0273-2289/96/5758—0763$8.25

Alternative Energy Sources and Technologies for the Pulp and Paper Industry

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ABSTRACT

Weyerhaeuser—together with Amoco Corporation, Carolina Power and Light, and Stone and Webster Engineering Corporation—carried out a feasibility study sponsored by the National Renewable Energy Laboratory and the Electric Power Research Institute to assess the economic merits of expanding the use of biomass at its New Bern, North Carolina, facility to produce electric power and liquid fuels. Biomass gasification is expected to be a means for improving utilization of wood and process wastes while producing gas turbine fuel and reducing environmental impact. The team also assessed the technical merits and business potential of integrating a nominal 1000 ton/day biomass processing facility to produce ethanol at the New Bern plant. The primary objectives were to evaluate biomass as a source of electric power and liquid fuels within the context of a specific operating pulp mill and to assess the relative value of biomass-derived electric power and liquid fuel. An additional objective was to define the most cost-effective process for commercializing advanced biomass to energy technologies. This article describes the conditions that make these technologies potentially attractive, outlines the approach taken to develop comparative economics and economic sensitivities, presents results of the analysis, and suggests options for proceeding to commercialization of these advanced conversion technologies.

Index Entries: Biomass; pulp industry; paper industry.

INTRODUCTION

Driven by process changes that are making pulp and paper mills ever increasingly dependent on purchased electric power, the industry is motivated to search for technology alternatives for the conversion of its biomass residuals to electricity and other useful energy products. Recent emphasis by the US Department of Energy in the area of renewables has provided an unusual window of opportunity for advancing to commercial viability this new more efficient energy-generation technology. This window of opportunity comes at a time when greater than 50% of the industry's power generation equipment will need major alteration or replacement in the next 15 yr, as a result of age.

Two technologies that can have a profound impact on the industry's or energy self sufficiency—even to substantially increasing the capability for Axle exporting electric power—have evolved to the point of commercial readiness. These technologies are biomass gasification combined cycle (BGCC) and black liquor gasification combined cycle (BLGCC). A third technology, ethanol production from biomass, although not as advanced in its commercial readiness, is also of increasing interest driven by recent advances in fermentation technology and a significantly increased market opportunity as a result of the environmental need for gasoline additives.

Black liquor gasification is being actively pursued by Weyerhaeuser and others and is not considered here. This paper compares, for an integrated pulp mill situation, the operating and economic realities of BGCC and biomass-to-ethanol technologies. As partners in the project, Amoco supplied the ethanol production technology input and marketing analysis; Stone and Webster Engineering of Boston provided the cost estimating and economic analysis; and Carolina Power and Light provided the power market information pertinent to North Carolina. The study was made possible through the NREL-EPRI sponsored "LOI" program.

Economic information presented here includes sensitivities to export power price, feedstock price, DOE capital support and, in the case of ethanol, additional sensitivities to ethanol price and enzyme cost are presented. The project report presented to NREL and EPRI contains additional information. Analysis of these sensitivities indicates that, in the case of ethanol, the market price and enzyme cost are by far the most influential in determining the project viability. Enzyme costs less than \$4/gallon and/or ethanol prices of approx \$1.40/gallon appear necessary to move the ethanol concept as presented here into an economically interesting range. It should be noted, however, that the state of development of biomass to ethanol is clearly precommercial at this time and that a number of design improvements that would significantly change this picture are possible. Also, if a high value marketable product can be developed for the lignin stream, this would have a very significant positive impact.

Based on the analysis of sensitivities with respect to gasification, capital cost and, in this case, the value of export power, have by far the most, significant impact on BGCC economics. Given a 50% shared cost for the first commercial plant, a positive economic result is achievable at export power prices of 5¢/kWh and above. It is Weyerhaeuser's belief that these BGCC results—coupled with the future possibilities of integrating this technology with BLGCC, the probability of a mature BGCC technology having 20–30% less capital cost, and anticipated trends in electricity prices—make biomass gasification combined cycle a viable, even exciting, future possibility that should receive early support for commercialization. With shared cost through DOE's commercialization programs similar to the current request for proposals advanced in the Biomass Power for Rural Development solicitation, BGCC should find an early home in the forest products industry, contributing to the country's energy self sufficiency from renewable resources and improving the industry's global competitiveness.

A LOOK AT THE FOREST PRODUCTS INDUSTRY OPERATING ENVIRONMENT

This is a time of great dynamics for the Forest Products Industry. There are a number of converging events occurring in and around this industry that will encourage, if not mandate, changes in the way the industry designs, builds, finances, and operates its process plants. The discussion here focuses on how these changes will impact the way the biomass utilized by the industry is acquired and converted to useful energy products as we enter the next century.

