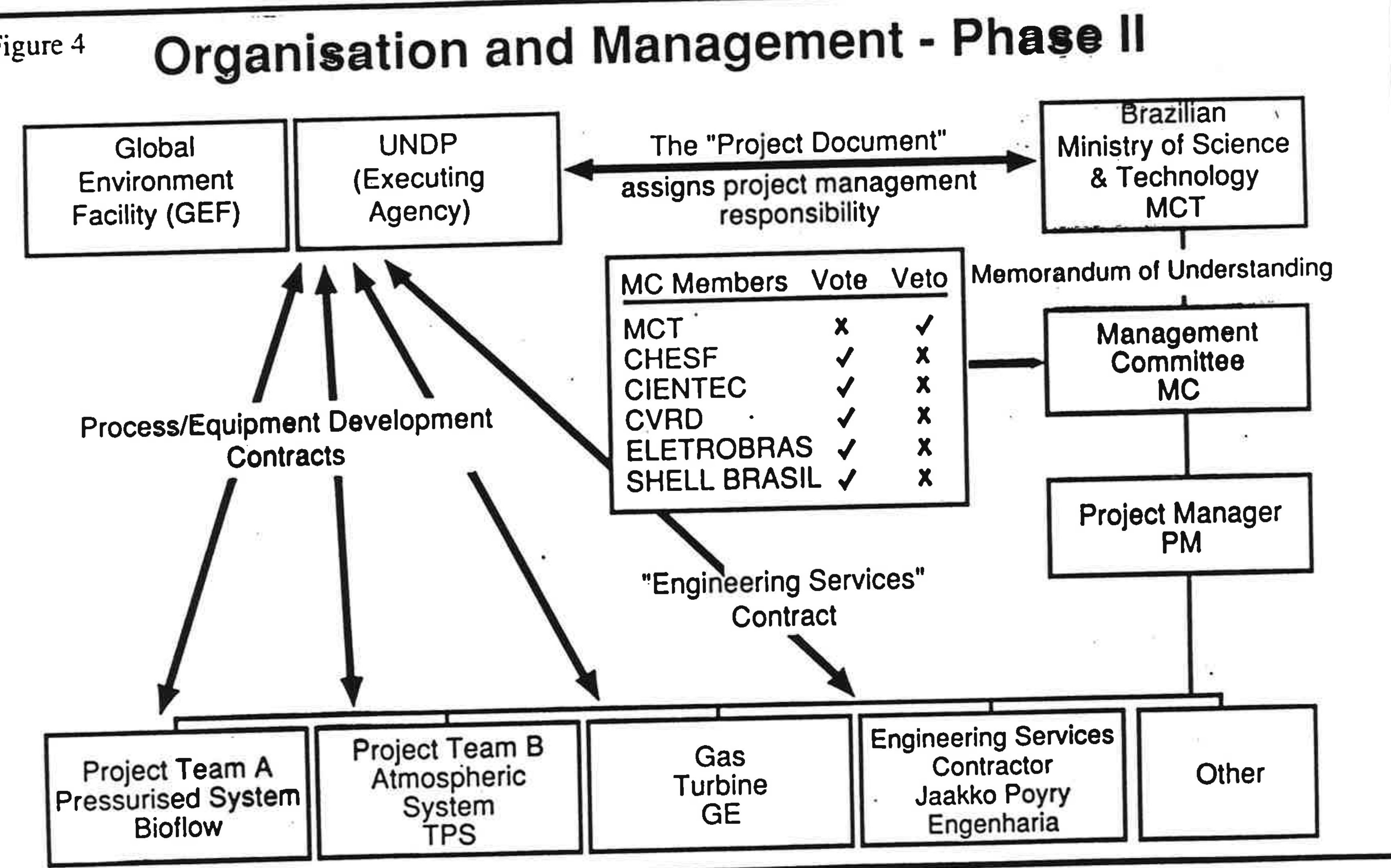


Figure 4



Organisation and Management - Phase II
Global Environment Facility (GEF)
UNDP (Executing Agency)
The "Project Document" assigns project management responsibility
Brazilian Ministry of Science & Technology MCT
Memorandum of Understanding
MC Members Vote Veto
MCT ✗ ✓
CHESF ✓ ✗
CIENTEC ✓ ✗
CVRD ✓ ✗
ELETROBRAS ✓ ✗
SHELL BRASIL ✓ ✗
Management Committee MC
Project Manager PM
Process/Equipment Development Contracts
"Engineering Services" Contract
Project Team A Pressurised System Bioflow
Project Team B Atmospheric System TPS
Gas Turbine GE
Engineering Services Contractor Jaakko Poyry Engenharia
Other

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

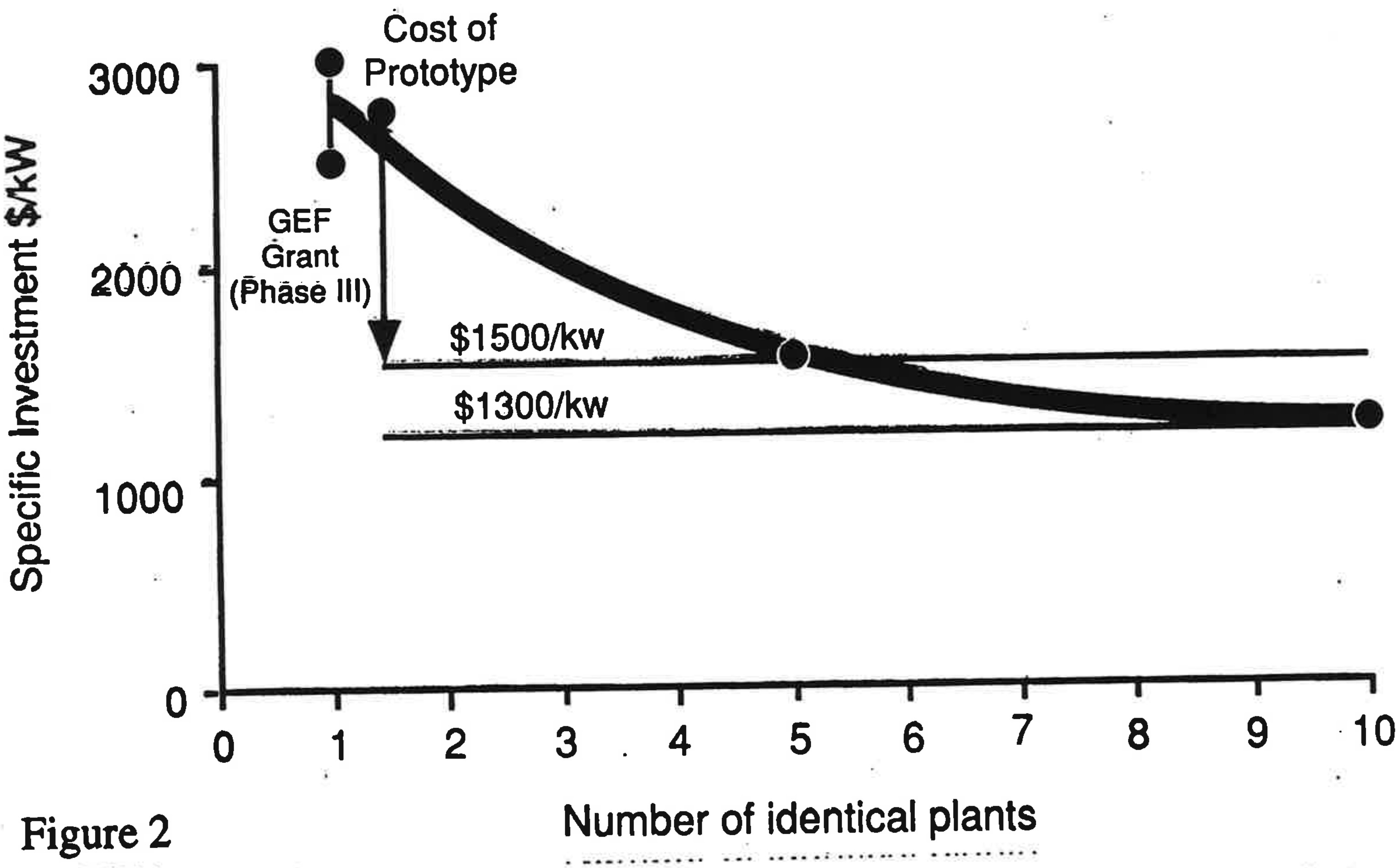


Figure 2

95-05-03 – 44

tps Termiska Processer AB

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

tps

EU Thermie Programme

8 MWe Combined-cycle Plant

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

tps

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

TPS GASIFICATION R&D PROJECT ACTIVITIES IN 1997

tps

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

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

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

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

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

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)

tps Termiska Processer AB

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

Sponsored by the
U.S. Department of Energy
Energy Efficiency and Renewable Energy Div.
Office of Industrial Technologies

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 thermodynamic performance and prospective economics of black liquor and biomass gasifier/gas turbine cogeneration for present (~2000) and future (~2020) kraft mills (bleached market pulp and integrated unbleached linerboard).
- Assess development status and commercial prospects for gasifier/gas turbine technology for paper industry applications.

