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ABSTRACT

This paper describes a dynamic simulation model of energy production and use by pulp and paper mills. The model can be used to assess the costs and benefits of the use of different proportions of wood waste (referred to as 'hog fuel') and fossil fuels to generate process steam and electricity, with the costs and benefits measured from several points of view, principally those of the mill management and of the economy as a whole. Using either point of view, the model has been fitted to the eighteen major pulp and paper mills in British Columbia, and used to assess the consequences of the size and nature of optimal hog fuel projects. Some results are reported in this paper and references are given to other papers containing more complete results of various aspects of the research project.

INTRODUCTION

Whenever there are big changes in technology or relative prices, many of the standard rules of thumb for optimal choices fall apart, and many new alternatives have to be considered in a systematic way. This offers great scope for the design and use of simulation models that capture the key elements of an industrial process and expose the key alternatives for

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[1] This paper was presented to the conference on Simulation Modelling and Decision in Energy Systems, held in Montreal in June, 1978 and sponsored by the International Association of Science and Technology for Development. It represents early results of work also reported in [1], [2], [3] and [4]. While Helliwell is a continuing member of U.B.C.'s Department of Economics, Cox is currently at M.I.T.'s Energy Laboratory Cambridge, Mass.

optimal choice. We perceived that the recent rapid rises in the costs of fossil fuels and purchased electricity would be leading pulp and paper mills in British Columbia to redesign their burner, boiler, and electrical generation facilities so as to use more hog fuel and less fossil fuel, and to adopt higher boiler pressures and back pressure (or "topping") turbines to generate more electric power. We also knew that the amounts of energy production involved are verylarge, as the eighteen major pulp and paper mills have been responsible for about half of B.C.'s use of crude oil and natural gas and more than half of B.C. Hydro's bulk sales to industrial customers.

We therefore built a simulation model to spell out the key elements in the generation and use of energy within a pulp and paper mill, and to permit the economic evaluation of the causes and consequences of alternative energy decisions.

We have prepared a series of papers explaining and using the model. The main paper explaining the structure of the model, complete with listings of the equations and data for all the mills modeled, is [1]. In [2] we present results portraying the total fossil fuel savings from hog fuel projects, and do a preliminary analysis of the supply and demand conditions for hog fuel in each region of British Columbia. Both of these papers present results for all eighteen individual projects as well as for the province as a whole. In [3] we discuss the broader economic implications of a greater use of wood wastes as an energy source, and the various institutional barriers (e.g. existing energy pricing structures and natural gas distribution systems that depend on their pulp and paper mill customers) that inhibit changes that may seem otherwise to make economic sense for the main participants. In [4] we analyze the effects of electricity pricing on the likely scale and profitability of electricity generation by pulp and paper mills. We also plan some case studies that explain in more detail how the model applies to specific mills, and that relate the model results to recent hog fuel projects that have been, or are being, undertaken.

In the current paper, which focuses on the joint use of simulation and optimization in the evaluation of alternative projects, we first explain our modelling strategy, and then outline the basic structure of the model. We shall then illustrate how optimization from private and public points of view can be compared to reveal the costs and benefits of various energy pricing and taxation policies that cause divergences between privately and globally optimal decisions. We proceed to provide a more detailed example of the scope for optimization by mills, by providing examples of different boiler pressures. This leads quite naturally to the final main section outlining the considerable scope remaining for broadening the range of possibilities covered by endogenous optimization in the model.

MODELLING STRATEGY

We have adapted for our purposes a simulation programme [5] designed originally for quarterly macroeconomic models. Our modelling strategy, like that in an earlier simulation study of the effects of taxes and royalties on optimal mine development decisions [6], has been to combine an explicit and rather complex modelling of the dynamic consequences of an investment decision with the capacity for finding an optimal investment strategy from among some pre-defined set of possibilities. The programming structure for this process is crudely simple, but we have found it very flexible and not excessively costly.

The starting point in our strategy is to construct a simple model of the key elements, taking many factors as given. In the present application, we take as given the product mix of the pulp and paper mill and the steam and electricity requirements for each type of output. For any predetermined choice of fuel mix, boiler pressure, and generator size, the equations of the model determine the energy inputs and outputs, and the flow of costs and benefits to the pulp and paper mills, their energy suppliers and the taxing authorities. These calculations are all conditional on a given price structure for the various types of energy bought or sold by the firm. The costs and benefits are cumulated forward through the lifetime of the fuel project and, finally, discounted back to form present values in the year of decision.