To set the stage, six of the converging events that are clearly impacting the industry are:

1. Increased dependence on purchased electric power: Improved efficiency of steam use and related reduction in byproduct power generation, increasing needs for environmental equipment, trends toward more thermomechanical pulps and recycling, new bleaching technologies, and other process changes all impact the pulp and paper mill steampower balance with a clear trend toward more purchased power per ton of product produced even though, in most cases, total energy use per ton has decreased.
2. Aging of kraft and hog boilers: The industry's expansion and capital replacement cycle has produced a set of power houses, the majority of which are 20–30 yr in age, that will need replacement or at least major alteration in the next 5–15 yr.
3. Tightening air emission regulations: The new emission rules currently being discussed with the EPA will greatly impact how the industry has historically operated its facilities as well as significantly increase its capital commitment.
4. Necessity for improved capital performance: As the most capital intensive industry in the industrial sector, future process changes and process equipment needs must cost less and deliver more if the industry's attractiveness to investors and global competitiveness is to be maintained.
5. Increased emphasis on renewable energy: In spite of great political pressure to significantly change government, including the US DOE, the country's again-growing dependence on imported fuels and increasing environmental pressures will, most believe, maintain the emphasis on renewable energy at all time high levels. The forest products industry has a unique opportunity to continue to lead the nation in the utilization of renewables.
6. Availability of emerging technologies: The best—and perhaps the only—time when new technologies can easily be adopted by a capitally intensive industry is when that technology is commercially available at a time when the normal capital replacement cycle mandates major system repairs or replacement. With respect to power and recovery systems, this situation may very well be about to exist.

It is not at all inconceivable that the power house of the next decade will see the conventional recovery and power boilers rapidly being replaced with BLGCC and BGCC or IGCC technologies and, in many cases, exporting significant quantities of electricity or liquid fuels. In making this change, the industry can nearly double the efficiency by which it produces useful energy as shown in Fig. 1 and become significantly more self sufficient on renewable sources. (A simple schematic of how this future power house might look is shown in Fig. 2.)

DESCRIPTION OF THE NEW BERN MILL

One of the primary objectives of this study was to look at the gasification and ethanol technologies in the context of a real operating pulp mill. Issues associated with integration with existing plants have been postulated in prior studies but, to the knowledge of this project team, an actual integrated mill study had never been

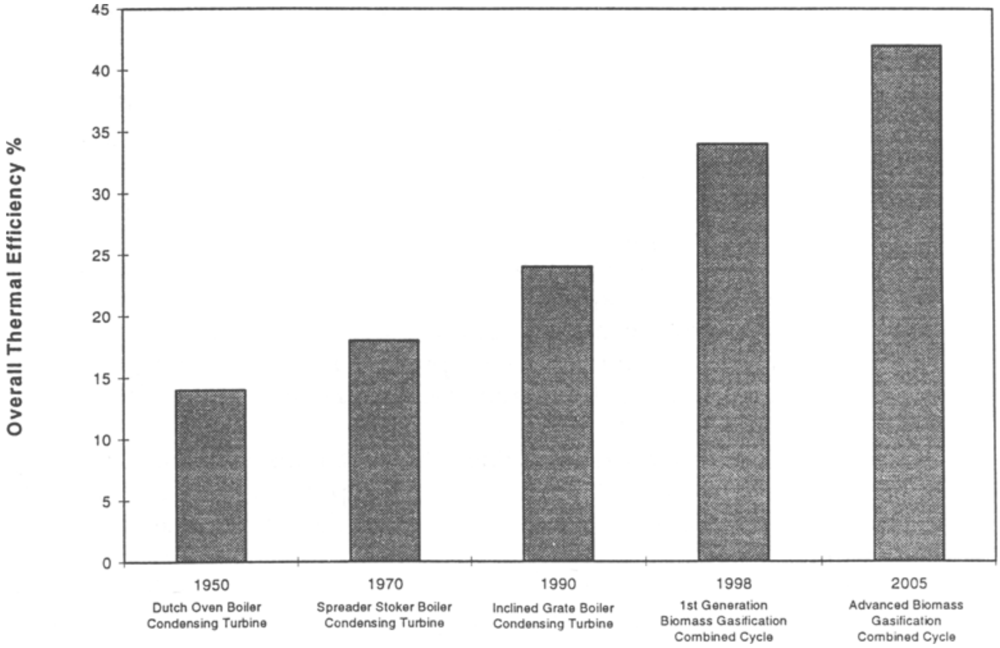

Fig. 1. Power generation efficiency comparison.

completed. The Weyerhaeuser bleached market pulp mill at New Bern, NC, was selected for the feasibility study. The mill has had a continuing interest in gasification technologies for many years. The New Bern Pulp generates process steam and electricity using a black liquor recovery boiler, a power boiler, and an extraction backpressure steam turbine generator. The power boiler, although designed to burn mill residuals (rejected or waste biomass), is currently able to fire only oil as a result of emissions limitations. The mill has evaluated the possibility of life extending (modifying) the power boiler and retrofitting emission controls, which would allow it to once again burn biomass. This boiler modification project is used as the base case for economic comparisons made with BGCC and ethanol technologies. A BGCC cogeneration plant or a combined BGCC-EtOH plant could be an alternative to the bark boiler modification project.

