NATURAL VARIABILITY AND THE SECOND CROP

John V. Hatton

John Hatton & Associates
3337 Quesnel Drive
Vancouver, BC
V6S 1Z7
Canada

ABSTRACT

Previously reported pulping data on the juvenile, mature and top wood components of second-growth lodgepole pine have been re-examined to illustrate how the forest products industry could benefit from the natural variability inherent in Canada's forests in establishing the "second crop". The data show clearly that some trees gave substantially higher kraft pulp yields than others, and that incremental increases in pulp tonnage of upwards of 10% were possible (i.e., at no cost other than for bleaching). Similarly, specific energy savings in refiner mechanical pulping in excess of 20% were demonstrated. These findings are supported by corresponding data from second-growth Douglas-fir and jack pine. However, such opportunities will avail themselves only following an intensive, ongoing evaluation of the resource, and selection of seed for breeding trees suitable for specific pulping processes and paper products. Planners of our future managed forest must focus on the wood *and* fiber quality of our resource, a largely uncharted territory.

INTRODUCTION

Whilst it is well known that the wood properties (chemical, mechanical and engineering) of naturally generated softwood and hardwood stands typically show large between-tree variation (see, for example, [1-9]), the question still remains as to how the forest products industry might best benefit from this variation. Although log and tree sorting has been practiced for decades (primarily on the basis of size and species, but also on form, taper, straightness, etc.) for a variety of purposes prior to sawing, or peeling, or chipping, or waferizing, almost nothing is ever known <u>before processing</u> about the specific wood properties of these logs/trees. This is important because of their effect on the eventual product quality. Whilst this inability to characterize raw material properties may not be a serious problem in the manufacture of many solid products (because of secondary manufacturing, for example, which allows for sorting and further upgrading), the same is not true for pulp mills which rely in whole or in part on sawmill residual chips as feedstock for chemical and mechanical pulps. Incoming chips normally arrive at the mill gate uncharacterized quantitatively as to species mix, chip quality and fiber type. The frequency and magnitude of downstream problems with cooking, bleaching and pulp quality variations generally reflect the degree to which control is, or can be, exercised over the composition and quality of the starting material. It is also recognized that many of these problems could be overcome principally by the use of trees, logs, and chips from forest stands which have been managed for growth and quality or, even better, by the use of material from plantations of trees grown specifically for certain wood properties [10-12]. However, these fiber sources contribute little to Canadian pulp mills at present.

It has been my contention for some time now that upwards of 10% of Canada's forest land base should be intensively managed if Canada is to exceed or even maintain its current share of world trade in forest products. Preferably, such managed areas would be close to manufacturing operations to minimize costs, but Canada's enormous diversity in species, soil type and terrain would cause managed forests to be developed in all areas of Canada and not just on choice, fast-growing sites such as Vancouver Island and coastal British Columbia, where preferred wood quality could be allied with faster growth rates.

As part of a major effort to quantify the differences in wood density, wood chemistry, and the kraft pulp and mechanical pulp properties between the juvenile and mature wood of second-growth Canadian softwoods [13], 12 trees of lodgepole pine from two sites in British Columbia and two sites in Alberta were examined. It was shown [14-17] that significant differences existed in all major wood chemistry and pulping properties both between trees within a given site and between sites. It was also shown that many of the kraft pulp and mechanical pulp handsheet properties were strongly influenced by the wood density of the trees from which these pulps were made, as well as their constituent fiber properties of length and coarseness. However, there was no discussion as to how these natural tree differences could be used to assist foresters in managing the resource for improved uniformity, better quality and cost savings.

In this paper, it will be shown, using our lodgepole pine data reinforced by corresponding data from second-growth Douglas-fir and jack pine, that the potential exists of substantial benefits to the pulp and paper industry by managing the resource so as to produce trees with preferred wood and fiber properties. The wide diversity so characteristic of our natural forests can be used to industry's advantage in the future growth of managed stands. Lodgepole pine is a significant component of forests in the British Columbia interior and in northern Alberta with a total mature timber volume of 2.1 billion m^3 and an immature volume (i.e., less than 80 years old) of 400 million m^3 [18]. The importance of this species in North America has been reinforced by two symposia [19, 20], and a recent three-volume text [21].

METHODS AND MATERIALS

Sample Procurement and Processing

Details of the sampling of 12 lodgepole pine [*Pinus contorta* Doug1.] trees from western Canada have been described [14]. In sampling these trees, it is worth noting that the objective (as it had been throughout these second-growth studies) was to obtain three trees from each site, one with average wood density for the site, one with wood density at the high end of the range, and one with wood density at the low end of the range. The trees had to be sound and with good form, but there was no conscious bias to select the "most handsome boys on parade". No attempt was made to identify genetic differences between the four sites. The only information available to identify the trees for selection was the wood density determined on interment cores taken from a number of trees in each stand. Processing of the selected trees into kraft [15] and mechanical pulps [16, 17] together with relationships developed between fiber and sheet properties have been fully described.

Scope

For purposes of illustrating potential benefits to industry, only the kraft pulping [15] and refiner mechanical pulping [16] data will be discussed here. The chemithermomechanical pulping data [17] do show similar behavior. Corresponding kraft and mechanical pulping data for second-growth Douglas-fir [22, 23] and jack pine [23, 24] are included in the Appendix; they show similar trends. Fiber properties, particularly fiber coarseness, also showed significant between tree variability, but are not discussed here. The reader is referred to [13].

