DIRECT CONSUMPTION OF PETROLEUM PRODUCTS IN PINUS RADIATA THINNING IN AUSTRALIA

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ABSTRACT

Harvesting, the largest consumer of energy in **Pinus radiata** D. Don plantation operations, is dependent on liquid fuel. While petroleum supplies are expected to be adequate until well into the twenty-first century, real prices for petroleum products are expected to show a steady rise. Assuming a merchantable stem mass of 0.15 tonne/tree and a haul distance of 50 km, mechanised harvesting appears to require considerably more fuel than traditional chainsaw-based systems. However, increases in mean tree size, haulage, or worker travel distance, favour the mechanised system. As petroleum fuel accounts for only 11% of total harvesting cost, a number of other operating factors are at least as important as the price of oil, or even more important.

WORLD OIL CONSUMPTION

Supplies of liquid fossil fuels are finite and their exhaustion is forseeable in a time scale not dissimilar to that of a radiata pine rotation. For this reason it is useful to consider the world oil trade situation as a background to any evaluation of energy consumption in harvesting of plantations. The rapidly increasing world oil prices during the decade of the 1970s slowed this expansion.

The long-term decline in the real price of oil until the 1970s led to an expansion in the use of oil, both to meet energy demands of rapidly growing western industrial economies, and because oil was being used in preference to other energy sources even (in such uses as electric power generation and ship propulsion) where coal had previously been used.

In 1965 oil supplied 42% of the world's energy needs. By 1980 this had grown to 47% (EXXON 1980) but oil is expected to become a very scarce commodity in the next half-century. Man has used about 40% of the oil so far discovered, three-quarters of it in the last 20 years. Over the last decade the rate of discovery of new oil has been 60% of the rate of consumption; also the expense of finding and producing new oil in ever harsher and more remote environments is increasing. For these two reasons – scarcity and cost of production – further rises in the price of oil can be expected. Saddler & Ulph (1979) suggested long-term average annual rises of between 1.7% and 3.6% over the period to 2005.

As a result of its increasing cost, energy is being used more efficiently. By 1979 the United States' energy consumption per unit of Gross National Product had declined 7% from the high average levels of the 1960s, Japan's by 9%. Projections for the year 2000 are for a fall of 33% in consumption of oil for the United States, 19% for Japan, and 39% for Europe (EXXON 1980). Despite this reduction in energy-use intensity, even the predicted slow growth of the world economy will lead to an expansion in energy consumption from about 140 million barrels/day (oil equivalent) in 1980 to 225 million barrels/day in 2000 (EXXON 1980). Oil price and physical scarcity are likely to ensure that most of this additional energy demand is met from alternative sources, i.e., coal, synthetic oil, or nuclear power, but even if the total oil demands of the Western industrial countries decline as expected, the EXXON projection of more rapid industrial growth in the developing countries will, if realised, add about 16% to the current oil demand by the turn of the century.

Australia is presently two-thirds self-sufficient in oil. Even with substantial discovery (2600 million barrels, rated 50% chance by Bureau of Mineral Resources) we will need to import 85% of our projected oil requirements by the year 2005 (N.E.A.C. 1980). Oil is a major trade commodity, and it is unlikely to "run out" world-wide during this century. Since Australia has a policy of parity with world prices for domestic oil, a change in proportion of domestic to imported oil would go largely unnoticed by the domestic consumer. Furthermore the effect of this transition on the balance of payments need not be serious because of Australia's potential as a coal exporter, which should allow a net surplus in the balance of payments on energy products. The transition would, however, be felt in the level of the exchange rates and in the decline of the central Government's "old oil" tax base. Over-all, the impact at the national level can be expected to be important, but not catastrophic.

OIL CONSUMPTION BY FORESTRY

Using data supplied by the New South Wales Forestry Commission and private contractors, Ferguson & Wells (1980) calculated the fuel usage in 1977–78 for plantation management and harvesting of a *P. radiata* plantation in the Tumut sub-district. Their figures show that liquid fuel costs, including the cost of fuel used by workers to travel to and from the job, were about 4% of the total expenditure on all operations.

Table 1, adapted from Wells (1981), projects total energy expenditure for a first-rotation *P. radiata* plantation based on the observed energy consumption for the Tumut plantation. The rotation length is assumed to be 40 years and the total yield 776 t/ha. Both direct and indirect energy are included in total energy consumption. Indirect energy is largely that used in the manufacture of machines and their replacement parts or consumables (tyres, etc.) and is accounted for by methods similar to those used by accountants for depreciation and repair and maintenance expenditure. For example, the energy embodied in the steel and the manufacture of powered machinery is about 88 MJ/kg and this is assumed to be "expended" in equal instalments over the projected operating life of the machine. Harvesting accounts for 79% of the estimated total energy consumption.