A General Electric Frame 6B gas turbine was selected as the basis for the BGCC plant evaluated in this study, since a biomass gasifier firing the 6B gas turbine with a heat recovery steam generator (HRSG) is of the right size to meet the steam requirements of the mill for the foreseeable future.

The pulp mill and associated saw mill produce approx 129,000 BDT/yr of biomass wastes. A BGCC project would require additional biomass feed to be supplied from forest management thinnings and other sources that are discussed in more detail below.

THE COST AND AVAILABILITY OF BIOMASS FUELS (FEEDSTOCK)

Feedstock or fuel cost and availability were also a major part of the feasibility study. The feedstock assessment was undertaken with the full involvement of

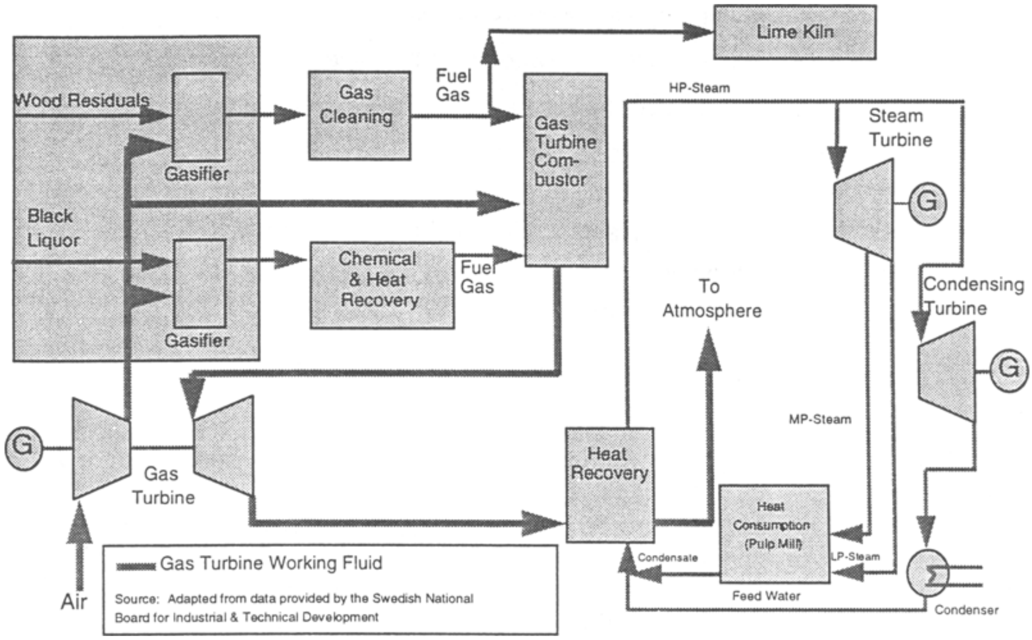

Fig. 2. Power-recovery island of 2010.

Weyerhaeuser's forestry research and raw materials people and drew from TVA and US Forest Service databases as well as company internal sources. Six possible strategies were considered, including a range of possibilities from utilizing existing residuals through managing plantation systems to produce significant additional quantities of material for energy while enhancing the sites productivity for wood and pulp products. These six strategies are shown in Fig. 3.

The first of these strategies involving company-controlled wood residuals is the simplest and most obvious to take advantage of since the material is already owned by Weyerhaeuser and, in the case of New Bern, is already on the mill site. The handling costs are the only incremental costs and the existing value is what other people are willing to pay for the fuel, less transportation costs. Approximately 110 kBDT/yr fall into this category with an additional 100 kBDT/yr within reasonable hauling distance of New Bern.

The second strategy involves utilizing the gasification or ethanol facility as a disposal opportunity for on-site generated sludges and other combustible material. This is a very small amount of material on a bone dry basis, but could reduce disposal costs for the mill. The implementation of this strategy would require a suitable drying technology and is not of significant energy value.

The third strategy, which involves the capture of residual chips from final harvest and plantation thinnings from current plantation operations both owned by and available to Weyerhaeuser, represents a very significant fuel opportunity. Though not necessarily the lowest cost, the woods residual component from natural stand final harvest is the single largest source of biomass for fuel identified in this study. It conservatively amounts to at least 600 kBDT/yr and, based on Weyerhaeuser's experience, could run significantly higher within a reasonable hauling distance of New Bern.