RESULTS AND DISCUSSION

Kraft Pulping

The relationships between pulp yield and Kappa number for kraft pulps from the juvenile (JW), mature (MW) and top wood (TW) components of the 12 trees cooked within the Kappa number range from 25 to 55 are shown in **Figures 1** to **3**, respectively [15]. For ease of comparison, the British Columbia and Alberta tree data are included together.

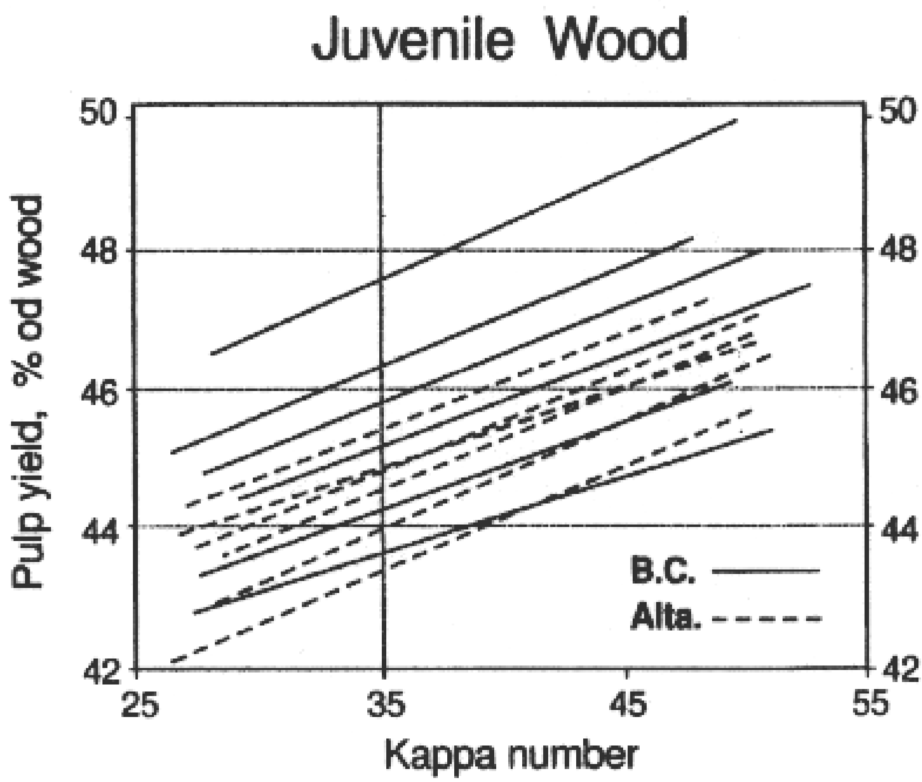

Figure 1. ***When kraft pulp yields are compared at Kappa 35 from the juvenile wood component of 12 lodgepole pine trees, they range from 43.6 to 47.7%, od wood. This is equivalent to an essentially cost-free incremental increase in pulp production of 9.4%.***

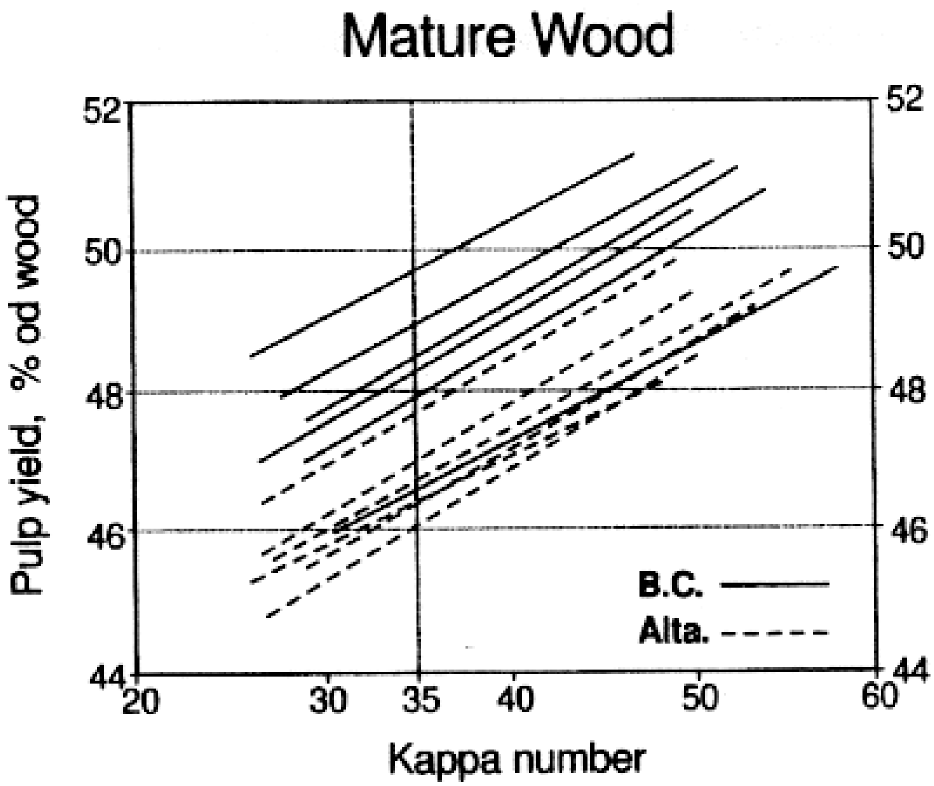

Figure 2. When kraft pulp yields are compared at Kappa 35 from the mature wood component of 12 lodgepole pine trees, they range from 46.1 to 49.7%, od wood, equivalent to an incremental increase in pulp production of 7.8%.

