PROSPECTS FOR BIOMASS-GASIFIER GAS TURBINE COGENERATION IN THE FOREST PRODUCTS INDUSTRY: A SCOPING STUDY

Eric D. Larson

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Introduction

Our biomass-based gas turbine cogeneration research to date has focussed primarily on the sugar cane processing industries. We chose these industries for our initial analysis because they are well-established in developing countries, because both sugar and alcohol production have traditionally involved using biofuels for cogeneration, and because there is growing interest in cogenerating excess electricity for sale to utilities to supplement factory revenues from sugar and/or alcohol. In the work reported here, we make a preliminary exploration of the potential for using biomass-gas turbine cogeneration in the forest products industry. Our objective in this scoping work is simply to understand whether more detailed analysis of particular sub-sectors of the industry seems warranted, as judged by the technical potential for these sub-sectors to have an important impact (through biomass gas turbine cogeneration) on the electricity supply situation in developing countries and by the commercial potential of introducing biomass-gas turbines and more efficient end-use technologies into the industry in the long term.

Motivation for this Scoping Study

The forest products industry, including pulp mills and sawmills, is the largest producer of by-product biomass residues among biomass-processing industries. Globally it generates roughly twice as much residue at the factory as the cane sugar industry. An initial estimate we made [1] of the potential for cogenerating electricity in the industry using these residues is correspondingly large: roughly 100,000 MW_e with biomass-integrated-gasifier/steam-injected gas turbines (BIG/STIG), compared to 52,000 MW_e in the cane sugar industry (Table 1). Sawmills were estimated to account for 82,000 MW_e and pulp mills for about 20,000 MW_e. As we will discuss below, this estimate for pulp mills turns out to be quite low because it included only bark and black liquor as potential feedstocks for BIG/STIG systems and excluded forestry residues, which appears to be a major potential gas turbine feedstock.

Table 1. **ESTIMATED POTENTIAL BIOMASS INTEGRATED-GASIFIER/STEAM-INJECTED GAS TURBINE (BIG/STIG) GENERATING CAPACITY (1000's of MW) THAT COULD BE SUPPORTED WITH THE CURRENT LEVELS OF RESIDUES PRODUCED IN FOUR BIOMASS-PROCESSING INDUSTRIES.**[a]

Residue Source	*Asia*	*Africa*	*Latin America*	*Industrial Market Economies*	*World*
Forest products	**37.1**	**1.5**	**7.7**	**91.3**	**101.6**
Saw mills	32.0	1.2	4.8	44.1	82.1
Pulp mills	5.1	0.3	2.9	47.2	19.5
Sugar cane	**13.9**	**4.9**	**27.9**	**4.8**	**51.5**
Corn Stover	**10.9**	**2.7**	**4.5**	**30.7**	**48.8**
Rice husks	**18.0**	**0.3**	**0.5**	**0.3**	**19.2**
TOTAL	**79.9**	**9.4**	**40.6**	**127.1**	**221**

(a) Assuming 33% conversion of residues to electricity and a 75% capacity factor. From [1].

Although sawmills account for 80% of the residues currently produced in the forest products industry, the largest user of biomass for energy is the pulp and paper industry. This industry currently has the most organized structure for collecting and using the biomass residues, and the quantity of residues at an average pulp mill is significantly larger than at an average sawmill. The familiarity of the pulp and paper industry with cogeneration, the highly structured biofuel collection system, and the relatively large quantities of biofuels available at single sites make the pulp and paper industry a particularly promising candidate for gas turbine cogeneration applications.

Global Distribution of Pulping Capacity

The pulp and paper industry is economically the most important subsector of the forest products industry in countries where all forest products industries are mature.

In most developing countries, pulp and paper industries are still relatively small. Significant expansion of production capacity is expected over the next few decades as global demand for paper grows [2]. The expansion of the industry will occur most rapidly in developing countries (Table 2), because the fastest growth in paper demand is occuring in these regions, and raw material and perceived environmental costs are lower than in most temperate industrialized countries. Furthermore, capacity expansions in some major industrialized paper-producing regions (e.g., Scandinavia) are limited by feedstock supply constraints.

The high capacity expansion rates expected in the future in developing countries might provide excellent opportunities for rapidly introducing new cogeneration technology, e.g. BIG/STIG cogeneration, and energy-efficient end-use technology. This situation is fundamentally different from that in the cane sugar industry, where essentially no major capital investments for new factory construction are being considered.[1] Most new investments in the sugar industry would be for retrofit applications (unless global alcohol production capacity were to grow significantly).