1) Company-controlled wood residuals
2) Mill produced non-woody combustibles
3) Energy fiber from present plantation operations
4) Maximize production of current plantation monoculture
5) Intermingle fast-growing species with plantation monoculture
6) Dedicated crops

Fig. 3. Six possible feedstock strategies.

Strategy 4 involves the growing of maximum pine volumes per acre while attempting to improve plantation productivity for primary pulp and wood products. Based on current operating approaches and currently available technology, the site-preparation cost for this approach is much too high (in excess of $50/BDT) and would require changes in approach and/or technology to become viable. The conclusions of this analysis should be of particular interest to those considering the establishment of softwood dedicated crops similar to the Southern Pine species found in North Carolina.

Strategy 5 involves growing maximum hardwood per acre intermingled with pine in existing plantations. Both hardwood sprouting between rows and hardwood inter-row plantings were considered. Again, with current technology there would be high plantation establishment costs and high harvesting costs to generate reasonably low volumes, such that this strategy also does not appear feasible with current approaches.

The sixth and final strategy involves the growing of maximum biomass per acre with a dedicated short rotation crop using mill and other locally available waste water as nutrient. Given the present understanding of fast-growing species tailored to eastern North Carolina, Weyerhaeuser foresters believe that even in this approach the Loblolly Pine would be the currently preferred species. Based on projections of growth and volume coupled with the expected planting, site preparation, and harvesting costs, this approach would become attractive at fuel values of ~$50/BDT. A number of factors—such as subsidies for waste water disposal, development of a genetically improved, faster growing crop, improved harvesting approaches, and so forth—all could reduce this fuel value. The development of these possibilities is beyond the scope of this study, particularly given the fact as discussed in the next paragraph that sufficient material is available without these measures.

The study determined the availability of feedstock material as a function of cost for each of these strategy. Costs for supplying fuel ranged from $20/BDT to over $50/BDT delivered to the energy facility at New Bern. Feedstock material availability was significantly greater than required to meet the needs of the study's three energy design alternatives (up to 350,000 BDT/yr) and can be provided at an average cost of less than $25/BDT. When only material sources which cost less than $35/BDT and could be quantified and confidently identified as available or unused were included, the amount exceeded 940,000 BDT/yr. This excess material avail-

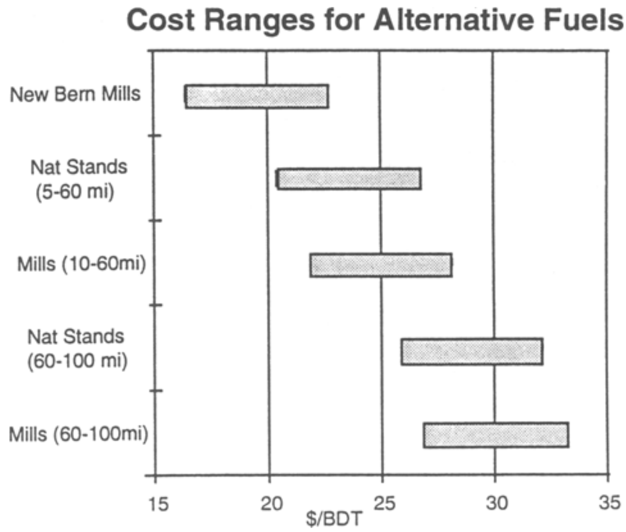

Fig. 4. Company-controlled wood residuals. Capture existing volumes of wood residuals: company-controlled wood residuals, 272,000 BDT; external forest residuals, 598,000 BDT; external mill residuals, 13,000 BDT.

ability provides a significant margin of safety if byproduct residuals are reduced through efficiency improvements in harvesting or primary product recovery.

In addition, there is a significant quantity of mill residual material (up to 160,000 BDT/yr) within 40 miles of New Bern that is currently utilized by others and could be available because of its close proximity to New Bern. This material would cost less than $25/ BDT, but was not included because of the associated uncertainty in cost and quantity. The primary sources proposed for use include residuals from Weyerhaeuser mill facilities at New Bern and within 60 miles of New Bern and forest residuals from final harvest operations.

The bottom line is that there is fuel available in the New Bern area at under $25/BDT for the foreseeable future in the amounts needed for the size plant under consideration. Although current approaches to plantation establishment and harvest recovery are too expensive to provide only biomass fuel from "energy plantations" or from planting additional trees for fuel, improvements in technology could make future combination fuel and fiber plantations viable. The approach and detailed results of this feedstock analysis are included in the final report to NREL and are summarized in Figs. 4 through 7.

FEASIBILITY OF BGCC

Working as part of the NREL-EPRI sponsored "LOI" program, Weyerhaeuser, Amoco, Carolina Power and Light, and Stone and Webster Engineering have, over the past year, completed a detailed feasibility study of the economic and operational realities of both BGCC and biomass-to-ethanol technologies. The study was focused on the New Bern, North Carolina, mill and associated dedicated feedstock system (DFSS). This mill already has a history of investigating black liquor gasification technology. The gasification technologies are discussed below.