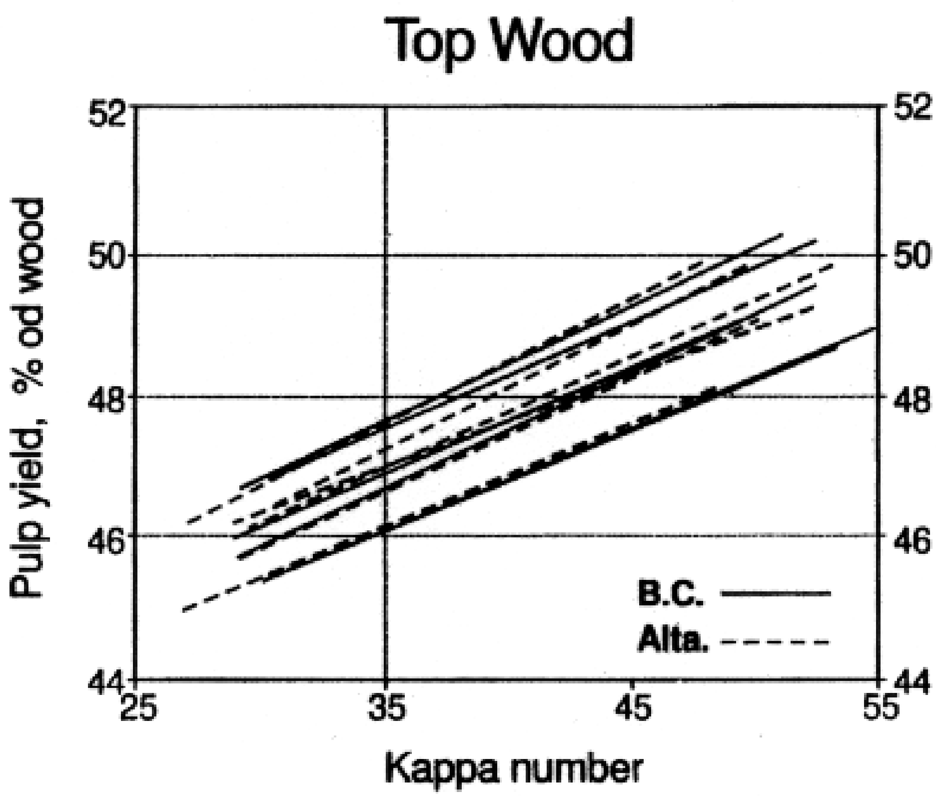

Figure 3. When kraft pulp yields are compared at Kappa 35 from the top wood component of 12 lodgepole pine trees, they range from 46.0 to 47.7%, od wood, equivalent to an incremental increase in pulp production of 3.7%.

There were large between-tree differences in pulp yield across the entire Kappa number range studied as well as significant between-province (site) differences. At Kappa 35, for example, the ranges in pulp yield for JW, MW and TW were 43.6 to 47.7%, 46.1 to 49.7%, and 46.0 to 47.7%, od wood, respectively. Alternatively, the corresponding low/high differences were 4.1, 3.6 and 1.7%, od wood. Consider the impact of these results on mill production. If chips from the highest-yield trees were pulped and then compared with those at the low end, production would increase by [(4.1 x 100)/ 43.6]% = 9.4%, or 4.7% over the average pulp yield value of 45.7% for the JW samples. Corresponding increases for the MW and TW samples would be 7.8% (3.9%) and 3.7% (1.9%), respectively. And remember that these significant increases in pulp tonnage are incremental in nature and are attainable at essentially no cost other than for bleaching. Now, it is true that these benefits would apply fully only to mills which are digester or recovery boiler bottlenecked and that only wood cost savings would apply to those mills which are machine limited. However, the conclusions and implications are clear and will become more evident following the discussion on mechanical pulping.

Refiner Mechanical Pulping

Two desirable objectives in mechanical pulping are uniformity of refiner operation and minimization of the specific energy requirements for a given pulp quality. Let us focus on the second of these by examining the data in **Figures 4** to **9**. These show the relationships between specific energy and unscreened pulp freeness for JW, MW and TW for British Columbia and Alberta samples, respectively. Note that the chips used in refining [16] originated from the same chip sources as those used in the corresponding kraft pulping trials [15]. As before, substantial between-tree and between-province differences were observed across the entire freeness range of 75 to 25 mL Csf. Specific energy requirements to reach 125 mL Csf are shown in **Table I.**