The optimization has been built into the program by means of a grid search over a feasible range of values for the predetermined choice variables. The crudeness of this optimization procedure is justified in part by the low and declining cost of computing power, in part, by the great variety of model structures that can be easily and comparably assessed,and partly by the descriptive richness of the model output. The latter point may require illustration. The grid search procedure permits us to prepare 'valuation surfaces' or contour maps of present values, from any number of points of view, all from the same set of model simulations. Thus it is possible to identify at once the optimal solutions from the point of view of each participant, and to ensure their uniqueness (if the valuation surfaces are smooth enough and the grid search uses a sufficiently fine mesh and a suitably broad scope). The valuation surfaces can also be used to measure the degree of preference that each participant has for his optimum choice relative to the results that would flow were the decision left to some other participant or to some rule of thumb.

Another important feature of our modelling strategy is to proceed from simpler to more complicated models of the process, in each case making additions and improvements to the model in those areas which past simulations have shown to be of considerable importance. In this way we attempt to conserve both modelling effort and computing resources by treating with greatest care those features of the process that we find to be crucial to the accuracy of the results.

MODEL STRUCTURE

Following the general strategy outlined above, we have developed a model with approximately 100 endogenous variables explaining the determinants and consequences of energy production decisions for B.C. pulp and paper mills. The model is described in detail in [1]. To apply the model to a specific mill, we use 27 coefficients describing its product mix, the degree of seasonality of its heat requirements, the nature and size of its current burner, boiler, and electrical generation facilities, and the amount of combustible residue produced from the chemical pulping process. Other coefficients and exogenous variables, which are the same for all mills, include the levels and expected rates of growth of fossil fuel and electricity prices to the mill, the general rate of inflation, the opportunity costs of fossil fuels and electricity for the economy as a whole, the purchase prices for burners, boilers, and generators of different sizes and specifications, and the opportunity costs of capital for the firm and for the economy as a whole.

There is a third set of project-specific coefficients, which can be altered from simulation to simulation with an optimizing run, that set the pressure of the power boiler, the proportions of hog fuel and fossil fuel to be used in the burner, and the amount of electrical generation capacity to install, measured as a proportion of the peak amount of available steam to generate electricity by non-condensing (back-pressure) turbines.

Once all the coefficients are set, and a date is chosen for the project to come on stream, the dynamic simulation run proceeds. For the given product mix, fuel mix, boiler pressure, and desired electrical production, the equations of the model determine heat requirements, and the sizes of the required burners, boilers and generators. The cost functions of the model (which are based on data from recent projects) then determine the capital costs, and the investment expenditures are triggered with the appropriate lead time before the target completion date. Corporation income taxes are calculated for each year according to established tax rates and capital cost allowances. After the project comes on stream, the amount of various types of energy produced are accumulated, allowing their values to be appropriated amongst the parties; British Columbia, for instance, being allotted the export value of natural gas displaced by hog fuel. As noted in the previous section, the costs and benefits to each participant are accumulated forward year-by-year and then discounted at the end of each simulation.

In setting up the model, we have made it possible to consider the replacement of fossil fuels by hog fuel separately from the use of hog fuel to generate extra steam for the purpose of generating electricity. Of these two aspects of hog fuel projects, the use of additional hog fuel (and, to some extent, fossil fuels) to generate electricity presents the most complex optimization problems. This is in part because of the complexity of electricity rate structures, with separate capacity and energy charges, and with separate prices for purchase and sales. (These issues are dealt with in [4]). Another reason for the complexity is that a choice needs to be made about the best boiler pressure, the scale and type of electricity generation, and the seasonal pattern of electrical generation. These are issues that we shall discuss in more detail in this paper, as they illustrate some of the potential uses of a simulation model in an optimizing mode, and expose some areas where the model structure could and should be enriched.