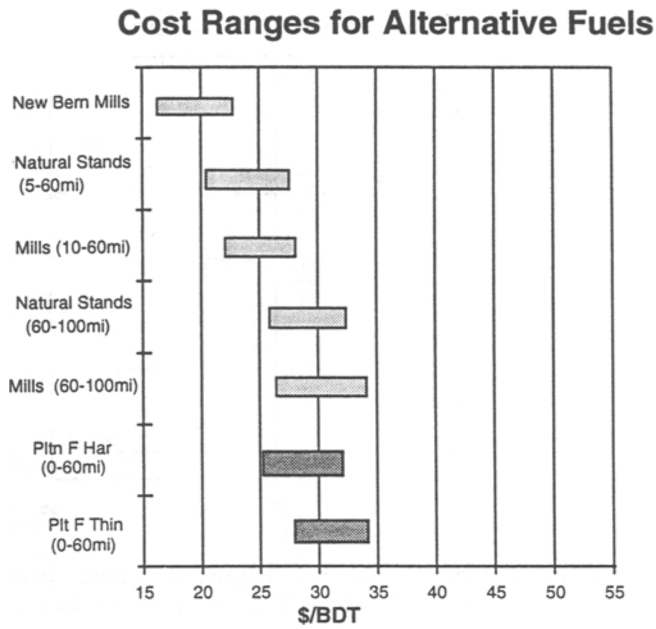

Fig. 5. Energy fiber from present plantations. Energy fiber from present plantations: 58,000 BDT.

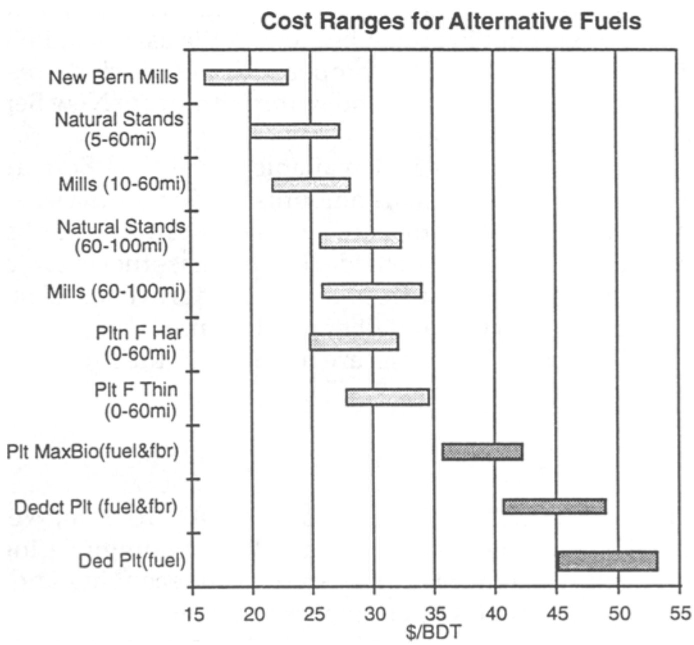

Fig. 6. Alternative fuel options. Maximize current plantation production; intermingle fast-growing species; dedicated crops.

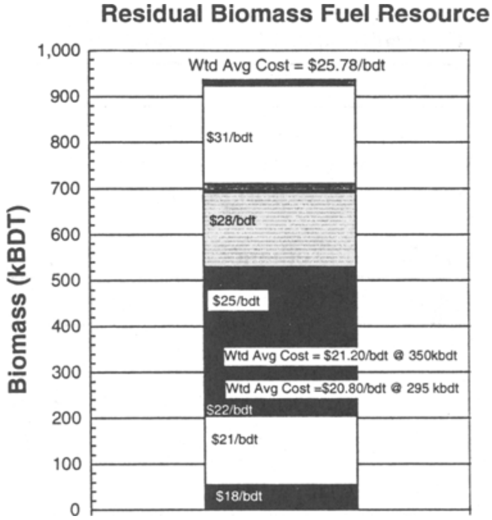

Fig. 7. Primary fuel sources for New Bern.

Leading suppliers offering biomass gasification systems include:

- Ahlstrom: pressurized (~20 bar) recirculating fluid bed;
- Tampella: pressurized (~30 bar) spouting bed;
- TPS: atmospheric sequential two-stage fluid bed; and
- FERCO/Zurn-Nepco/Battelle: atmospheric indirect two-stage fluid bed.

Also studied but not investigated in detail were American Carbons/Kaiser, Lurgi, and Noell.