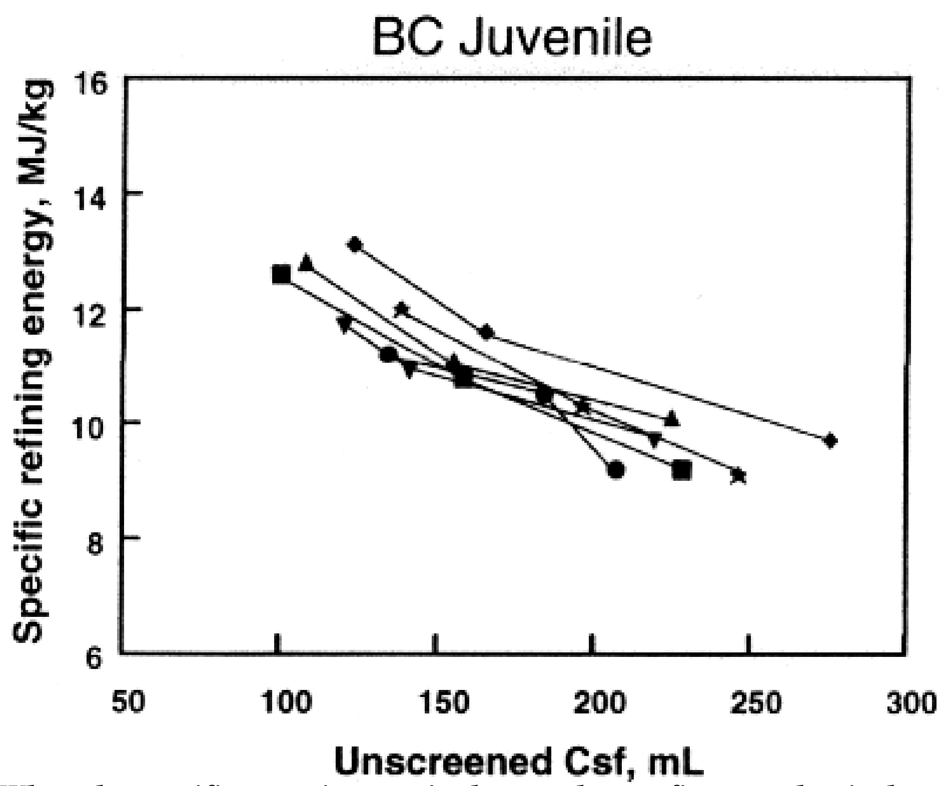

***Figure 4.** When the specific energies required to produce refiner mechanical pulps from the juvenile wood component of six lodgepole pine trees from British Columbia are compared at 125 mL Csf, they range from 11.3 to 12.9 MJ/kg, a difference of 12.4%.*

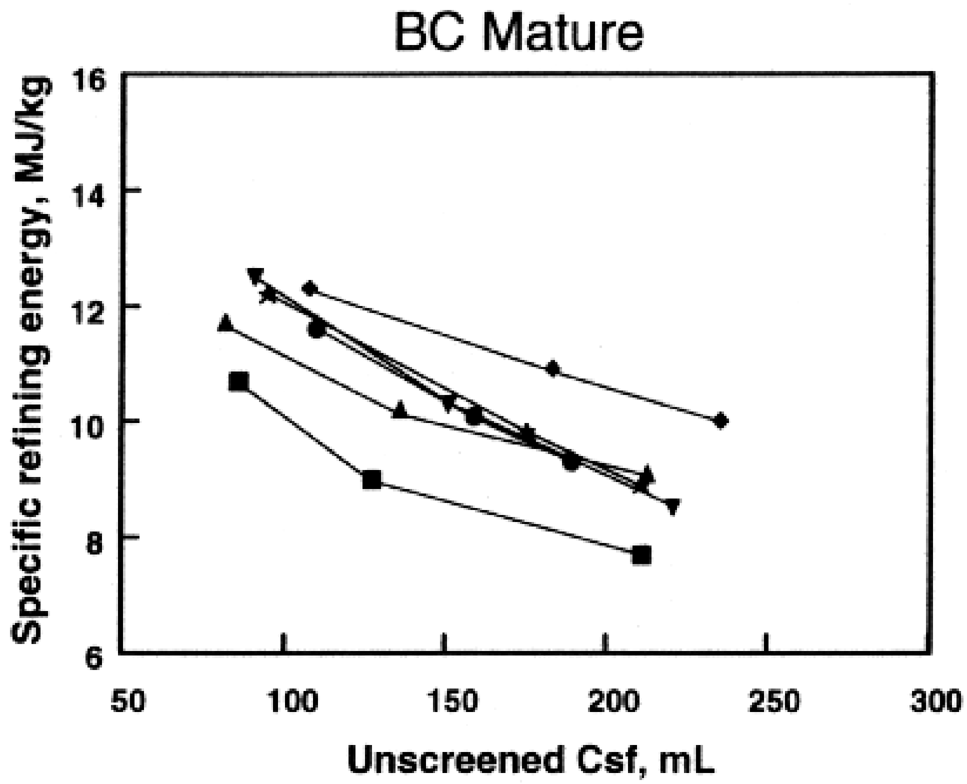

Figure 5. When the specific energies required to produce refiner mechanical pulps from the mature wood component of six lodgepole pine trees from British Columbia are compared at 125 mL Csf, they range from 9.1 to 12.0 MJ/kg, a difference of 24.2%.