OPTIMIZATION FROM TWO POINTS OF VIEW

A key feature of our use of a series of simulation results to construct present values of alternative projects is that we can easily see divergences in optimal decisions between participants with different points of view. As in [2], the two main viewpoints we use are those of the firm making the decision and of the economy as a whole. This provides a helpful way of assessing various public policies, e.g. tax incentives and regulated energy prices, in terms of their failure or success in encouraging optimal private decisions that are also optimal, or nearly so, when seen from the viewpoint of the economy as a whole. One of the attractive features of our strategy is that we can quantify the total and private economic gains from alternative policies, and measure the potential gains from further changes. This strategy seems applicable to a fairly broad range of problems.

Another valuation issue is more specific to the assessment of hog fuel projects. We have a choice about how to measure the net value of the project. On the one hand, we can assume some cost for wood (which may be negative if disposal costs are thereby eliminated) and then compute the net present value of the project to the various participants. Alternatively, we can translate the present value of the project into a shadow price for hog fuel - a value that indicates how high a price could be paid for hog fuel and still have the project be worthwhile. When the latter procedure is used, we must recognize that the average unit value of hog fuel is not an appropriate goal of optimization. From the point of view of the firm, the optimization must be based on the net present value of the project with hog fuel utilized until its marginal value (not its average value) is equal to its marginal cost. This implies that the optimal choice of hog fuel project for each firm cannot be made until the marginal value of hog fuel is known (at each location, as transport is expensive). The marginal value of hog fuel, however, may depend on the hog fuel supply and demand decisons by other mill operators, by sawmills, by other users of wood wastes, and by logging firms deciding how much of the tree to bring out of the bush.

Thus there is a sense in which the autonomous evaluation of the individual hog fuel projects is not possible. This suggests that at some stage it would be useful to link our eighteen separate mill models into a geographically explicit model of hog fuel supply and demand. This would permit us to test the degree of interdependence between the optimal choices and to see whether coordinated decisions could produce better results for all the parties. We are likely to find, however, that the serial nature of the decision, the committments implied by past decisons, and the large distances separating the mills, are such that the individual mill decisions are likely to be importantly interdependent within certain regions. We have made some tentative analysis of this sort in [2].

Table 1

RESULTS OF SIMULATIONS ON EXAMPLE PULP AND PAPER MILLS

Characteristic	[1] P.V.to Firm at 600 p.s.i.(10^6 1978 dollars)	[2] P.V.to Firm at 1250 p.s.i.(10^6 1978 dollars)	[3] Total P.V. at 600 p.s.i.(10^6 1978 dollars)	[4] Total P.V. at 1250 p.s.i.(10^6 1978 dollars)	[5] Avg.Cost of Elec. at 600 p.s.i. mills/kwh	[6] Avg.Cost of Elec. at 1250 p.s.i. mills/kwh
(1) Base Case	10.24	11.13	38.32	44.89	8.8	10.0
(2) Low Cost for 600 p.s.i. Boiler	11.16	6.85	40.73	35.11	8.0	12.6
(3) Increased Seasonal Oscillations in Heat Requirements	8.89	8.92	36.56	41.84	9.15	10.6
(4) Lower Proportion of Non-condensing Potential Used	9.09	9.25	35.59	40.45	8.93	10.33
(5) Kraft Mill with Large Seasonal Oscillations in Heat Requirements	7.29	5.27	31.08	34.57	9.38	10.67
(6) Kraft Mill, Large Oscillations, Some Hog Burners & Generators on Site	0.75	2.39	23.29	23.83	9.96	11.16
(7) Newsprint/Kraft Mill, Small Oscillations, Some Hog Burners & Generators on Site	0.18	0.08	18.9	20.24	10.00	10.87

CHOICE OF BOILER SIZE AND PRESSURE: SOME EXAMPLE RESULTS

In this section we illustrate how our model can be used to disentangle some of the many factors that influence the optimal choice of boiler size and pressure for using hog fuel to generate electricity. We shall proceed in two stages, first explaining the model by means of an example mill, and then presenting a table of results covering all eighteen mills.

We shall start by presenting the results from the model's evaluation of 600 p.s.i. and 1250 p.s.i. boilers for an example mill. These are shown at the top of Table 1. There are six columns, which show four present values of the electricity generation project and two average costs of electricity produced, in mills/kwh (1 mill = $.001). The costs relate to two alternative electricity generation projects, one using a 600 p.s.i. boiler and the other a 1250 p.s.i. boiler. For each of these alternative projects, there are two present values calculated in millions of 1978 $. The present value to the firm is based on the reductions in the firm's B.C. Hydro bill, and the sales of any surplus electricity to B.C. Hydro, less the net capital and operating costs of the project, making due allowance for the effects of corporation income tax, 40% partial debt financing for the project, and 7.5% average real after-tax cost of capital to the firm.