Summary of Project Tasks

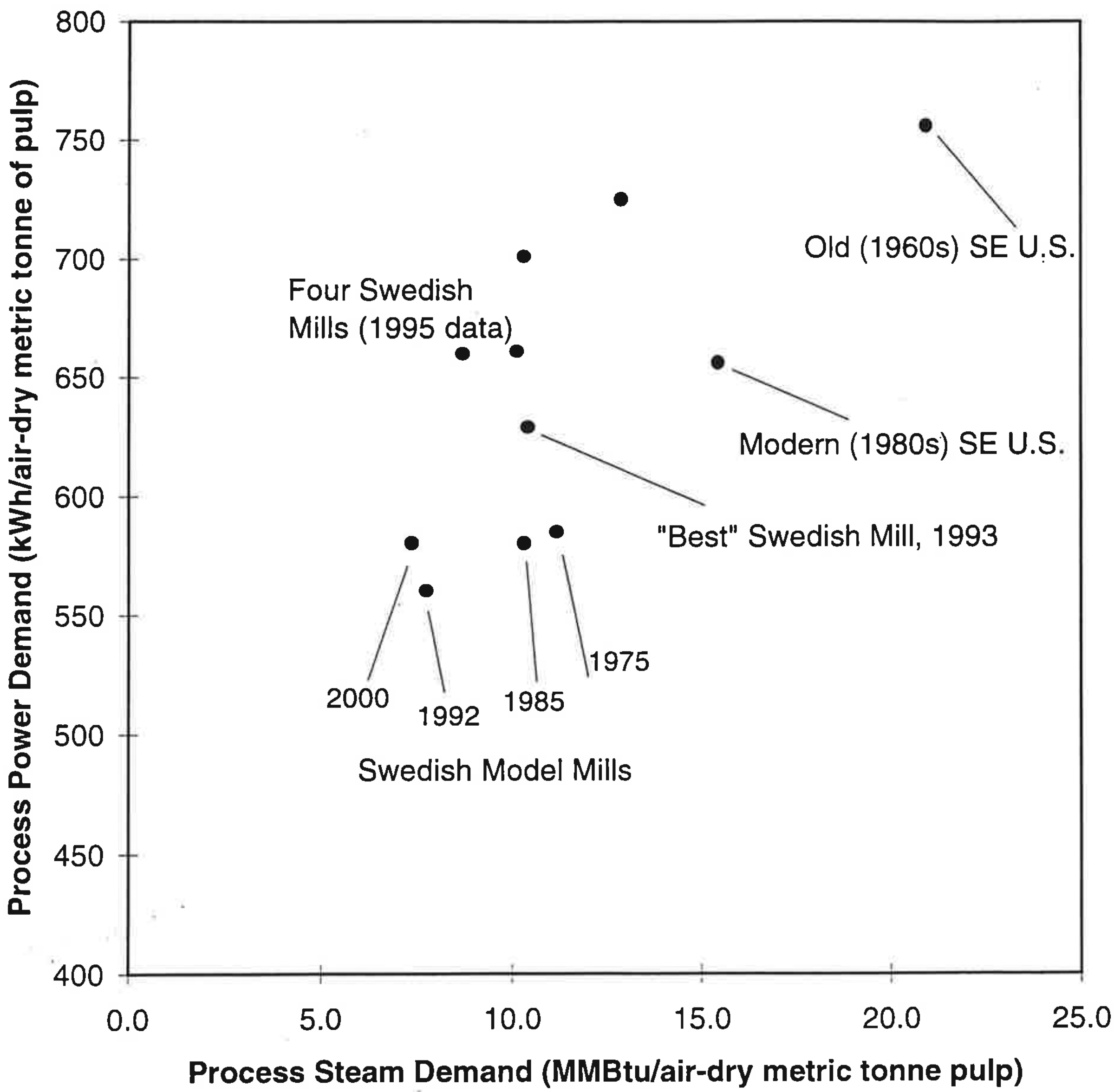
- Define steam and power demands for ~2000 and ~2020 mills.
  - Future-mill features: closed bleach cycle, direct drying with gas turbine exhaust (?)
- Assess status and commercial prospects for gasifier/g.t. cogeneration systems
- Model heat/mass balances for gasifier/g.t. cogeneration in context of different mill demands.
- Examine economics of gasifier/ g.t. cogeneration.
- Outreach to decision makers.

Results to Date

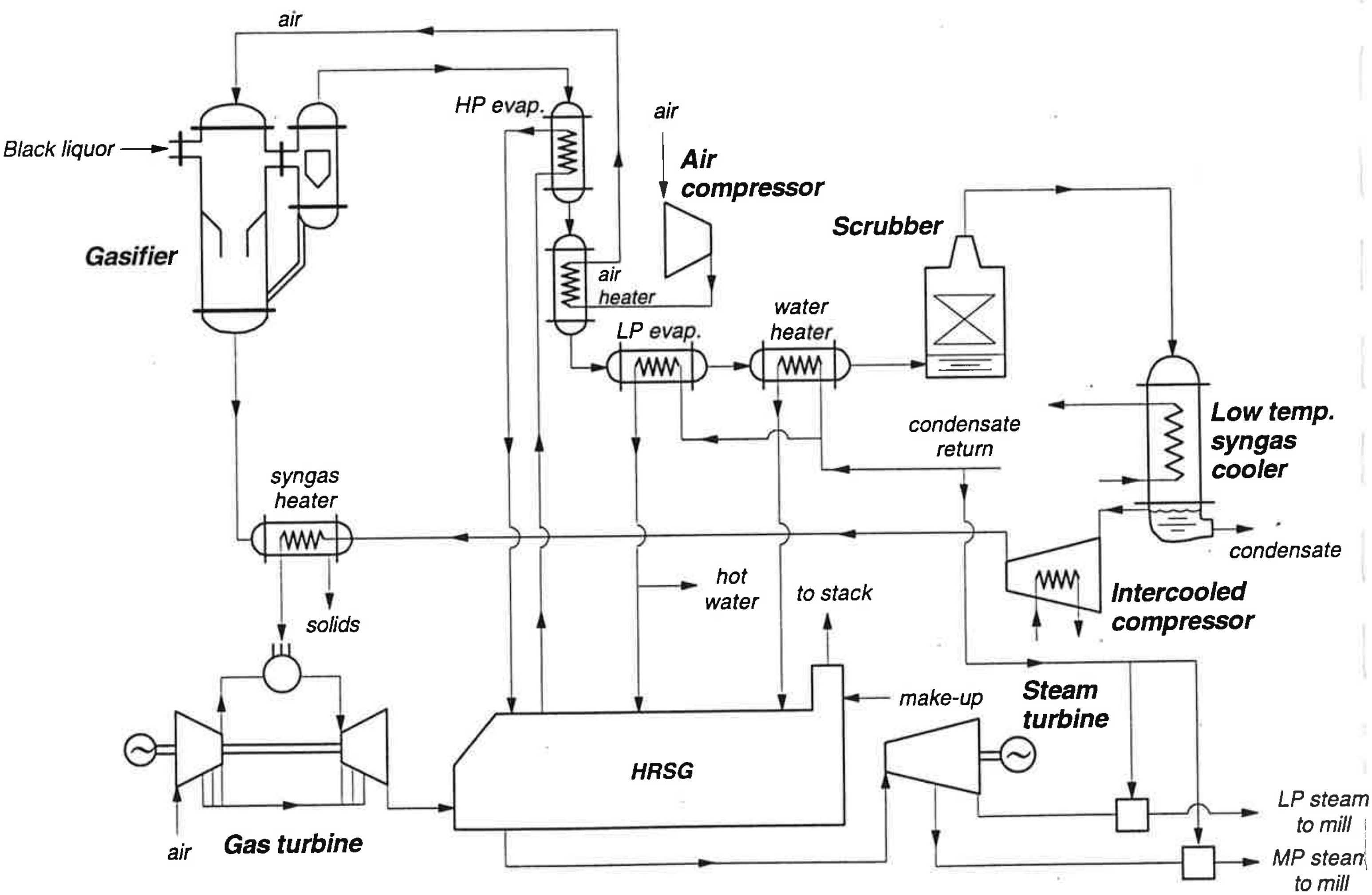
- Mill energy demands estimated
- Spreadsheet modeling of present-technology mills in progress
- Detailed mill modeling ongoing