TABLE 1—Estimated total energy consumption for the first rotation

Operation	Energy/ operation (GJ/ha)	Operations/ rotation	Energy/ rotation (GJ/ha)*	Fraction of total (%)
Roading	16.03	1	16.0	7
Road maintenance	1.08	6	6.59	3
Site preparation	12.67	1	12.8	6
Nursery	0.47	1	0.5	
Planting	0.63	1	0.6	1
Tending	0.27	2	0.5	
Pruning	2.24	2	4.5	2
Protection	0.09	40	3.7	2
Harvesting:				
Pulplog-only thinning	0.36†	86 t‡	30.6	
Mixed sawlog and pulplog thinnings	0.29†	130 t‡	37.1	79
Sawlogs-only thinning and clearfelling	0.19†	560 t‡	104.7	

* These figures were calculated from basic data using more significant figures than reproduced in Column 1

† GJ/t

‡ Total tonnes (wet) extracted per rotation

The data in Table 2, drawn from the same paper, provide values for direct energy in fuels, oils, and lubricants required for the same hypothetical rotation. The harvesting operation has by far the largest requirement for petroleum products. Even in the first rotation, where site preparation and roading might be expected to be at their most expensive, harvesting accounts for 83% of the total petroleum required for all forestry operations. If petroleum consumption for site preparation and roading were one-quarter of their given values in the second rotation, on current consumption patterns harvesting *P. radiata* would consume about 90% of the total petroleum required for plantation forestry.

Figures in Table 2 were based on conventional motor-manual felling and conversion, subsequent extraction and loading of logs by forwarder, and transport to mill by semi-trailer.

FUEL USE OF TWO THINNING SYSTEMS

Gasslander *et al.* (1979) suggested that, in Swedish forests, a conventional mechanised system of logging has higher energy requirements than a motor-manual system, and that both are strongly influenced by the average size of trees processed. Since the first pulpwood-only thinning consumes more petroleum products per unit output

TABLE 2—Estimated total direct liquid-fuel energy consumption for a first rotation

Operation	Energy/ operation (GJ/ha)	Operations/ rotation	Energy/ rotation (GJ/ha)*	Fraction of total (%)
Roading	7.22	1	7.2	5
Road maintenance	0.56	6	3.3	2
Site preparation	7.59	1	7.6	5
Nursery	0.18	1	0.2	1
Planting	0.37	1	0.4	1
Tending	0.16	2	0.3	1
Nursery	0.18	1	0.2	
Planting	0.37	1	0.4	1
Tending	0.16	2	0.3	
Pruning	1.33	2	2.7	2
Protection	0.04	40	1.7	1
Harvesting:				
Pulpwood-only thinning	0.24†	86 t‡	20.6	
Mixed sawlog and pulplog thinning	0.19†	130 t‡	24.5	83
Sawlogs-only thinning and clearfelling	0.13†	560 t‡	71.9	

* These figures were calculated from basic data using more significant figures than reproduced in Column 1

† GJ/t

‡ Total tonnes extracted per rotation

than other harvesting operations (Table 2), these propositions are evaluated below for two alternative systems of harvesting similar to those currently being used for first thinning:

- The motor-manual system (System I);
- The recently introduced Kockums feller-buncher and processor systems (Systems II).

Both systems require residual hardwood logs on the site to be cross-cut to allow machine access. The felling, trimming, and docking phases are followed by forwarder extraction and trucking. Both systems include the transport of workers to the forest in light passenger and service vehicles. Consumption of petroleum products has been estimated in Table 3 using available sources, including the machine manufacturers, overseas reports relating to similar equipment, local owner's records, and some field recording. (For some notes on particular machines see Appendix 1.) The data are for a hypothetical *P. radiata* plantation located 50 km from the workers' homes and the wood-processing factory. Estimated rates of production by men and machines, assuming an average tree size of 0.15 tonnes, are listed in Table 4. Obviously values such as those given in Tables 3 and 4 are subject to large variations due to terrain, operator skills, and forest factors; we propose these figures as "reasonable" estimates. Readers with knowledge of actual field values for their own situation may substitute their own data.