The total, or social, present value of the project, as described in the last section, has as its 'revenue' the cost of additional electrical capacity and energy projects built by B.C. Hydro, and the cost of capital is based on its estimated real yield (7-1/2% after-tax and 3% in corporation taxes) if invested elsewhere in the economy. Thus the social value of the project involves a higher rental price for capital, and a higher value for power produced (unless the rate at which B.C. Hydro sells electricity is set equal to B.C. Hydro's marginal cost of producing electricity), but does not make any separate allowance for corporation income taxes on the revenues from the project.

The example mill modelled in the first row of Table 1 is assumed to have a coastal location (and hence only a small seasonal fluctuation in process heat requirements); a product mix of 60% newsprint and 40% kraft pulp (and hence a relatively high demand for electricity relative to process heat); an average electrical load of 86 megawatts (MW); and no existing investment in hog fuel burners or electrical generators. In both the 600 p.s.i. and and 1250 p.s.i. base cases, the firm chooses to generate only non-condensing power, and to install electrical generation capacity sufficient to utilize 98% of the maximum non-condensing capacity available when process steam requirements are at their seasonal peak. Our base case involves capacity sufficient to fully utilize the summer generation potential plus 80% of the amount by which the winter's peak potential exceeds the lowest summer potential. The generator is therefore less than fully utilized at any time during the year when steam requirements are less than 98% of their winter peak. In the example mill, the lowest summer heat requirement is about 95% of the winter peak, which, since the seasonal heat requirements are modelled to follow a cosine function with winter peak and summer trough, means that, in this case, the generator is less than fully utilized for about 70% of the year, and its annual average utilization is 98%.

The base case results at the top of Table 1 show that the social and private values of the project are both higher for the 1250 p.s.i. case than for the 600 p.s.i. case, and that the average cost of electricity produced is higher for the 1250 p.s.i. project than for the 600 p.s.i. project. There are two offsetting factors affecting the average cost of power as we move from 600 p.s.i. to 1250 p.s.i. boiler pressure. On the one hand, the use of a 1250 p.s.i. pressure boiler provides about 30%

more generation capacity than does the 600 p.s.i. boiler, for any given peak requirement for process steam. The generator must be increased in size from 33 MW to 43 MW as we move from 600 p.s.i. to 1250 p.s.i. under the base case conditions. Because of the economies of scale in our cost equation for generators, this makes the 1978$ cost of the generator rise only from $5.7 million to $6.6 million. The effect of this factor is to reduce the average cost of electricity as we move from 600 p.s.i. to 1250 p.s.i.

On the other hand, the ability to generate more electricity also increases the required size of the boiler, even though the heat-conversion efficiency of back-pressure turbines is very high (about 80%), the extra steam energy for generation must nevertheless be provided. The peak boiler capacity required increases from 962 thousand lbs/hr. to 997 thousand lbs/hr., increasing the capital costs of burner and boiler complex from 26.7 million 1978$ to 31.3 million 1978$ in the sample case. However, since the thermal efficiency of the generation is not modelled to depend on the steam pressure used, and since our B.C. data do not indicate economies of scale in the capital costs of the burner and boiler (see[1]), there is no change in the average cost of power coming from the change in the size of the boiler.

However, there is some evidence ([7] p.11-19; [8] p.C-13; [9] p.3-17) that the capital cost of the burner and boiler complex does depend on boiler pressure. In our base case assumptions we have followed [7] and [8] and assumed the capital costs of 600 p.s.i. boilers to be 10% less than those for 1250 p.s.i. boilers, for any given size measured in lbs/hr. of steam capacity. The higher capital cost for 1250 p.s.i. boilers tends to raise the average cost of electricity.