Biomass Fuels Available at Kraft Pulp Mills

Kraft pulp mills are of particular interest because they produce the largest tonnage (Table 2) and highest quality of pulp worldwide and also have available the largest quantities of biomass by-products per tonne of pulp produced. Up to three different biomass streams are potentially available as fuels at stand-alone kraft pulp mills (or the pulping section of integrated pulp and paper factories): hog fuels, black liquor, and forest residues.

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[1] Although global demand for sugar is projected to grow 1.5% per year [3], much of the increase could be met by utilizing the existing factory capacity more fully and efficiently.

Table 2. **GLOBAL PULPING CAPACITY IN 1986, WITH GROWTH RATES TO 1991 PROJECTED BY THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.**[a]

Region	***Pulping capacity (1000 air-dry tonnes/year)***		***Projected growth in pulping capacity (%/yr)***	
	Total	**Kraft pulp**	**Total**	**Kraft pulp**
North America	76,700	56,113	0.76	0.51
Scandinavia	20,985	12,545	0.78	0.90
Eur/S.Afr./Ocea.[b]	19,870	12,093	1.5	1.2
Japan	12,268	8,302	1.4	1.4
Soviet Union	12,050	8,700	0	0
South America	6,528	5,234	5.5	6.0
Asia (ex. Japan)	4,594	2,883	4.3	5.1
Africa (ex. S.Afr.)	853	713	3.4	3.3
Total	**153,848**	**106,583**	**1.2**	**1.1**

(a) Based on [4].
(b) Includes Western and Eastern Europe, Australia, New Zealand, and S. Africa.

Hog fuel consists of bark, sawdust and other scrap material produced during debarking and chipping of logs, which occurs at pulp mills that purchase logs for feedstock (rather than chips). The energy contained in the hog fuel (based on data for one pulp mill in Sweden) is approximately 3 GJ per tonne of pulp (GJ/tp) produced [5].[2]

Black liquor is produced as a by-product of digesting wood chips. The cellulose in the wood chips is converted to pulp, with the remaining components making up the black liquor. The energy content of black liquor is some 13 GJ/tp [5], or roughly two-thirds of the energy in the original wood chips.

An important additional biofuel that is potentially available at pulp mills are the residues of forestry operations (tree thinning and harvesting) which are currently left in the forest. In many cases, a significant fraction of these residues can be removed from the forest with no negative long-term environmental or soil-productivity impacts. For example, in Sweden, where this issue has been intensively investigated, the energy

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[2] Pulp production tonnages are expressed here according to industry convention, which assumes 10% moisture content.

value of removable forest residues is, on average, some 1.9 times that of the black liquor currently produced in the Swedish pulp and paper industry [1]. A similar level has been estimated for the United States in a much less detailed study [6]. Based on these estimates, the average production of forest residues is some 24 GJ/tp.

Gasification Technologies for Biomass Residues of Pulp Production

Most kraft pulp mills today cogenerate electricity using black liquor as the primary fuel, with hog fuels accounting for a much smaller fraction of the total. The black liquor is burned in Tomlinson recovery boilers, which produce steam for steam-turbine cogeneration and a smelt containing sodium carbonate (Na_2CO_3), which is recovered and recycled to the process. The Tomlinson boiler has been used commercially for over 50 years and is currently used at essentially all kraft mills. A number of kraft mills worldwide are nearly energy self-sufficient using the Tomlinson technology.[3] As in the cane sugar industry, however, electricity is generally not produced in excess of onsite needs, largely because there has been little incentive to do so. With greater incentive (e.g. higher payments from utilities for privately generated power), electricity production could be increased to some extent using existing steam turbine technology. However, much larger amounts of electricity could be produced using gas turbine systems. Doing so would require gasification of the biofuels for use in the gas turbine.

Based on our previous assessment of gasification technologies [1,7,8], it appears that any of the solid residues that are potentially available at kraft pulp mills (hog fuels and forest residues) could be gasified using fixed-bed or fluidized-bed technology that would be developed for gas turbine applications with other solid biomass fuels

[3] Entirely energy-self-sufficient mills substitute gasified hog fuel for the clean fuel (oil or natural gas) used in the lime kilns (which are part of the chemical recovery cycle).

(bagasse, wood chips, etc.). There are several commercially successful atmospheric-pressure fluidized-bed gasifiers operating in Europe at pulp mills, where the gas displaces oil for firing lime kilns. The fluidized-bed gasifier has been the technology of choice in these applications because of its flexibility in handling a wide range of feedstocks (e.g. bark and sawdust) in the same unit, with drying as the only preprocessing step. Fixed-bed gasification would require some feedstock preprocessing in most cases.