Each of the suppliers mentioned above has commercial or near commercial offerings. Angstrom is operating a 15 MW_{th} BGCC plant at Värnamo, Sweden, and is participating in a design competition for a project in Brazil. Tampella operates a 15 MW_{th} gasification plant on biomass and coal at Tampere, Finland, on an intermittent basis and is prepared to make commercial offerings of both biomass and coal as well as combined systems. TPS has operated a 2 MW_{th} facility at Studsvik, Sweden, for a number of years and is also a participant in the Brazilian project. The pilot 2 MW_{th} Battelle gasifier has logged the most operating hours of any system with well over 20,000. Currently FERCO and Zurn/Nepco are engineering a 40 MW_{th}, BGCC plant to be integrated into the biomass plant at Burlington, Vermont.

After discussing BGCC options with these seven potential suppliers, Tampella and TPS were selected for in-depth analysis. The ability to work with these two suppliers provided an excellent opportunity to contrast a pressurized system represented by the Tampella technology with an atmospheric system represented by the TPS technology. Given the degree of accuracy of this analysis, the capital cost and heat rates of the two technologies investigated were sufficiently similar that no clear preference of one over the other could be determined based on these factors alone. However, since the operating efficiency of the pressurized technology was higher, the Tampella case was taken forward for detailed economic analysis. It should be noted, however, that the pressurized system eliminates the possibility of a staged implementation, which is the preferred approach at the New Bern facility.

Table 1
Capital Costs of Cases Considered

Case	Cost
Base Case	$21,100,000
BGCC with 33.4 MW export power	$97,930,000
BGCC/ethanol with 19.5 MW export power plus 70,000 GPD ethanol	$189,802,000
Ethanol only with 79,000 GPD ethanol	$117,930,000

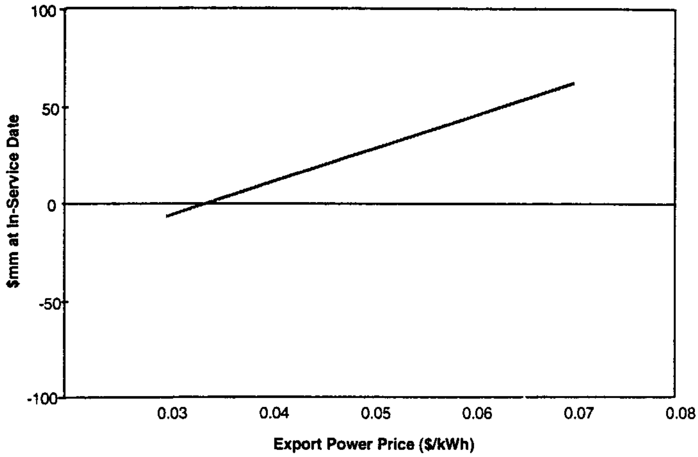

Fig. 8. Sensitivity of incremental plant's NPV to power price (50% capital support). NOTE: Assumes feedstock cost of $14/wet ton. Zero line represents NPV @ 12% and 20 yr compared to base case power boiler conversion with condensing turbine.

These gasification technologies were compared with the Amoco biomass-to-ethanol technology. Three designs were considered:

1. BGCC with 33.4 MW export power;
2. BGCC/ethanol with 19.5 MW export power and 79,000 GPD ethanol; and
3. Ethanol only with 79,000 GPD ethanol production.

In all cases, the energy needs of the New Bern mill were satisfied. The capital cost of the base case and the three cases described here are shown in Table 1.

The attractiveness of the BGCC technology is significantly impacted by the capital cost of the plant, the value of the power produced, and the cost of the feed stock These impacts are shown in Figs. 8 through 10. These sensitivities are portrayed as incremental net present values relative to operating the New Bern mill as it is configured today. By looking at the results in this way, the difficult and often controversial task of assigning costs and values to all streams crossing the powerhouse boundary is avoided. The zero NPV line on these curves is calculated at 12% return on capital invested over a period of 20 yr and is believed to be a somewhat normal investment yardstick for evaluating investments within the industry. In layman's terms, anything falling below the zero line would likely be considered a bad investment, a project falling on or near the positive side of the zero line would likely be considered a marginal investment and projects falling well above the zero line would likely be considered an interesting investment possibility.