The average cost figures in the first row of Table 1 are higher for the 1250 p.s.i. case than for the 600 p.s.i. case, showing that the 10% lower capital costs for 600 p.s.i. boilers more than offset the economies-of-scale effect on generator costs. The marked increase comes about because the 10% higher capital costs for the 1250 p.s.i. boiler apply to the entire boiler while only a relatively small fraction of the steam generating capacity (about 16%)is used for electrical generation rather than for process heat. Our model allocates the extra costs of a 1250 p.s.i. boiler relative to a 600 p.s.i. boiler (of a size just sufficient to provide the process heat requirements) entirely to the costs of electrical generation, on the presumption that the higher pressure boiler would only be chosen because of its greater potential for generating electricity.

Despite the higher average cost of electricity in the 1250 p.s.i. case, the present values (PV) of the 1250 p.s.i. project, for the base case shown in the first row of Table 1, are higher than for the 600 p.s.i. case, for the firm as well as for the economy as a whole. What this implies is that the marginal cost of the extra electricity generated by choosing 1250 p.s.i. rather than 600 p.s.i. boiler pressure is less than B.C. Hydro's average price for electricity and B.C. Hydro's costs for new generation projects.

The top row of Table 1 shows that the relative costs of electricity pressure boilers have an important impact on the relative costs of electricity from 1250 p.s.i. and 600 p.s.i. projects. The second row of the table shows that if the 600 p.s.i. boilers are one-third cheaper than the 1250 p.s.i. boilers (as might be inferred from [9], p. 3-17), the average cost of electricity from the 1250 p.s.i. project is 50% more than that for the 600 p.si. project. With the average cost of power produced rising from 8 to 12.6 mills, with the average amount of power produced rising by less than 30%, the marginal cost of the extra electricity from the 1250 p.s.i. project is of the order of 28 mills, in terms of 1978 dollars. This is about twice B.C. Hydro's announced 1980 price of electricity to bulk users (converted back to 1978 prices using the inflation forecast in [10]), and is about 4 mills more than our estimate of the marginal cost of B.C. Hydro's new generation projects. As a consequence, the present value of the 1250 p.s.i. project is lower than that of the 600 p.s.i. project, both for the firm and for the economy as a whole.

For the remainder of Table 1, we return to the cost assumptions of the base case and study various mill and project characteristics that influence the relative attractiveness of different boiler pressures and sizes.

In the third row of the table, we raise the seasonal fluctuations in heat requirements to a ratio more typical of mills in the B.C. interior. If winter peak requirements are about double the lowest summer requirements, and if the mill continues to install electrical capacity sufficient to utilize all of the summer capacity and 80% of the excess of winter peak over summer trough capacity, then power costs rise and present values drop, as shown in the third row of Table 1. Although the average heat requirements, and hence the average potential for electricity generation, are the same as in the base case, the average utilization of the boiler and generator is bound to be less than if there were less seasonality in the heat requirement. This lowers the profitability of any generation project, and tends to damage the PV of the 600 p.s.i. case less than that of the 1250 p.s.i. case. There is a bright spot, however, as the greater seasonality of the electricity means that the projects add more winter capacity to the British Columbia electricity supply system, and the winter is when the value of power is greatest. Neither B.C. Hydro's rates nor our estimate of marginal costs involves an appropriate premium for winter power production, so that our results slightly understate the advantages of electricity production in interior mills.

Our next experiment shows that for mills with highly seasonal heat requirements it is advantageous for the firm to cut the size of the boiler and generator in order to increase the average degree of utilization. For the fourth, fifth, and sixth rows, all of which refer to a mill with highly seasonal heat requirements, we have installed generation capacity only sufficient to utilize the average capacity to generate non-condensing power. This means that the generator and associated extra boiler capacity are fully utilized for half the year. As can be seen by comparing the third and fourth rows, this slightly cuts the average cost of electricity and also increases the PV of the 600 and 1250 p.s.i. projects from the point of view of the firm. Note that the PV of both the 600 and 1250 p.s.i. projects is decreased from the point of view of the economy as a whole. This implies that the marginal cost of power involved in moving from the fourth row to the third row is more than B.C. Hydro's selling price for electricity but less than the cost of new electricity to B.C. Hydro.

In the fifth row we start with the assumptions used in the fourth row and shift the product mix to include just kraft pulp and no newsprint. This dramatically drops the average electrical load of the mill, from 86 MW to 25 MW, because newsprint production uses much more electricity than does kraft pulp. This in itself lowers the PV of the project to the firm (but not to the economy as a whole) because the price B.C. Hydro is willing to pay for power that is surplus to the mill's own needs (8 mills at 1979 prices) is less than what the mill has to pay for power. The large heat requirements for the production of kraft pulp, relative to their own electrical requirements, results in kraft mills generally having a non-condensing potential surplus to their own electrical requirements.