- Baseline cogen performance modeling based on Seimens V64.3a gas turbine:
  - Black liquor: ABB, Noell, Kvaerner
  - Biomass: TPS, BCL, Ahlstrom

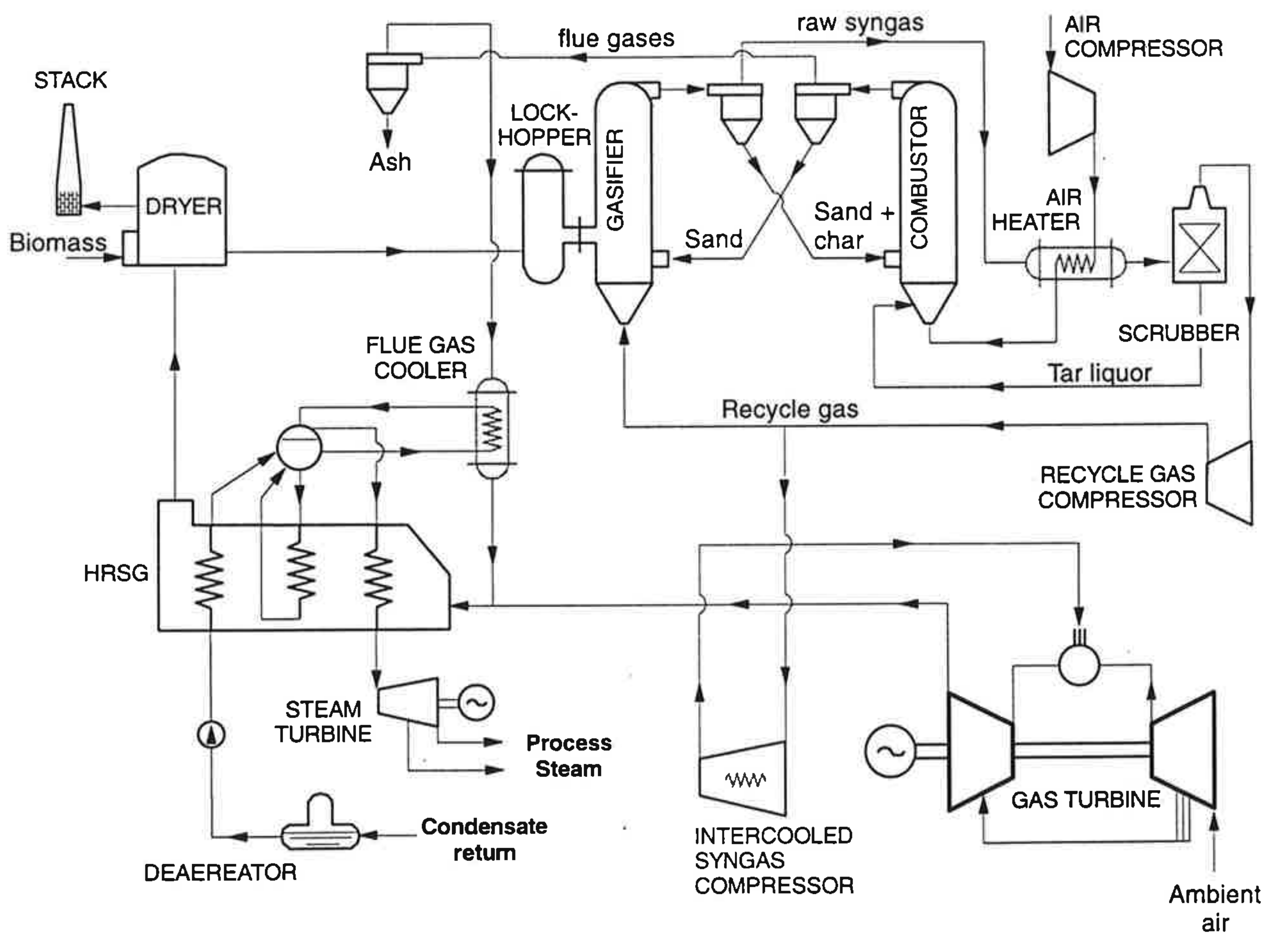
Bleached Kraft Market Pulp Steam and Power Demands
(excluding powerhouse)



Sample Black Liquor Cogeneration Model (ABB Gasifier)

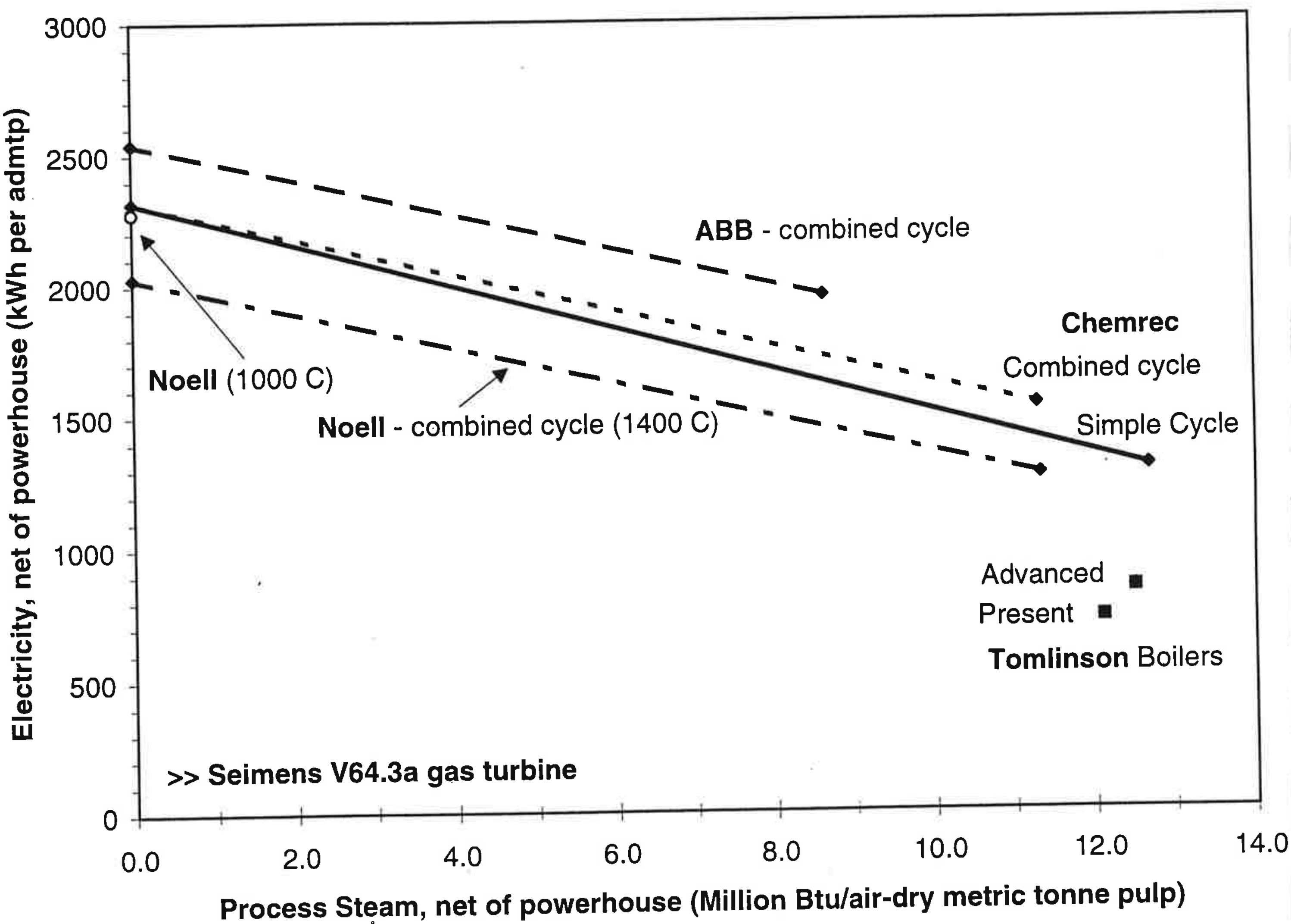


Sample Biomass Cogeneration Model (Battelle Gasifier)