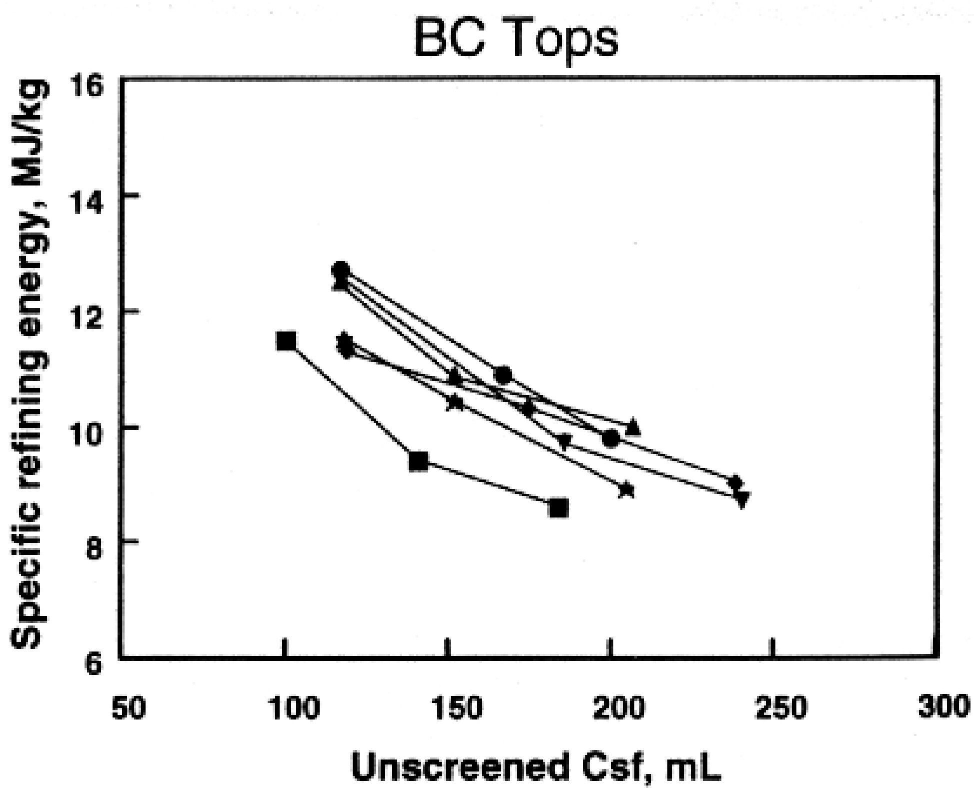

Figure 6. When the specific energies required to produce refiner mechanical pulps from the top wood component of six lodgepole pine trees from British Columbia are compared at 125 mL Csf, they range from 10.2 to 12.4 MJ/kg, a difference of 17.7%.

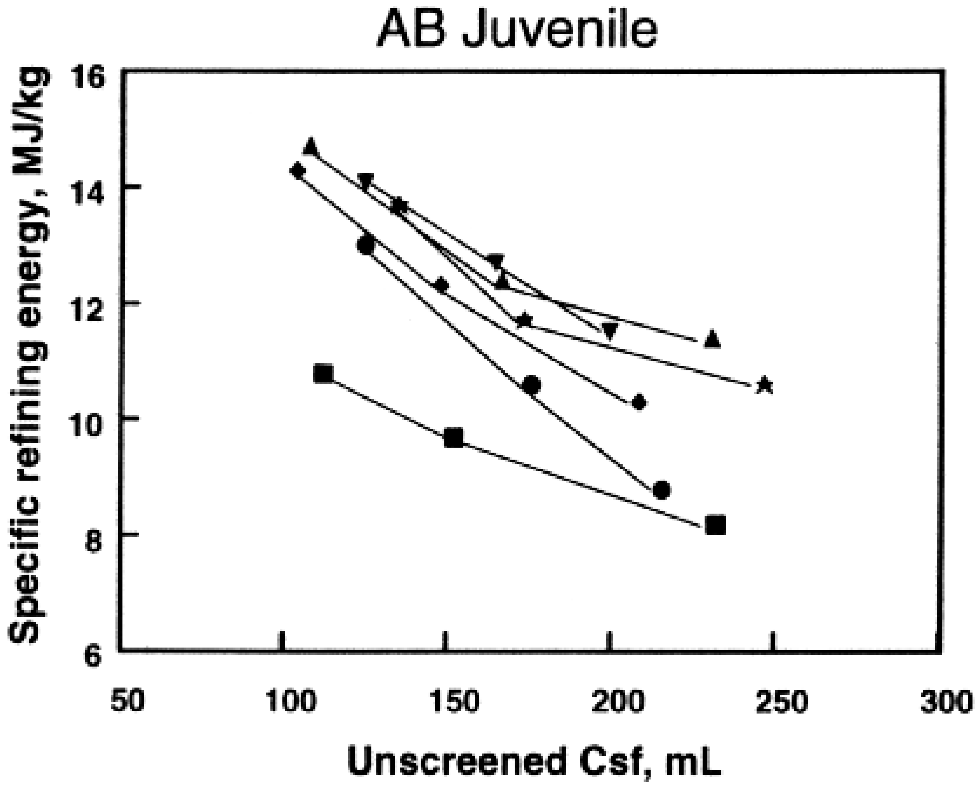

Figure 7. When the specific energies required to produce refiner mechanical pulps from the juvenile wood component of six lodgepole pine trees from Alberta are compared at 125 mL Csf, they range from 10.4 to 14.2 MJ/kg, a difference of 26.8%.