However, the results in row 5 show that the average cost of power does increase, for the kraft mill, and the total PV's are lower than for the base case mill with 60% newprint production. There are two reasons for this. On the one hand, the average amount of process steam required is lower, thus making the generator smaller and therefore slightly more expensive per unit of electricity produced. Furthermore, the kraft mill produces more combustible residues that produce steam in the recovery boiler. This steam from the recovery boiler is available in roughly equal quantities all year, and thus increases the seasonality of the steam requirements from the power boiler, increasing the seasonality and the average costs of electrical generation.

In the sixth and seventh rows, we show the effects on costs and profitability if the mill already has 600 p.s.i. boilers and some generators are already installed. Row 6 is like row 5, except that 6 MW of electrical capacity are already installed and the mill already has a 600 p.s.i. hog fuel boiler providing half its steam requirements. Row 7 is like the base case in row 1, except that in row 7 there are 15 MW of capacity already installed. Again, half the mill's steam comes from lower pressure hog fueled boilers. The existence of some already installed capacity means that the new project is smaller, and has to absorb more seasonal steam flows (because the existing project gets access to the even flow of the 'base' stream).

Note that the results in rows 6 and 7 show very low present values to the firm yet still have very substantial present values from the view point of the economy as a whole. This indicates, as our mill-by-mill results in Table 2 show in a more striking way, that post and current electricity pricing policies by B.C. Hydro have created a large discrepancy between the optimal choices as seen by firms and those as seen from the economy as a whole. As a consequence, firms have chosen boiler pressures and generator sizes that are below those that are optimal from society's viewpoint. This means not only that the existing level of electrical generation in pulp and paper mills is less than it should be (relative to the costs of generation by B.C. Hydro), but also that the scope for profitable future projects is constrained by the existing stock of boilers and burners.

Table 2 shows results for all of the 18 pulp and paper mills in British Columbia. We have also indicated the chief characteristics of each mill, including;

a) in column 1, the proportion of kraft (or sulphur) pulp and kraft paper produced at the mills,

b) in column 2, the proportion of heat required in the summer over heat requirement in the winter,

c) in column 3, the resulting usual electric capacity required,

d) in column 4, the current steam generation from hog fuel and recovery boilers as a proportion of total steam requirements for process heat;

e) in column 5, the current installed electric generation capacity,

f) in column 6, the non-condensing potential from a new 1250 p.s.i. wood-waste-fired boiler to replace 85% of fossil-fuel consumption, and

g) in the remaining columns, the present values and costs due to the production of electricity.

These facts about the mills, when combined with our earlier discussion about the cases examined in Table 1, should help to explain the large mill-to-mill variations in the profitability of expanded electrical generation. The gas-burning mills are almost all in the interior of the province (with the exception of Prince Rupert and Kitimat),