Because black liquor is a viscous liquid and chemical recovery is a necessary part of the gasification process, black liquor gasifier (BLG) technology differs from the more familiar fixed- or fluidized-bed technologies. While there has been some consideration given to fluidized-bed black liquor gasification [9], most R&D attention has been given to modified entrained-flow [10] and other less-familiar processes like molten salt gasification [11] and pulse-combustor-based gasifiers [12]. Using modified entrained-flow and molten salt gasifiers, black liquor has been gasified at atmospheric pressure at pilot scale, and at least one commercial demonstration unit at larger scale is under construction.

The pulp and paper industry worldwide has made significant investments toward developing black liquor gasification technologies [12,13]. The current industry interest in BLGs is for enlarging recovery boiler capacity without having to invest in a complete retrofit of the recovery boiler, which would be very much more capital intensive. (Recovery boiler capacity limitation is currently the bottleneck to expanding production capacity at many existing mills.) However, developers of BLG systems have recognized the potential benefits of BLG-gas turbine systems and are working toward this possibility in the longer term [14], although there appears to have been little detailed analysis done on this topic.

Potential Electricity Generation with Gas Turbines at a Kraft Pulp Mill

Preliminary estimates we have made of the potential electricity generation using biofuels at a kraft pulp mill are summarized in Table 3. The electricity that could be generated (kWh per tonne of pulp) are shown for biomass-gasifier/steam-injected gas turbines (BIG/STIG) and biomass-gasifier/intercooled steam-injected gas turbine (BIG/ISTIG) systems, assuming hog fuel, black liquor, and forest residue production levels discussed above and electrical conversion efficiencies for BIG/STIG (35.6%, higher heating value basis) and BIG/ISTIG (42.9%) estimated for the power-only modes of operation (i.e., no steam to process). The BIG/STIG and BIG/ISTIG systems could produce some 4060 and 4900 kWh/tp, respectively, about 60% of which would be from forest residues, 30% from black liquor, and 10% from hog fuels.

If the electricity were sold for 5 cents/kWh, the maximum revenue from electricity would be about $200/tp with BIG/STIG and $250/tp with BIG/ISTIG (Table 3). For comparison, the average value of pulp shipments from mills in the US in 1989 was estimated to be $770/tp [15].

Since the pulp mill itself requires some steam (about 4300 kg/tp at a relatively modern factory) and electricity (about 740 kWh/tp), the amount of power available for export would be less than indicated in Table 3. In our previous assessments of cogeneration in the cane sugar industry, we found that the economic potential for electricity generation would be greatest when on-site electricity and steam demands were reduced as far as possible: in most cases, the extra capital investments required to achieve "low-energy" factories would be more than recovered through the increased revenues from additional electricity exports (see, e.g., [16]). It appears that the situation may be similar for kraft pulp mills. For example, a recent Swedish study

Table 3. **PRELIMINARY ESTIMATES OF POTENTIAL BIOMASS-GASIFIER/GAS TURBINE POWER GENERATION IN THE KRAFT PULPING INDUSTRY.**

Residue	*Recoverable energy (GJ/tp)*[a]	*Potential electricity generation*[b] *and revenues (@ 5 c/kWh)*			
		BIG/STIG		**BIG/ISTIG**	
		(kWh/tp)	**($/tp)**	**(kWh/tp)**	**($/tp)**
Hog Fuel	3.1	306	15	369	19
Black Liquor	13.1	1295	65	1561	78
Forest Residues	24.9	2462	123	2967	148
TOTALS	**41.1**	**4064**	**203**	**4897**	**245**

(a) Estimates for average Swedish conditions [1].
(b) Assuming 35.6% and 42.9% (HHV) efficient biomass-gasifier/STIG and ISTIG units, respectively.

indicates that at a kraft pulp mill, steam and electricity demands could be reduced from that at the most efficient mills today by 30% and 20%, respectively [17].[4]

Market Outlook

Using Table 3, we can update the estimates in Table 1 for gas turbine capacity that could be supported by the pulp and paper industry. There were some 550 Tomlinson recovery boilers operating worldwide in 1987, with a total associated pulp production capacity of some 95.6 million tp/year [13]. Based on the electricity production rates in Table 3, the potential BIG/STIG or BIG/ISTIG capacity that could be supported by the associated hog fuel and black liquor production alone would be some 18 GW_e or 22 GW_e, respectively (Table 4, the two colums of numbers on the left). These estimates are in rough agreement with those shown in Table 1. If the option of using forest residues is also considered, however, the potential capacity nearly triples-- to 47 GW_e or 56 GW_e, respectively.