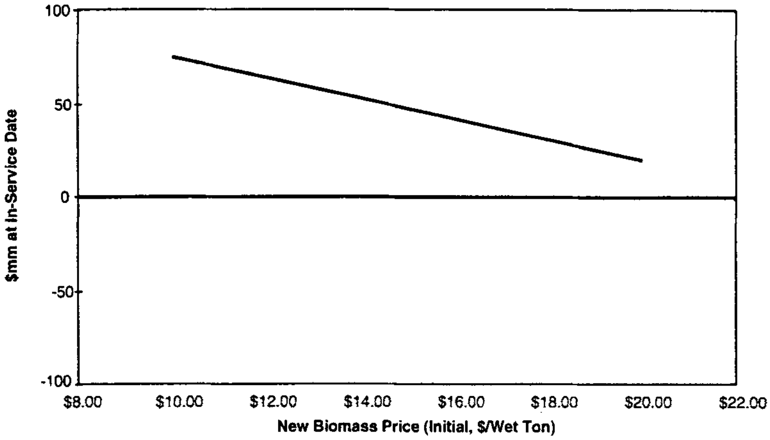

Fig. 9. Sensitivity of incremental plant's NPV to initial biomass price (50% capital support). Economic sensitivity—cost of feedstock. NOTE: Assumes power sale price of $0.05/kWh. Zero line represents NPV @ 12% and 20 yr compared to base case power boiler conversion with condensing turbine.

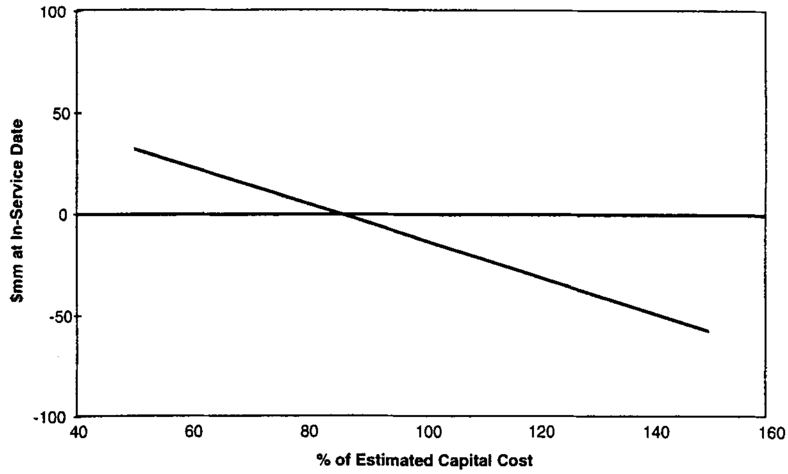

Fig. 10. Sensitivity of incremental plant's NPV to capital cost. NOTE: Assumes feed stock cost of $14/wet ton and power sales price of $0.05/kWh. Zero line represents NPV @ 12% and 20 yr compared to base case power boiler conversion with condensing turbine.

Since the current operating situation at New Bern is somewhat unique, a second comparison was made—this time utilizing a new greenfield multifuel boiler. This boiler is visualized as a bubbling or recirculating fluidized bed, capable of handling the same variety of feedstock that would potentially be utilized in the BGCC technology. The same comparison approach was utilized. Figure 11 shows the results of this comparison as a function of export power price.

A comparison with Fig. 8 shows an enormous similarity. However, in Fig. 8, a 50% capital support for the project was assumed; in Fig. 11, no such capital support is included. Therefore, an unsubsidized BGCC facility looks interesting at power cost above 3.5¢/kWh. It is important that a result of this nature appears achievable. If all future projects required a subsidy to proceed, it would be difficult to justify development dollars to commercialize the technology. However, given this analysis and the potential of the technology, BGCC appears well justified for commercial-

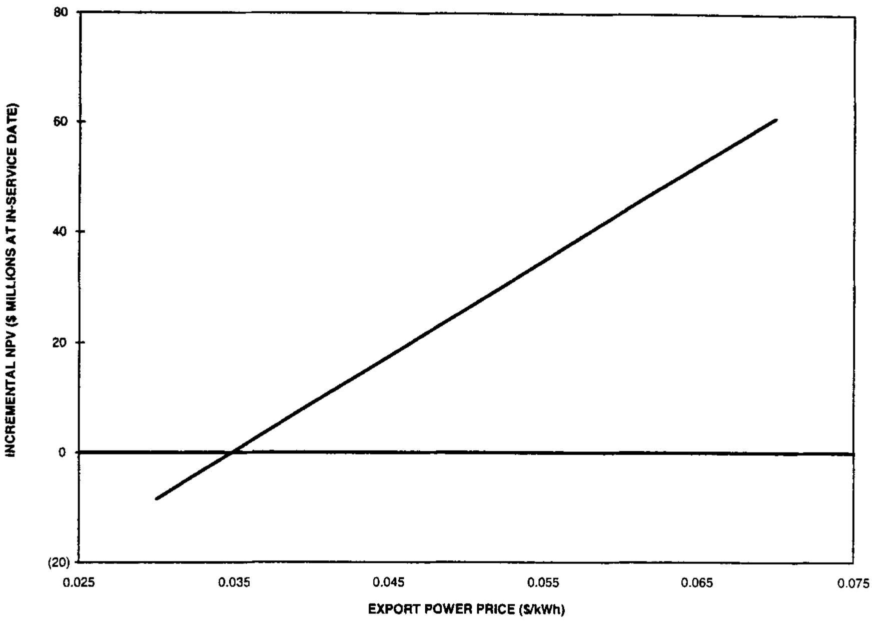

Fig. 11. BGCC compared to multifuel boiler base case—no capital support. NOTE: Assumes feedstock cost of $14/wet ton. Zero line represents NPV @ 12% and 20 yr compared to a multifuel boiler base case.

ization. Figure 12 taken from the EPRI "Technical Assessment Guide" presents an argument that capital cost reductions of 20–30% may be possible for this technology, based on the history of other developments.