TABLE 3—Direct consumption of petroleum products (litre/h)

	Fuel*	Oil†	Total
Light chainsaw	0.8	0.3	1.1
Heavy chainsaw	1.4	0.5	1.9
Feller-buncher	16	0.7	16.7
Processor	19	1.0	20.1
Forwarder	14	0.5	14.5
Light car (l/km)	0.12	—	0.12
Heavy service vehicle (l/km)	0.2	—	0.2
Truck (l/km)	0.6	0.01	0.61

* The volume of all fuels, oils, and lubricants has been converted according to their calorific value, to an equivalent volume of diesel oil, i.e., 1 litre diesel = 1.1 litre petrol = 38.3 MJ

† Include hydraulic oil where appropriate and an allowance for lubricants

— Minimal

TABLE 4—Estimated production rates at tree size 0.15 t ("wet")

Cross-cut hardwood	30 t/h production equivalent*
Motor-manual cutting	2.3 t/h
Feller-buncher	16 t/h
Processor	12 t/h
Forwarder	13 t/h

* Cutter is assumed to cut in 1 hour all hardwood from an area which will yield 30 t. A cutting time of 5 hours/day is assumed

Table 5 presents the main results in terms of litres of fuel (diesel oil equivalent, *see* Table 3 footnote) consumed directly in harvesting operations at the work sites, transport of wood to the mill, and in transporting workers to and from work. Fuel used indirectly, e.g., in obtaining spare parts or in the supply of goods and services, is not included. Table 6 shows the proportion of each system's estimated total direct fuel consumption which is used for worker transport. As is common practice in the Tumut region, each cutter is assumed to travel to work in his own vehicle, while machine operators are assumed to travel in service vehicles. Trucks are assumed to be garaged at drivers' homes and no worker transport is required for them.

Over-all, the mechanised system (System II) appears to use about 27% more fuel per unit production than the motor-manual system (System I). The System II machines (feller-buncher plus processor) consume about 2.7 l to fell, delimb, and cross-cut 1 t of logs, compared to an estimated half litre for the chainsaw of System I. However, almost 1 l of fuel per tonne is attributed to worker transport in this phase of System I compared to about one-sixth of a litre for System II, a consequence of System II's much greater productivity per man-day. Fuel requirement for forwarding and trucking is the same for Systems I and II. Road transport consumes a larger amount of fuel than any other phase of harvesting at the haulage distance chosen (50 km).

TABLE 5—Estimated fuel consumption in harvesting* (litres diesel-oil-equivalent/tonne "wet" wood)

	Machine use	Operator transport	Total
System I — motor-manual			
Chainsaw (hardwood)	0.08	0.08	0.16
Chainsaw	0.48	0.95	1.43
Forwarder	1.03	0.08	1.11
Truck	2.61	—	2.61
Total	4.20	1.11	5.31
System II — mechanised			
Chainsaw (hardwood)	0.08	0.07	0.15
Feller-buncher	1.04	0.08	1.12
Processor	1.68	0.08	1.76
Forwarder	1.03	0.08	1.11
Truck	2.61	—	2.61
Total	6.44	0.31	6.75

* 0.15 t tree size, 50 km haul distance

TABLE 6—Proportion of total fuel used by each system in transporting workers to the job site

System I		System II	
Chainsaw operator cutting hardwood	2%	Chainsaw operator cutting hardwood	1%
Chainsaw operators	18%	Feller-buncher operator	1%
		Processor operator	1%
Forwarder operator	2%	Forwarder operator	1%
Truck	—	Truck	—
Total	22%	Total	4%

SOME SENSITIVITY ANALYSES

To evaluate the effects of forest location, values were recalculated for an assumed one-way travel distance of 25 km (Table 7). System I consumption declined by 35% and System II consumption by only 22%. The effect of increased tree-size on fuel consumption was evaluated by estimating log production for a tree size of 0.2 t (Table 8) on the same basis as for Table 3. System I consumption declined by 5% and that of System II by 15% (Table 9). This is because the mechanised system is more sensitive to tree size than the motor-manual system.

To evaluate the effects of price rises of petroleum products on the cost of thinning operations, a schedule of operating costs (and the fuel component of these for each harvesting operation) has been drawn up (Table 10). These estimates are based on assumptions about production rates (Table 4), machine life, utilisation, repair bills,

TABLE 7—Estimated fuel consumption in harvesting with decreased haul distance* (litres diesel-oil-equivalent/tonne wet wood)

	Machine	Operator transport	Total
	System I		
Chainsaw (hardwood)	0.08	0.04	0.12
Chainsaw	0.48	0.47	0.95
Forwarder	1.03	0.04	1.07
Truck	1.30	—	1.30
Total	2.89	0.55	3.44
	System II		
Chainsaw (hardwood)	0.08	0.04	0.12
Feller-buncher	1.04	0.04	1.08
Processor	1.68	0.04	1.72
Forwarder	1.03	0.04	1.07
Truck	1.30	—	1.30
Total	5.13	0.16	5.29