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[4] It appears the best prospects for steam saving are through application of new pulp digestion and drying technologies and advanced black liquor evaporators. The largest electricity savings would probably be achieved through use of energy efficient motors and electronic adjustable speed drives.

The most promising initial applications for biomass-gas turbines would probably be in greenfield mills or at mills where recovery boilers are slated for replacement. Table 4 shows the potential capacity that could be supported at new mills and where recovery boilers are planned for replacement between now and 2001. A total of some 32 GW_e of BIG/STIG or 38 GW_e of BIG/ISTIG could be supported.

Table 4. **PRELIMINARY ESTIMATE OF THE POTENTIAL GLOBAL MARKET FOR BIOMASS-GASIFIER/GAS TURBINE POWER GENERATING CAPACITY (GW_e) IN THE KRAFT PULPING INDUSTRY.**

Residue	***Potential capacity at existing kraft pulp mills*** [a]		***Potential gas turbine capacity associated with planned changes in recovery boiler capacity, 1989-2001*** [b]				***Total potential capacity in year 2001*** [c]	
			New		**Replacement**			
	STIG	ISTIG	STIG	ISTIG	STIG	ISTIG	STIG	ISTIG
Hog Fuel	3.51	4.24	1.02	1.23	1.36	1.64	4.53	5.47
Black Liquor	14.9	17.9	4.32	5.20	5.75	6.93	19.2	23.1
Forest Resid.	28.3	34.1	8.21	9.89	10.9	13.2	36.5	44.0
TOTALS	**46.7**	**56.2**	**13.5**	**16.3**	**18.0**	**21.7**	**60.2**	**72.5**

(a) Assuming electricity production rates in Table 3, a 95% capacity factor, and total existing kraft pulping capacity (in 549 mills) of 95,560 thousand tp/yr [13].
(b) Based on [13]. The potential market for new and replacement recovery boilers in the kraft pulping industry is estimated to be: 60 new boilers on pulp lines averaging 1333 tonnes of pulp per day and 94 replacements on lines average 1133 tonnes of pulp per day.
(c) Sum of potential capacity at existing mills and that associated with new recovery boiler capacity planned up to 2001.

Conclusion

This scoping study indicates that there is a large technical potential for biomass-gas turbine electricity production based in the pulp and paper industry. While sawmills produce a larger total amount of biomass residues than pulp mills, the highly organized systems in the latter industry for collecting and using biomass residues for energy, the relatively large scale of operation, and the expected growth in pulping capacity in developing countries makes this industry a better candidate among all forest products industries for more detailed study. Kraft pulp mills are of most interest in the pulp and paper industry because they produce the largest tonnages of pulp and have available the largest quantities of biofuels per unit of pulp production.

Hog fuels and black liquor are currently available biomass fuels at most kraft pulp mills. A substantial biomass resource, residues left in the forest during thinning and harvesting, goes unutilized in most parts of the world today. A significant fraction of these residues can be removed without doing long-term damage to soil productivity in many regions of the world. Hog fuels and forest residues could be gasified in fluidized-bed or fixed-bed gasifiers that would be developed for using other solid biofuels (bagasse, barbojo, wood chips, etc) with gas turbines. Black liquors require a different gasification technology, one on which development work is ongoing.

Our preliminary estimate is that pulp mill revenues might be increased by up to 40% if all available biofuels were used for electricity production (in BIG/ISTIG units). The use of forest residues would be important, since over half of the additional revenue would come from using this resource.

In the period to the turn of the century, the total potential electricity production capacity that could be supported at kraft pulp mills is some 60 GW_e or 73 GW_e, based on BIG/STIG and BIG/ISTIG cogeneration technology, respectively, assuming use of all hog fuel, black liquors, and recoverable forest residues. There are an estimated 32 to 38 GW_e of potential capacity that could be installed in either new pulp mills planned for construction between now and 2000 or at existing mills where old recovery boilers are expected to be replaced during this same time period.

Based on this scoping study, four major activities would be of interest for further investigation: (1) A more detailed, probably region-specific, assessment of the availability and costs of the three biomass by-products of kraft pulp production (with particular attention to the level of forestry residues that can sustainably be removed from the forest); (2) A technical, economic, and commercial feasibility assessment of gasifier-gas turbine systems for using biomass residues of kraft pulp production, with particular attention on black liquor gasification technologies; (3) A detailed technical and economic assessment of opportunities for reducing on-site energy use at kraft pulp mills; and (4) A more detailed assessment of the likely future evolution of the kraft pulping industry, with particular emphasis on identifying developing regions of the world where the introduction of gas turbine cogeneration seems most feasible and could have an important impact on the national energy situation.

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