Table 2

Mill	(1) % Kraft	(2) Summer Winter Heat Ratio	(3) MW Req-uired	(4) % Heat from Wood & Rec. Boiler	(5) Current Gener-ation Cap. (MW)	(6) N-C Poten-tial (MW)	(7) Pr. P.V. 600 p.s.i.	(8) Social P.V. 600 p.s.i.	(9) Pr. P.V. 1250 p.s.i.	(10) Social P.V. 1250 p.s.i.	(11) Avg. Cost 600 p.s.i.	(12) Avg. Cost 1250 p.s.i.
							10^6 1978 Dollars				1978 mills/kwh	
GAS CONSUMING MILLS												
Castlegar	100%	59%	18.0	47%	1.8	27.4	2.0	17.5	1.2	18.4	11.7	12.0
Kamloops	100%	80%	37.5	48%	31.0	49.5	-2.4	9.6	-2.6	9.9	14.0	14.4
Kitimat	100%	100%	35.1	0%	0.0	37.5	8.7	31.7	10.1	40.7	9.7	9.2
Northwood	100%	80%	21.6	8%	20.0	31.2	-2.3	0.9	-2.3	4.0	20.7	17.1
Mackenzie	100%	73%	17.4	30%	0.0	26.2	4.0	19.1	3.7	22.5	11.6	10.9
Pr.George	100%	73%	44.9	20%	0.0	65.3	11.7	51.5	12.3	61.9	9.9	9.7
Pr.Rupert	100%	100%	33.5	19%	34.0	52.8	-2.0	8.3	-1.5	15.9	14.0	11.9
Quesnel	100%	81%	22.5	53%	28.0	29.2	-1.1	-2.2	-1.0	-2.2	65.1	58.7
Skookumchuk	100%	87%	13.8	0%	0.0	17.9	2.6	12.4	2.7	15.9	11.6	11.0
OIL CONSUMING MILLS												
Crofton	61%	100%	80.9	19%	0.0	54.8	12.4	48.0	16.0	61.1	9.7	9.4
Elk Falls	59%	100%	82.0	36%	0.0	55.4	13.5	51.9	16.4	62.6	9.4	9.2
Gold R.	100%	77%	21.7	29%	0.0	26.2	3.4	20.6	3.9	23.2	11.1	11.1
Harmac	100%	80%	39.7	28%	27.0	58.8	-3.4	18.6	-3.5	23.7	12.8	12.4
Port Alberni	32%	100%	91.8	73%	27.5	35.9	-1.6	6.1	-1.6	6.1	13.6	13.7
Port Alice	100%	100%	12.4	15%	12.0	19.4	-1.7	-1.2	-1.8	3.8	26.6	16.2
Port Mellon	100%	72%	12.3	27%	0.0	28.3	1.6	20.3	1.5	24.3	11.5	11.3
Powell R.	15%	100%	136.2	50%	33.0	36.2	-1.5	-1.9	-1.6	-0.4	34.9	23.4
Woodfibre	100%	100%	18.0	30%	5.5	27.3	1.8	15.6	3.9	21.4	11.6	10.9

and hence tend to have more highly seasonal heat requirements than the oil-burning mills.

The results in Table 2 are shown for 600 and 1250 p.s.i. cases, and all employ the Table 1 base case assumption about the proportion of non-condensing generation potential that is to be utilized. From our discussion about Table 1, it should be clear that the circumstances of individual mills differ enough that there is scope for explicit optimization for each mill covering boiler pressure (600 p.s.i., 1250 p.s.i., probably 900 p.s.i., and possibly some pressure above 1250 p.s.i.) and the proportion of non-condensing generation to be utilized. The results of this optimization would obviously not be independent of the cost of hog fuel, so that care must be taken to develop a more precise view of the supply and demand conditions for wood wastes in the region surrounding each mill.

SCOPE FOR FURTHER OPTIMIZATION

In addition to the optimization over two choice variables described in the last section, there are several ways in which our model could be developed to permit further optimization. Some possibilities include:

1. Mixing condensing and non-condensing power in some proportions. One possible alternative to our base case, one which is adopted in [7], is to build a boiler and generator large enough to fully utilize the seasonal peak requirements for steam, and then use the potential surplus steam at other times of the year to generate electricity, with condensers used to handle the exhaust steam from the generators. Condensing power is not thermally efficient

compared to non-condensing power, but it does make fuller use of the boiler and generator, and can be economically advantageous, if the costs of condensing facilities are not too high and if there is an excess supply of hog fuel that would otherwise require disposal.

2. By-passing the generator at times of peak demand for process steam. This provides some potential for increasing the average utilization of generator, burner, and boiler.
3. Altering the proportion of fossil fuel in the burner mix. In our current modelling, we take as fixed at 15% the proportion of fossil fuel use required to stabilize and optimize burning. This fraction is no doubt variable and subject to some further optimization.

The examples above by no means exhaust our list, but they at least illustrate our view that our current model has taught us enough that further investment in research would be worthwhile.

CONCLUSION

In this paper we have faced the familiar problem of rendering a brief explanation of a fairly complex model of an unfamiliar process. We have found that the model provides, through its simulation capabilities, the material for a methodical explanation and exploration of the properties of a highly interdependent process. By testing various aspects of the model's structure, we are able not only to understand it better, but also to see where explicit optimization is needed and where further model developments are likely to have a high payoff. In the course of this process of model development, we have also managed to learn a good deal about the economic potential for using wood wastes as an energy source.

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