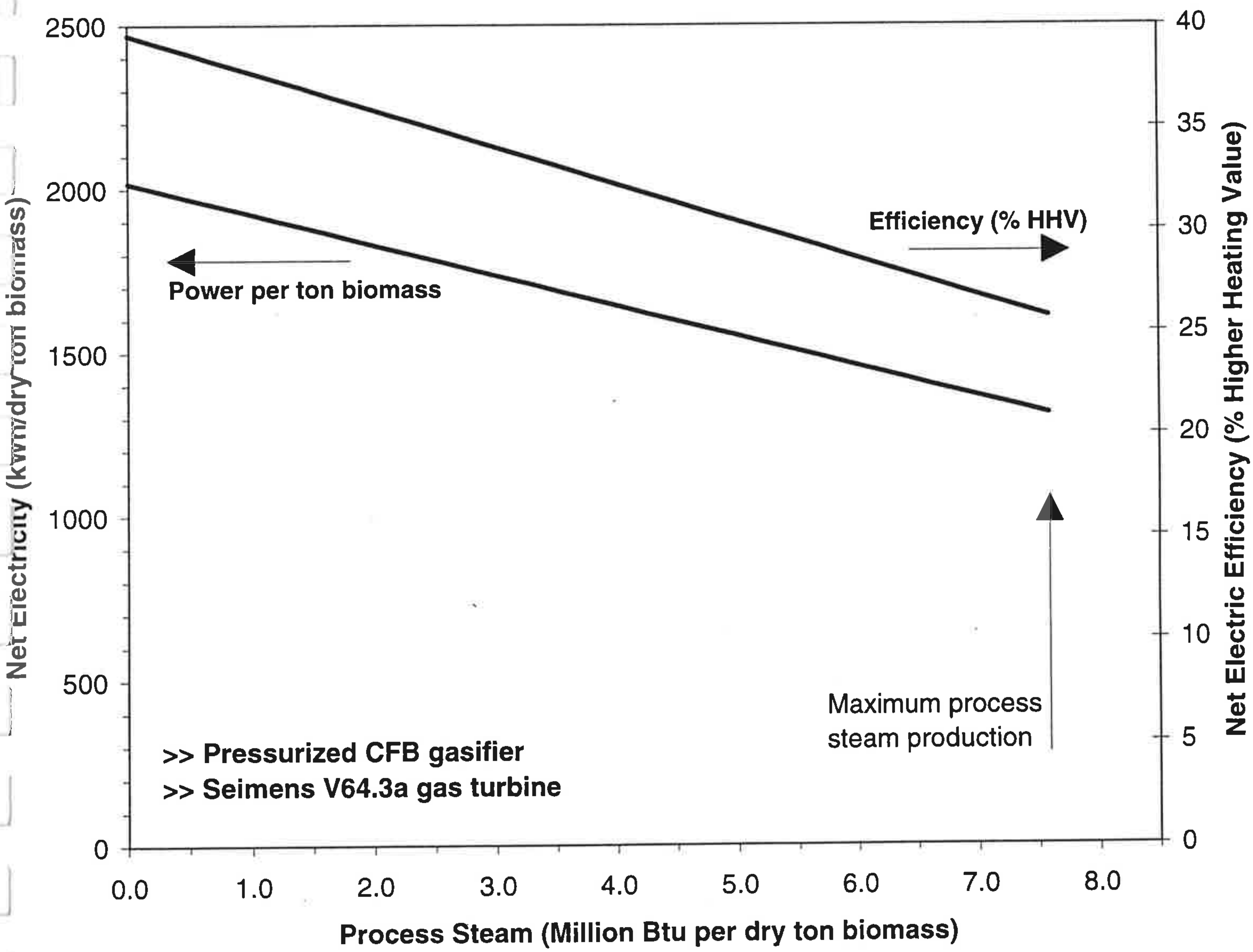
Performance Comparison for Black Liquor Cogeneration Systems

(preliminary)



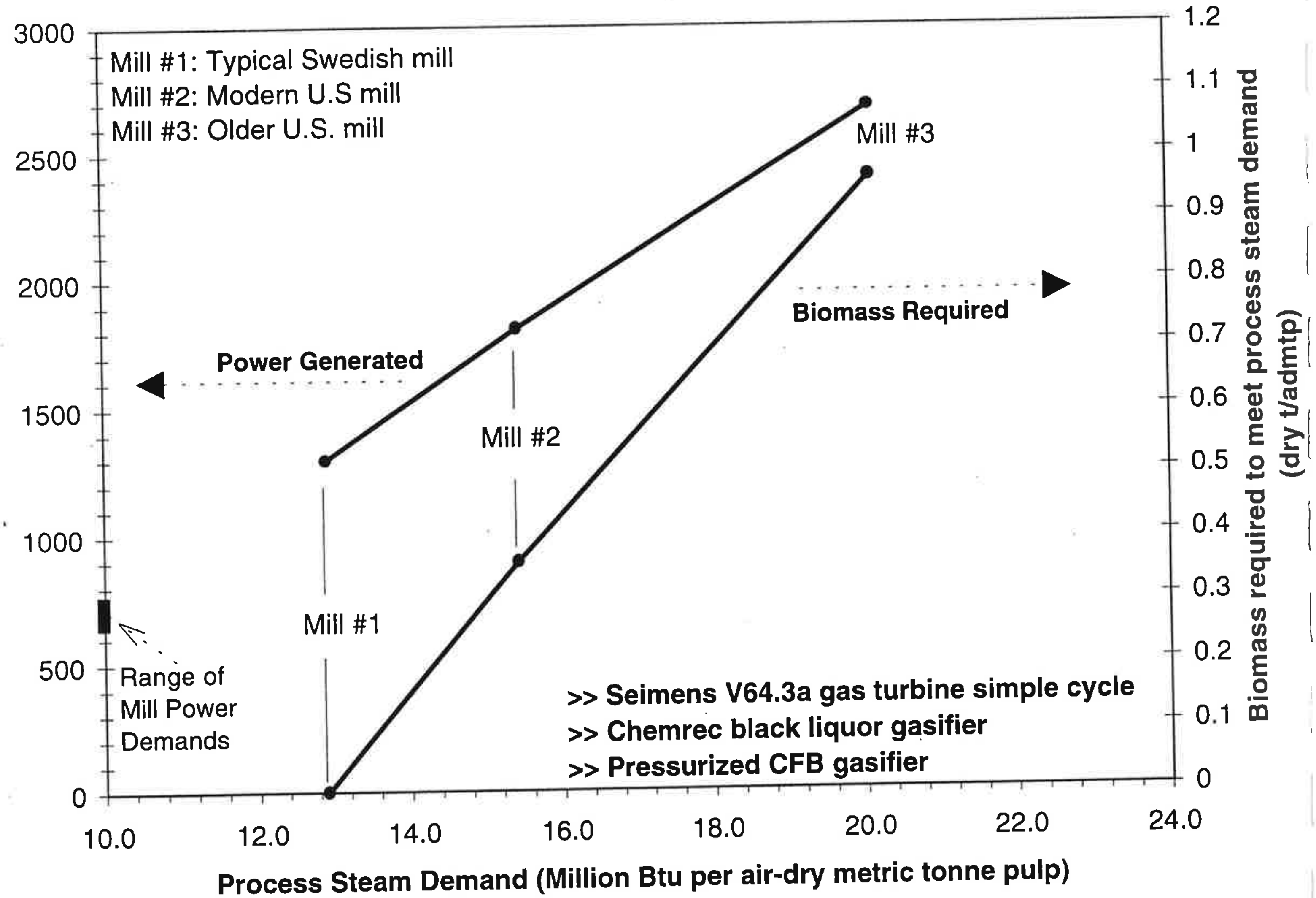
Performance Estimate for Biomass-Gasifier/Gas Turbine Cogeneration

(preliminary)