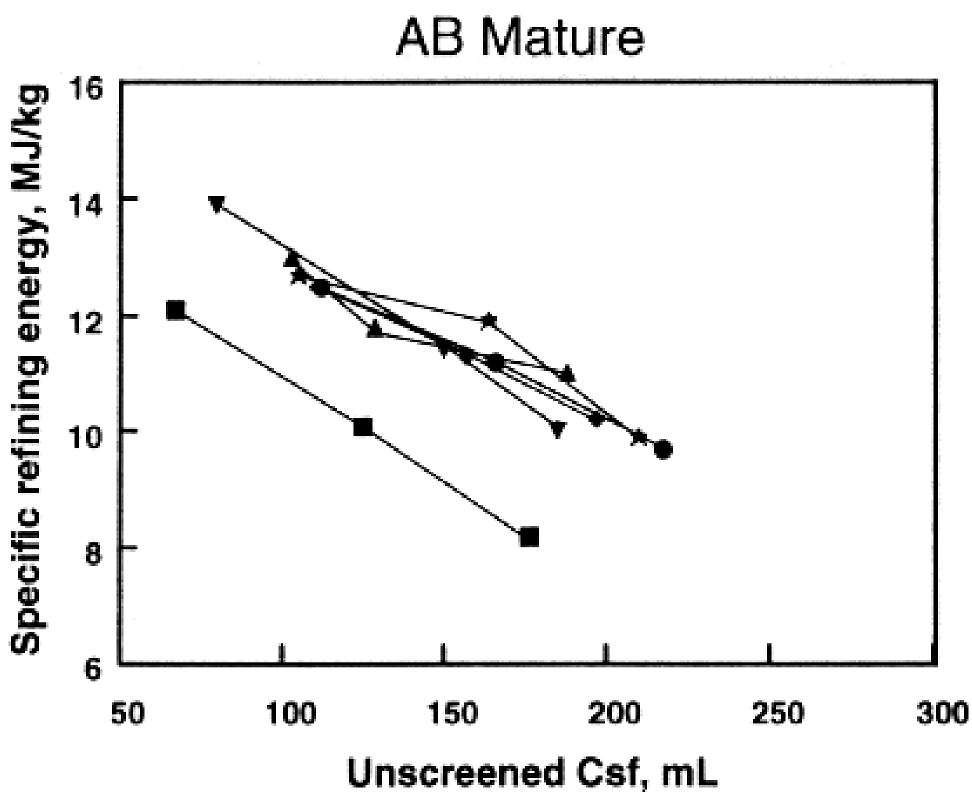

Figure 8. When the specific energies required to produce refiner mechanical pulps from the mature wood component of six lodgepole pine trees from Alberta are compared at 125 mL Csf, they range from 10.0 to 12.6%, a difference of 20.6%.

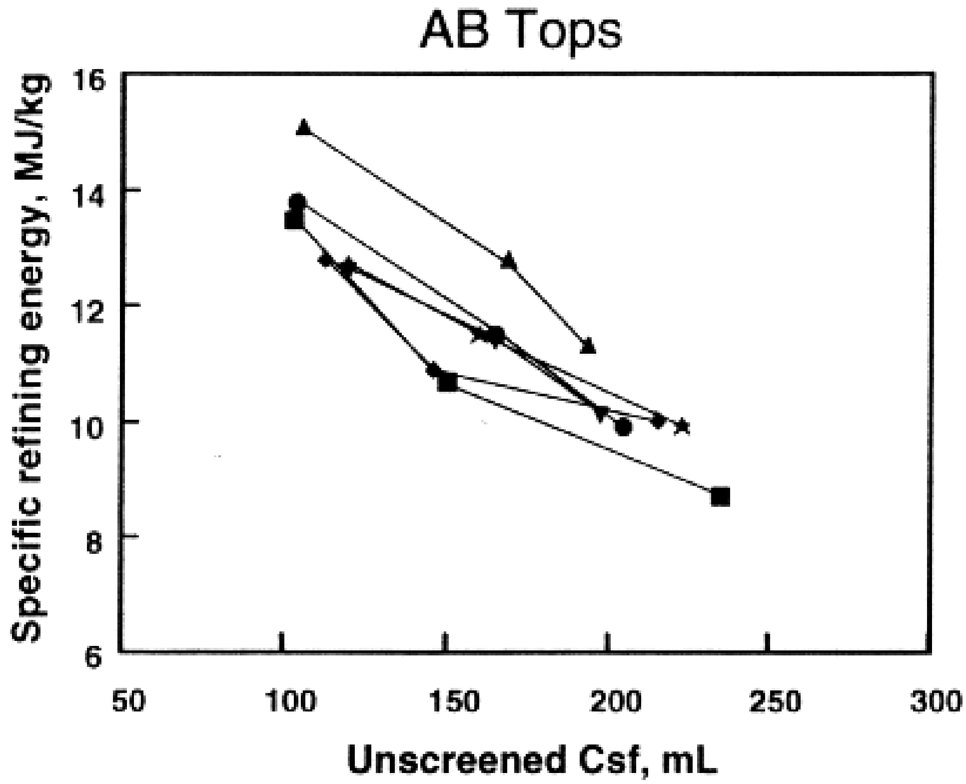

***Figure 9.** When the specific energies required to produce refiner mechanical pulps from the top wood component of six lodgepole pine trees from Alberta are compared at 125 mL Csf, they range from 12.0 to 14.6 MJ/kg, a difference of 17.8%.*