Given that these reductions in capital cost are achievable as subsequent facilities are cost engineered and built—and that power values of 5¢/kWh and greater are realizable through power contracts, wheeling, or displacement of purchased power—the results of the study demonstrate that BGCC technology has significant potential for achieving improvement in pulp mill operation and biomass utilization efficiency. It also has the potential for developing additional product revenue streams, which could enhance for product industry economic productivity. These conclusions when coupled with the possibility of future integration of BGCC with BLGCC technology (*see* Fig. 2), the probability of these technologies at maturity being less capitally intensive than present plants and anticipated trends in electricity prices, make BGCC a viable and exciting future option.

FEASIBILITY OF BIOMASS TO ETHANOL

In addition to the commercial and economic realities of BGCC, Weyerhaeuser shared Amoco's interest in determining the site-specific feasibility of a biomass-to-ethanol facility. This part of the study was focused on determining how an integrated ethanol plant would compare with power generation, both as a stand-alone facility and in combination with a gasification plant that would utilize the reject lignin from the ethanol process. Assuming favorable economics, an additional objective was to enhance the understanding of the market for biomass-to-ethanol conversion technologies as related to the forest products industry.

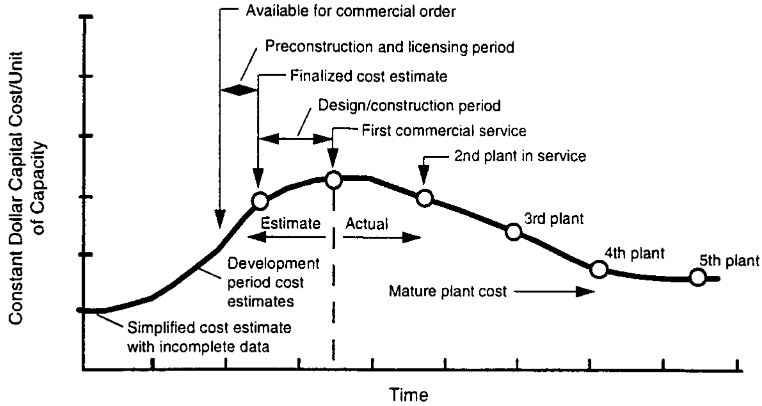

Fig. 12. Capital cost learning curve. Source: EPRI Technical Assessment Guide.

The basis for the ethanol plant design was being developed by Amoco, which is based on a proprietary pretreatment step followed by simultaneous sacrification and fermentation. The basic process utilized is discussed elsewhere in the literature. Sensitivity analyses were carried out in the same manner as discussed with BGCC. These studies indicated that project economics were most sensitive to enzyme cost and ethanol price. The sensitivity of the enzyme cost could very well influence the decision as to make or buy.

The details of this analysis are available in the report provided to NREL under the LOI contract. The basic conclusion to be reached is that, given the maturity of the technology and the anticipated benefits of on-site enzyme production, the economics for an integrated BGCC/ ethanol facility at a site similar to the New Bern mill become comparable with a BGCC plant alone at ethanol prices somewhere in the range of $1.25–1.40/gallon. This picture could be improved even further if a better use than energy could be found for the lignin byproduct.

CONCLUSIONS

Events that will impact the forest products industry over the next decade present a mandate for change in the way energy is provided and used in the industry's operating facilities. This is happening at a time when more environmentally benign and significantly more energy efficient technologies are becoming commercially available. In addition, options exist to significantly increase alternative feedstock availability and for producing valuable chemical byproducts. The industry has a unique opportunity to productively lead the nation in its goals for increased use of renewable energy and continue, if not enhance, its history of global competitiveness. One result will be that the power island of the future will utilize emerging BGCC and BLGCC technologies, cost less, and be substantially more efficient in energy conversion. As biomass-to-ethanol technologies are matured, there appears to be an operating range where the economics can be quite attractive. However, this range is highly influenced by site-specific factors such as the value of the lignin as an energy source, the capital cost of integration with the pulp mill, and by the cost of enzyme production and sale price of the ethanol. A final conclusion is that it appears and a combined ethanol and power integrated facility has a high probability of being more profitable than ethanol production or power generation taken alone.