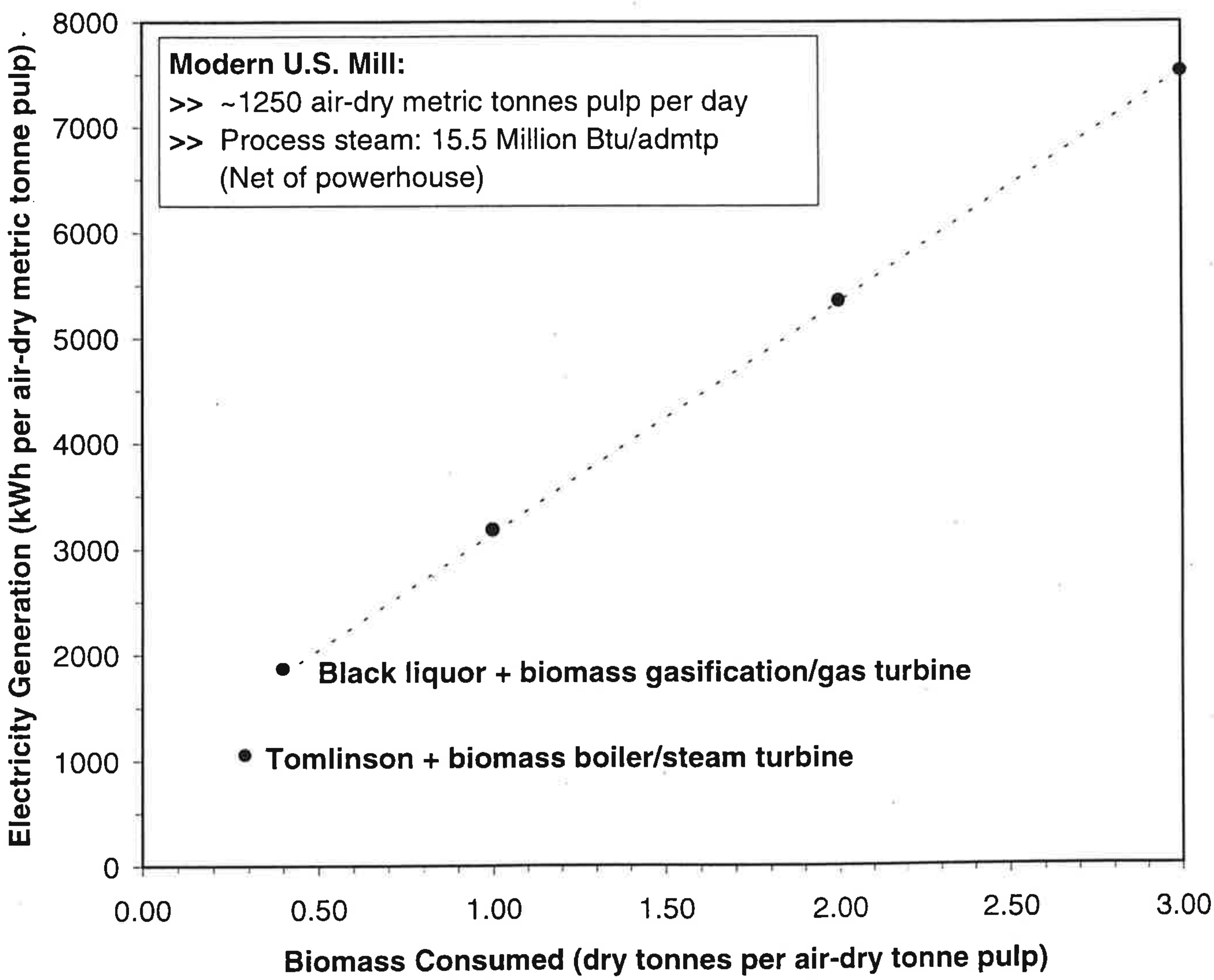
Combined Performance Using Black Liquor and Biomass Gasification

(preliminary)



Potential Power Generation at a Bleached Market Kraft Pulp Mill

(preliminary estimates)



Future Work Planned

- Finish baseline modeling for all gasifiers with Seimens 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)

ack 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."*

itical Paths to Rapid Commercialization

- Bench - pilot - demo - first commercial
- First commercial plant needs to succeed
- Paper industry partners
- Better communication with potential market

...ow 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 technogy*
- *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 - Zurn-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 - Zurn-NEPC

Commercializing biomass gasifier/gas turbine systems

Company	Type	Product gas	Pilot plants	Demonstration
Carbona	Pressurized Bubbling Bed	4.2 MJ/nm^3	70 bdmtpd	Biocycle - pilot unit to Enso mill MAP - 70 MW alfalfa (2001)
Foster-Wheeler	Atmospheric CFB			5 x 30 MW lime kiln fuel 40-70 MW hot raw gas to boiler
	Pressurized CFB	5 MJ/nm^3	7 MW (1993)	17 MW IGCC (Varnamo)
TPS	Atmospheric CFB w/ tar cracker	5-6 MJ/nm^3	2 MW	7 MWe RDF (Italy) 3 proposals at 8-30 MWe
Zurn-NEPCO	Indirectly heated atmospheric gasifier	17 MJ/nm^3	BCL	15 MW startup Q2 '97 (Burlington)

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"

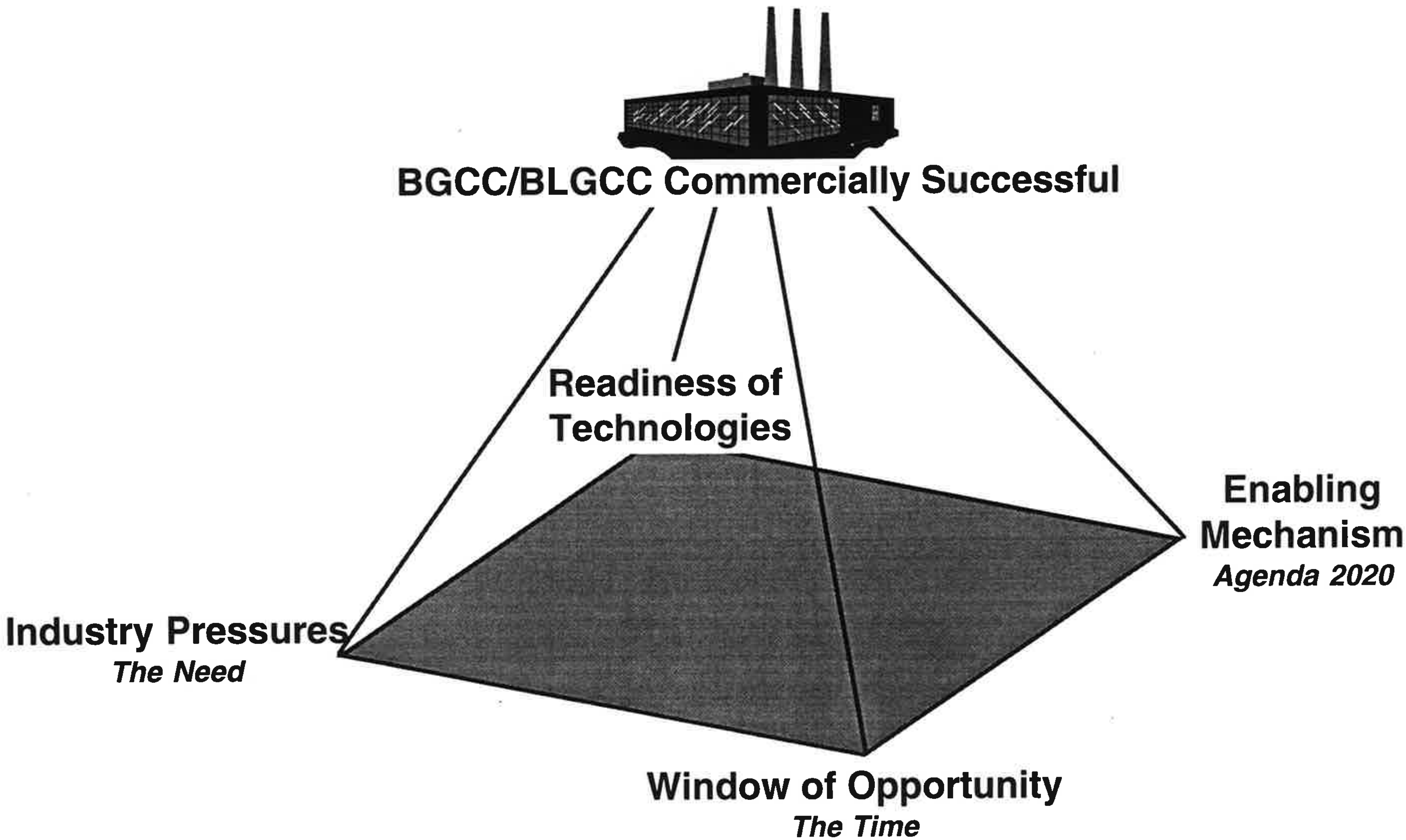
Biomass & Black Liquor Gasification Combined Cycle