Province	*Tree component*	*Energy, MJ/kg (Low/high spread)*	*Difference, MJ/kg*
British Columbia	Juvenile wood	11.3 to 12.9	1.6
	Mature wood	9.1 to 12.0	2.9
	Top wood	10.2 to 12.4	2.2
Alberta	Juvenile wood	10.4 to 14.2	3.8
	Mature wood	10.0 to 12.6	2.6
	Top wood	12.0 to 14.6	2.6

***Table I.** Specific energy requirements to reach 125 mL Csf.*

These ranges are once again large. Using the same argument as earlier, the energy savings possible by refining the low energy compared with the high energy tree component amount to 12.4, 24.2, and 17.7% for JW, MW and TW from British Columbia, and 26.8, 20.6, and 17.8%, for the corresponding Alberta samples. Potential savings of specific refining energy of these magnitudes would clearly be of enormous benefit to mechanical pulp mills in Canada.

CONCLUSIONS

Re-examination of kraft and refiner mechanical pulping data from earlier published papers [15-17] on the quantification of differences between juvenile, mature and top wood from 12 trees of second-growth lodgepole pine from four sites, two in British Columbia and two in Alberta, have revealed the following:

- There were considerable between-tree differences in the yields of kraft pulps at Kappa 35 for all three tree components. The largest yield difference was 4.1%, od wood. These increases are incremental in kind and provide enormous benefits at essentially no additional cost.
- There were, similarly, large savings to be found by refining those trees which require low specific refining energies. The largest energy saving amounted to 26.8%.
- Similar trends to the above were shown by kraft and mechanical pulps from second-growth Douglas-fir and jack pine.

IMPLICATIONS

The lodgepole pine data discussed here strongly suggest that one approach to building the "second crop" would be to carry out an ongoing, intensive evaluation of selected[1] areas of the Canadian forest resource with the object of learning more about their wood quality and how variable it is (and why). Simultaneously, we must continue to identify opportunities for selection of seed for breeding trees suitable for specific end products, or with the capability to provide higher kraft pulp yields and/or energy savings in refining. Whilst this is a long-term approach, the serendipitous benefits of better understanding the resource in all its facets would allow Canada to compete with the rest of the world on a more even playing field. Remember, too, that the data here were obtained from 12 trees chosen without conscious bias. Therefore, evaluation of considerably more trees such as we have done in a recent western hemlock progeny trial would reveal even larger potential benefits than those described above [25].

Two questions come to mind. The first is how much of the between-tree phenotypical differences are attributable to genetic effects (i.e., different seed sources), and how much to environmental effects (i.e., different growing conditions)? This could be answered by conducting a well-planned progeny trial. The second question relates to the possibility of any relationship between the kraft pulp yield and energy data. Do the trees and wood components which give pulp yields at the high end of the scale also provide the greatest energy savings in mechanical pulping? Or will we (as has also been suggested by others) have to manage our resource with a specific end-product in mind?

If kraft pulp yield is plotted *vs* specific energy to 125 mL Csf for each of the three components JW, MW and TW, using the data shown in **Table II**, then the results are inconclusive.

[1] There is no evidence to suggest that the lodgepole pine data presented here would not be typical of Canadian softwoods. Accordingly, the argument for ongoing characterization of the resource should apply to all selected areas and to all species.

Tree component	*British Columbia*		*Alberta*	
	Pulp yield, % od wood	*Energy, MJ/kg*	*Pulp yield % od wood*	*Energy, MJ/kg*
Juvenile wood	46.2	11.7	44.6	10.4
	44.3	11.3	44.2	13.0
	47.7	12.1	45.5	14.0
	45.8	12.3	43.6	14.2
	45.2	11.4	44.9	14.1
	43.6	12.9	44.8	13.4
Mature wood	46.6	9.1	46.7	10.0
	49.7	11.2	47.0	12.2
	48.5	10.5	46.4	12.1
	48.9	11.2	46.1	12.6
	47.9	11.3	47.7	12.4
	48.2	12.0	46.4	12.2
Top wood	46.1	10.2	46.5	12.1
	46.9	12.4	46.9	13.0
	47.7	12.2	47.3	14.6
	47.6	11.3	47.1	12.5
	46.0	12.2	47.7	12.5
	46.6	11.2	46.2	12.0

[1] *Energies to 125 mL Csf*

Table II. Kraft pulp yields and specific refining energies[1] (to 125 mL Csf) for lodgepole pine JW, MW and TW.

It could be that there are insufficient data from which to answer this question or that no relationship exists, no matter how large the data base. It therefore remains unsolved, but must be addressed later.

ACKNOWLEDGEMENT

The author is grateful to Kelly Wadham, Pulp and Paper Research Institute of Canada, Vancouver Laboratory, for formatting the original text and for all artwork.