* 0.15 tonne tree size, 25 km haul distance

TABLE 8—Estimated production rates at tree size 0.20 t

Cross-cut hardwood	40 t/h production equivalent*
Motor-manual cutting	2.5 t/h
Feller-buncher	21 t/h
Processor	15 t/h
Forwarder	15 t/h

* See footnote Table 4

TABLE 9—Estimated fuel consumption in harvesting with increased tree size (l/t)*

	Machine	Operator transport	Total
	System I		
Chainsaw (hardwood)	0.06	0.06	0.12
Chainsaw	0.44	0.87	1.31
Forwarder	0.93	0.07	1.00
Truck	2.61	—	2.61
Total	0.04	1.00	5.04
	System II		
Chainsaw (hardwood)	0.06	0.06	0.12
Feller-buncher	0.80	0.06	0.86
Processor	1.33	0.06	1.39
Forwarder	0.93	0.06	0.99
Truck	2.61	—	2.61
Total	5.73	0.24	5.97

* 0.20 t tree size, 50 km haul distance

labour costs, and market interest rates. (Some of the assumptions used are detailed in Appendix 2.) The final column of Table 10 shows the estimated direct effect of a 50% price rise on harvesting costs. The mechanised system is more sensitive to fuel cost increases because of its higher rate of fuel consumption; however, fuel costs over-all are only about 10% of estimated logging costs. Trucking is the most sensitive of the harvesting operations to fuel price rises at the haulage distance studied.

TABLE 10—Estimated direct logging costs*

	Total cost ($/t)	Fuel cost		Effect of fuel price rise of 50% on total cost (%)
		($/t)	(%)	
	System I			
Hardwood cutting motor-manual	0.50	0.02	4	+2
Motor-manual felling	7.00	0.45	6	+3
Forwarder	3.98	0.31	8	+4
Truck	4.74	0.73	15	+7
Total	16.22	1.53	9	+4
	System II			
Hardwood cutting	0.50	0.02	4	+2
Feller-buncher	3.60	0.31	9	+4
Processor	5.50	0.56	10	+5
Forwarder	3.98	0.31	8	+4
Truck	4.74	0.73	15	+7
Total	18.32	1.93	11	+5

* 15 t tree size, 50 km haul distance

CONCLUSIONS

Harvesting requires far more energy than all other operations in *P. radiata* plantation forestry. Of two harvesting systems examined, the direct consumption of petroleum products by a mechanised system for first thinning was estimated to be greater than that by a conventional motor-manual system. Almost half of the estimated petroleum consumption of the local shortwood motor-manual system was attributed to road transport of the logs; a further 21% was required for worker transport. Halving the transport distance reduced fuel consumption by 35% for the motor-manual system and 22% for the mechanised system. The mechanised system showed a greater reduction in fuel consumption per tonne-harvested with increased tree size than did the motor-manual system.

It is predicted that fuel supplies will continue to be available during this century although their price is expected to rise. Fuel costs were only a small proportion (10%) of total harvesting costs, and therefore fuel efficiency is only one of a number of factors (capital efficiency, labour efficiency) which contribute to projected cost over a planned operating period.

Finally it is important to point out that there are currently in use other systems of harvesting *P. radiata* first thinnings. Separate analyses are required to establish each system's operating characteristics such as desirable tree size range, tolerance of defects in tree form, energy efficiency, and operating cost.

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APPENDIX I

Machine	Comments
Heavy chainsaw	80 cc class
Light chainsaw	60 cc class
Feller-buncher	Kockums 880, 127 kW Consumption estimates: Gasslander **et al.** (1979) 20 *l*/hr; Field reports 15 *l*/hr
Processor	Kockums Logma, 127 kW Estimated load factor 0.5
Forwarder	Kockums 85-33 127 kW: Bostrom (1973) load factor 0.4, 15 *l*/hr; Field reports 15 *l*/hr
Truck	200-250 kW class Macarthur (CSIRO, pers. comm.) 50-60 *l*/100 km

APPENDIX 2

Hardwood cutter	\$75/day
Motor manual price	\$7/t
Operator	\$18 000/yr
System production	26 400 t/yr
Machine value	
Feller-buncher	\$160 000
Processor	\$235 000
Forwarder	\$160 000
Truck & Trailer	\$90 000
Residual after 5 years	25%
Finance cost including depreciation allowance	\$24.00/\$1000/month
Service vehicle	< \$0.10/t and ignored