Timing is Critical

Princeton University

January 17, 1997

Commercialization of BGCC & BLGCC Technologies - *Why Now?*

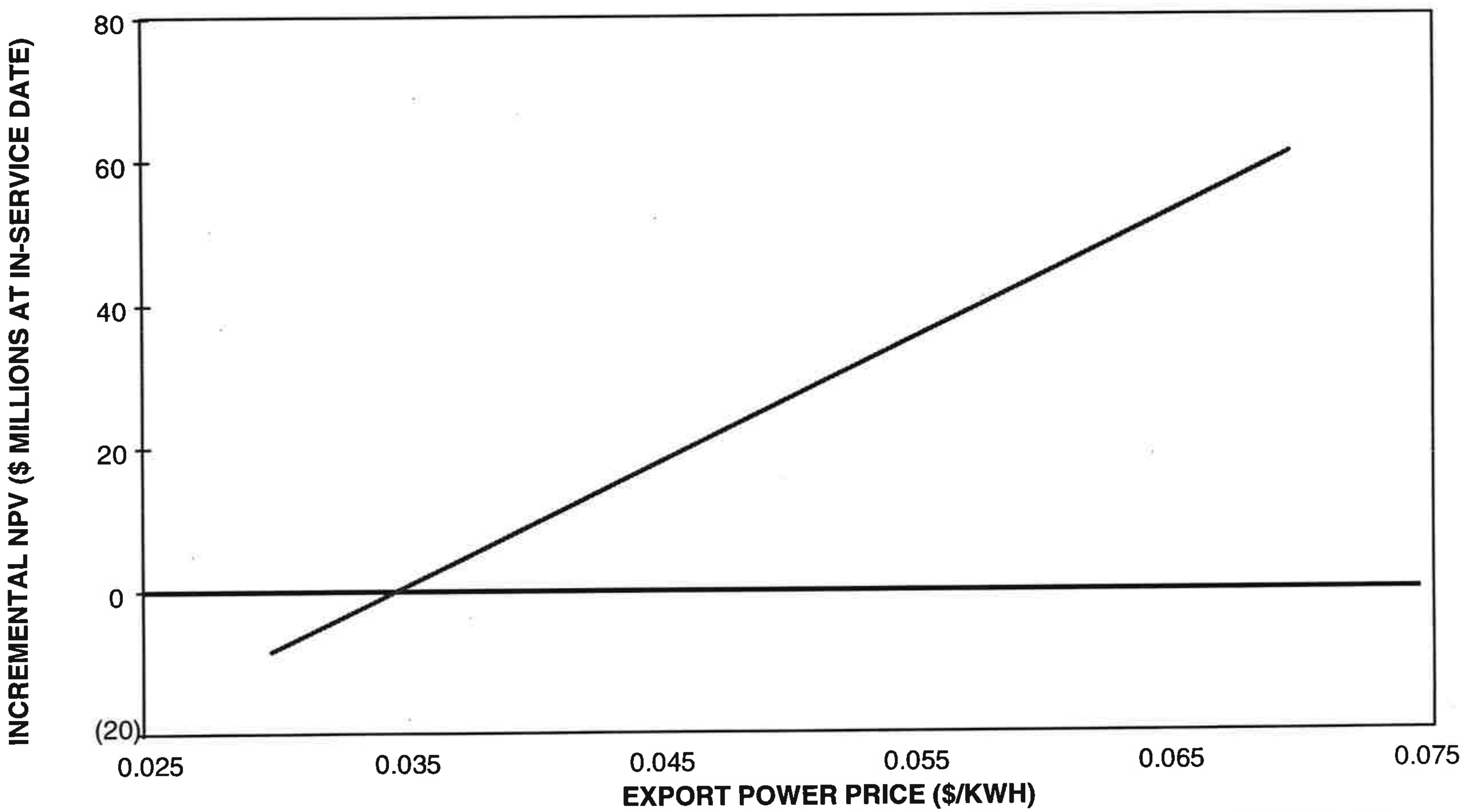


Summary of Recent Weyerhaeuser Gasification Technology Activities

- 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

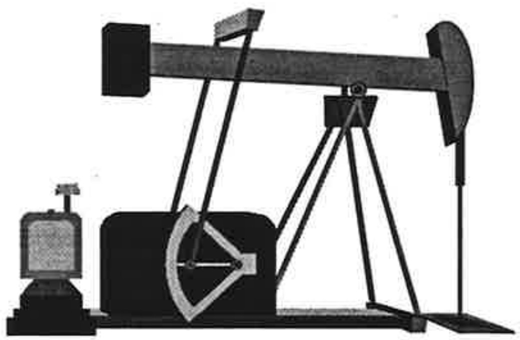
BGCC Economic Sensitivities

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.

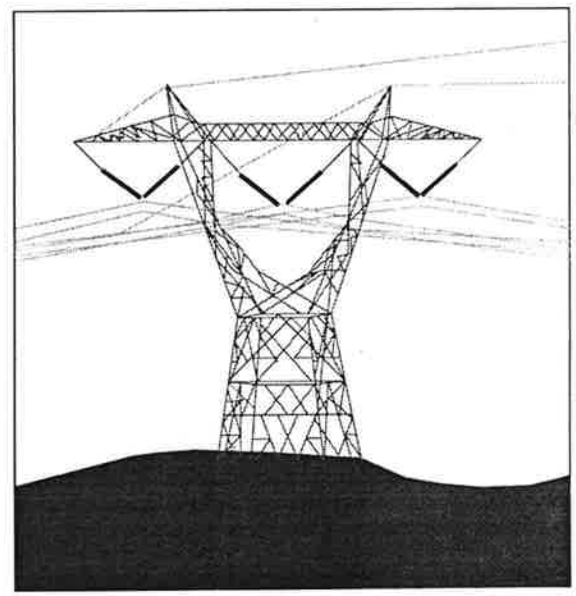
Possible Alternatives - New Bern



- 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

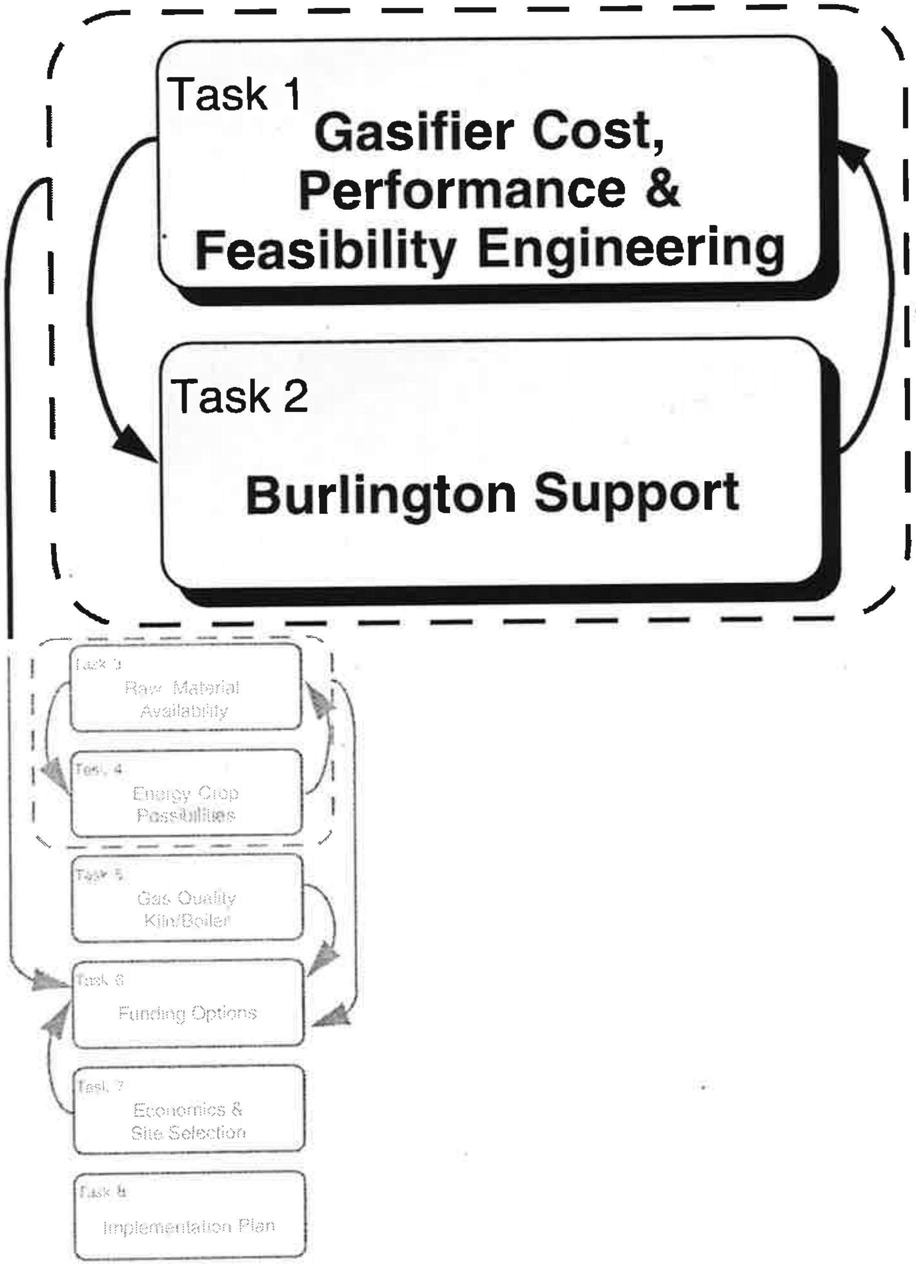
- Power Values (or Chemical Values)
- Fuel Cost (Fossil)
- Fuel Cost (Biomass)
- Capital Cost