REFERENCES

1. Zobel, B. J. and van Buijtenen, J. P., *Wood Variation, its Causes and Control*, Springer-Verlag, Berlin, 1989, 363 pp.
2. Gonzalez, J. S., *Wood Density of Canadian Tree Species*, Forestry Can., Northwest Region, Northern Forestry Centre, Edmonton, AB, Inform. Rept. NOR-X-315, 1990.
3. Van Buijtenen, J. P., Alexander, S. D., Einsphar, D. W., Ferrie, A. E., Hart, T., Kellogg, R. M., Porterfield, R. L., and Zobel, B. J., *Tappi* 58(9): 129 (1975).
4. Eguiluz-Piedra, T. and Zobel, B. J., *Wood Fiber Sci.* 18(1): 68 (1986).
5. Palmer, E. R., *Appita* 38(3): 182 (1985).
6. Kibblewhite, R. Paul, *Appita J*. 52(6): 429 (1999).

7. Evans, Robert, Kibblewhite, R. Paul, and Lausberg, Marco, *Appita J.* 52(2): 132 (1999).
8. Campinhos, E., Jr., *Tappi* 63(11): 145 (1980).
9. Pereira, H. and Sardinha, R., *Appita* 37(8): 661 (1984).
10. Hunt, K. and Hatton, J. V., *Pulp Paper Can.* 96(11): T386 (1995).
11. Hatton, J. V., Hunt, K., and Gee, W. Y., *Kraft Pulping of Commercial Thinnings of Six Softwoods from New Brunswick.* Preprints, 1995 Spring Conf., Technical Section CPPA, Pacific Coast and Western Branches, Whistler, BC, May 18-20, 1995, Session 3B, Paper 1.
12. Hatton, J. V. and Johal, S.S., *Pulp Paper Can.* 97(12): T420 (1996).
13. Hatton, J. V., *Tappi J.* 80(1): 178 (1997).
14. Hatton, J. V. and Hunt, K., *Pulp Paper Can.* 94(12): T470 (1993).
15. Hatton, J. V. and Gee, W. Y., *Tappi J.* 77(6): 91 (1994).
16. Hatton, J. V. and Johal, S. S., "Refiner Mechanical Pulps from Second-growth Lodgepole Pine", Unpublished, 1993.
17. Hatton, J. V. and Johal, S. S., *Tappi J.* 78(6): 81 (1995).
18. Koch, P., Part I, Chapter 3, in "Lodgepole Pine in North America", a 3-volume text pub. by Forest Products Society, Madison, WI, 1996, 1096 pp.
19. Baumgartner, D. M. (Ed.). "Management of Lodgepole Pine Ecosystems". Symposium Proceedings held at Washington State University, Pullman, Oct., 9-11, 1973. Pullman Cooperative Extension Service, Wash. State Univ., 2 vol., 1975.
20. Baumgartner, D. M., Krebill, R. G., Arnott, J. T., and Weetman, G. F. (Eds.). "Lodgepole Pine: the Species and its Management". Symposium Proceedings, May 8-10, 1984, Spokane, WA and repeated May 14-16, 1984, Vancouver, BC. Pullman, Wash, State Univ., 1985, 381 pp.
21. Koch, P. "Lodgepole Pine in North America". Forest Products Society, Madison, WI, 1996, 1096 pp.
22. Hatton, J. V. and Hunt, K. TAPPI 1989 Pulping Conference Proceedings. TAPPI PRESS, Atlanta, p. 573.
23. Hatton, J. V. and Johal, S. S., *Proceedings of the 18th International Mechanical Pulping Conference,* EUCEPA, Paris, 1993, p. 32.
24. Hatton, J. V., *Tappi J.* 76(5): 105 (1993).
25. King, John N., Cartwright, C., Hatton, J., and Yanchuk, A. D., *Can. J. For. Res.* 28(6): 863 (1998).

Received: June 24, 2000
Revised: July 15, 2000
Accepted: October 23, 2000

This paper was accepted for abstracting and publication in the April 2001 issue of *TAPPI JOURNAL.*

TAPPI Website: www.tappi.org

APPENDIX

Kraft and Mechanical Pulping Data for Second-Growth Douglas-fir and Jack Pine

Data corresponding to those shown earlier for lodgepole pine are tabulated below for Douglas-fir and jack pine.

Kraft Pulp Yields at 5% Lignin Content

Species	*Tree component*	*Yield, % od wood (Low/high spread)*	*Difference, % od wood*
Douglas-fir	Juvenile wood	44.6 to 48.2	3.6
[22]	Mature wood	45.9 to 49.2	3.3
	Top wood	45.3 to 48.4	3.1
Jack pine	Juvenile wood	39.9 to 46.4	6.5
[24]	Mature wood	44.0 to 47.6	3.6
	Top wood	44.3 to 47.5	3.2

Specific Energy Requirements Reach 100 mL Csf

Species	*Tree component*	*Energy, MJ/kg (Low/high spread)*	*Difference, MJ/kg*
Douglas-fir	Juvenile wood	10.9 to 13.0	2.1
[23]	Mature wood	9.0 to 12.5	3.5
	Top wood	9.7 to 12.7	3.0
Jack pine	Juvenile wood	10.4 to 14.8	4.4
[23]	Mature wood	9.2 to 13.2	4.0
	Top wood	11.6 to 14.6	3.0

Both in terms of pulp yield and energy requirements, outstanding benefits and savings can result from a combination of knowing the wood and pulping characteristics of our resource much better than we presently do, and stocking our second crop forests with seedlings which will perpetuate these good traits.