Biomass Gasification Combined Cycle Project

Task Flows & Significant Outcomes

Tasks 1 & 2
Significant Outcomes

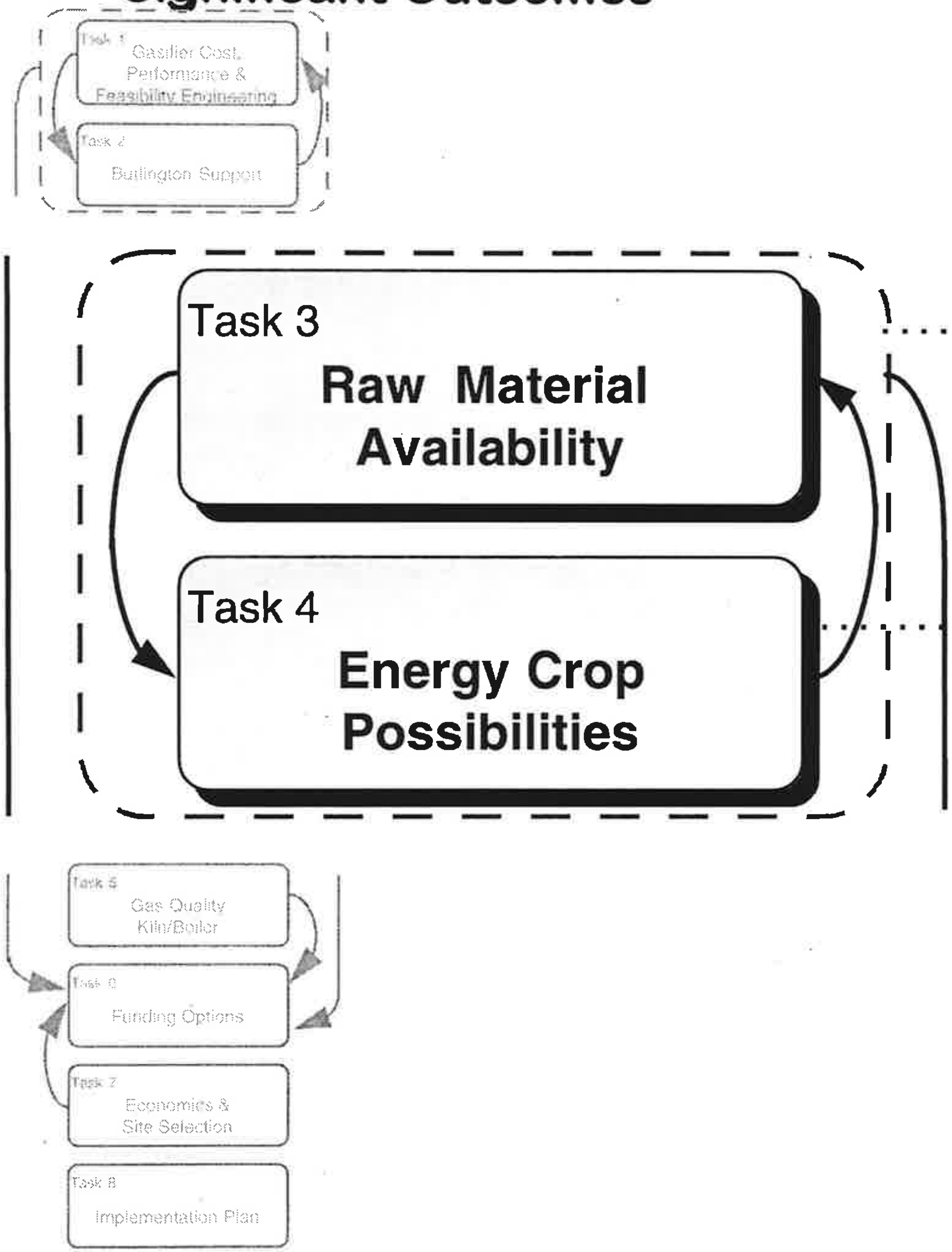


Lowest capital cost for gasifier island realistically bounded

Time/knowledge to achieve capital cost reductions quantified

Risk of implementation related to time/knowledge/cost

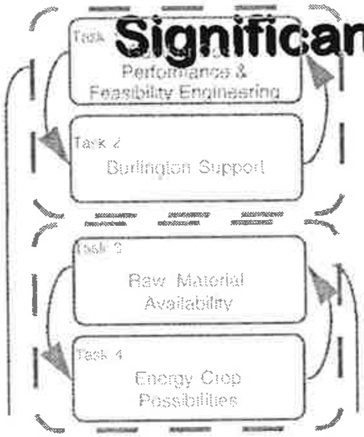
Tasks 3 & 4
Significant Outcomes



Raw material availability/cost for Weyerhaeuser NC implementation quantified

Realities of using municipal waste-water as a nutrient source for energy fiber production quantified

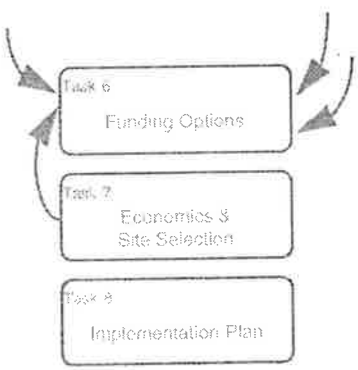
Task 5
Significant Outcomes



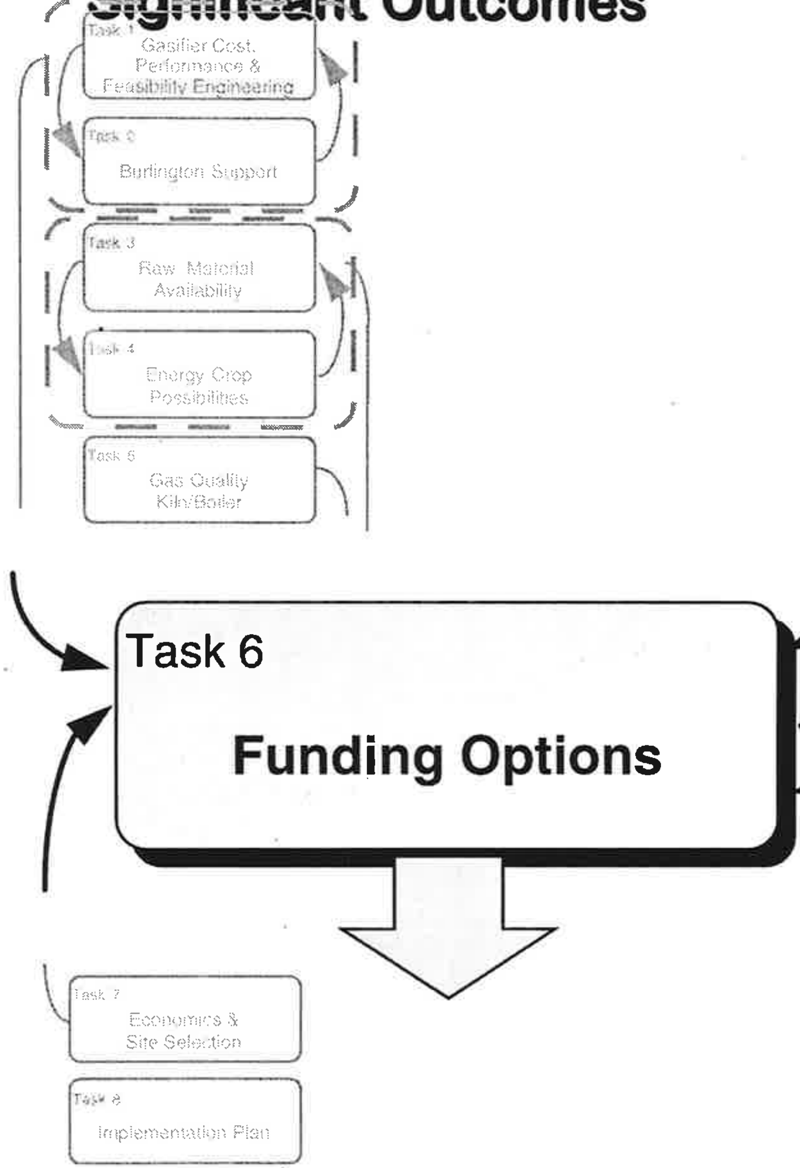
Task 5

Gas Quality
Kiln/Boiler

Kiln/boiler impacts for Weyerhaeuser NC implementation understood

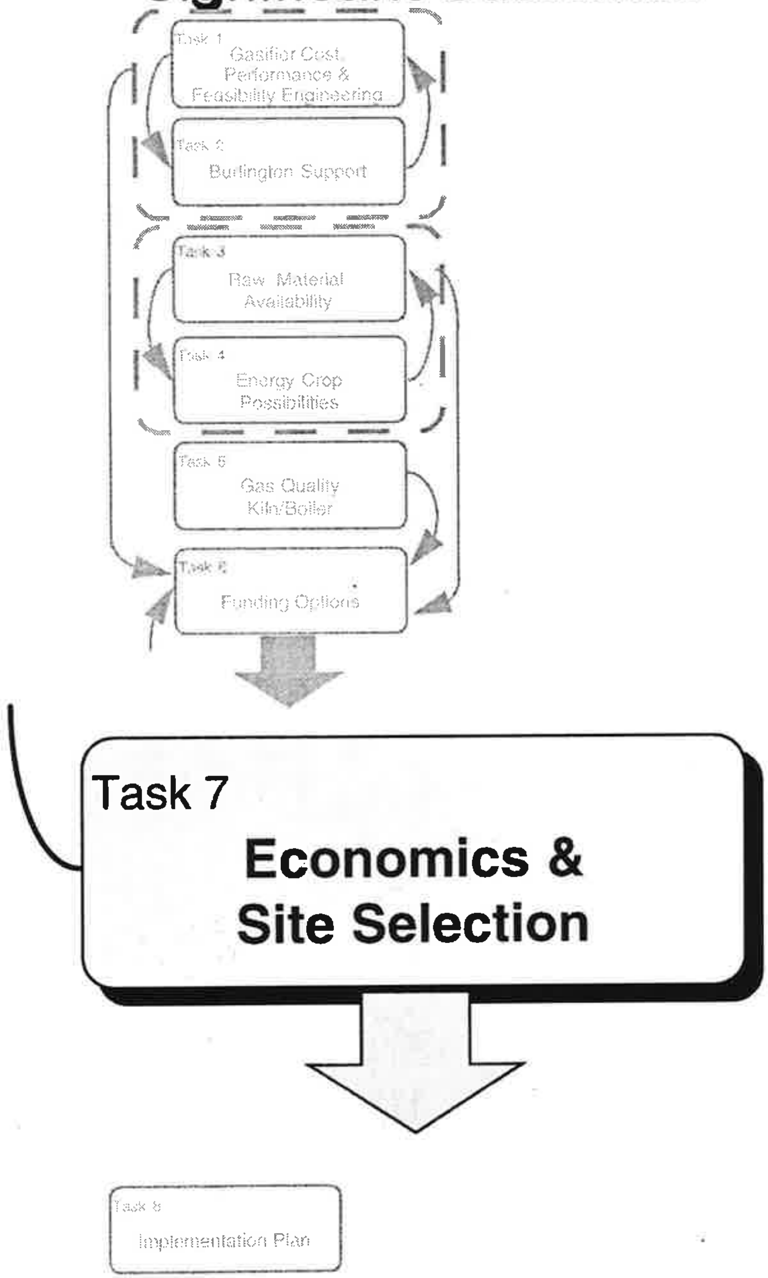


Task 6
Significant Outcomes



- Best economics for a Weyerhaeuser NC implementation
- Funding options identified

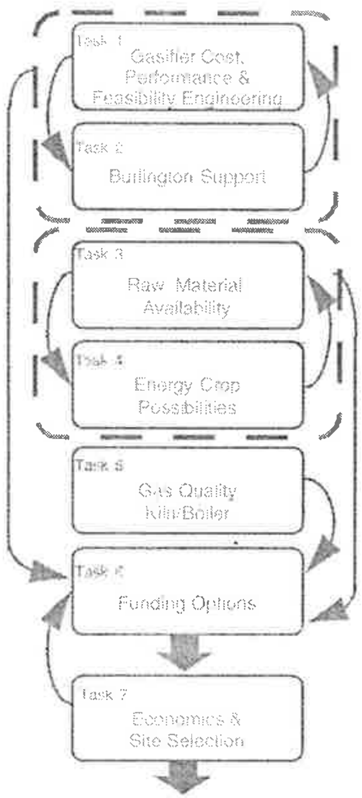
Task 7
Significant Outcomes



Best Weyerhaeuser NC site selected

Non-Weyerhaeuser options identified

Task 8
Significant Outcomes



Task 8

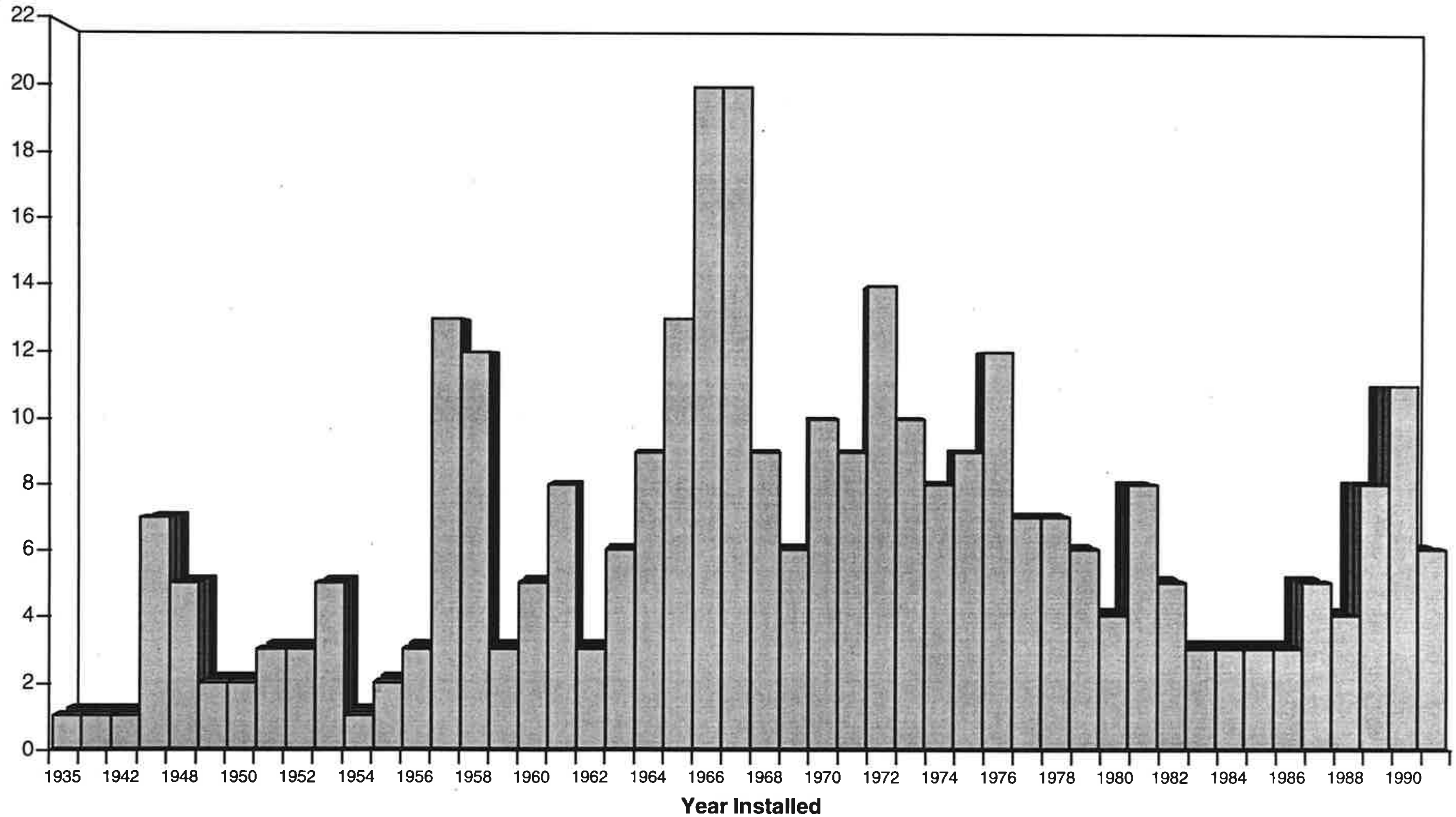
Implementation Plan

- 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?**