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TREE POWER

An Assessment of the Energy Potential of Forest Biomass in Canada

Report ER 78-1

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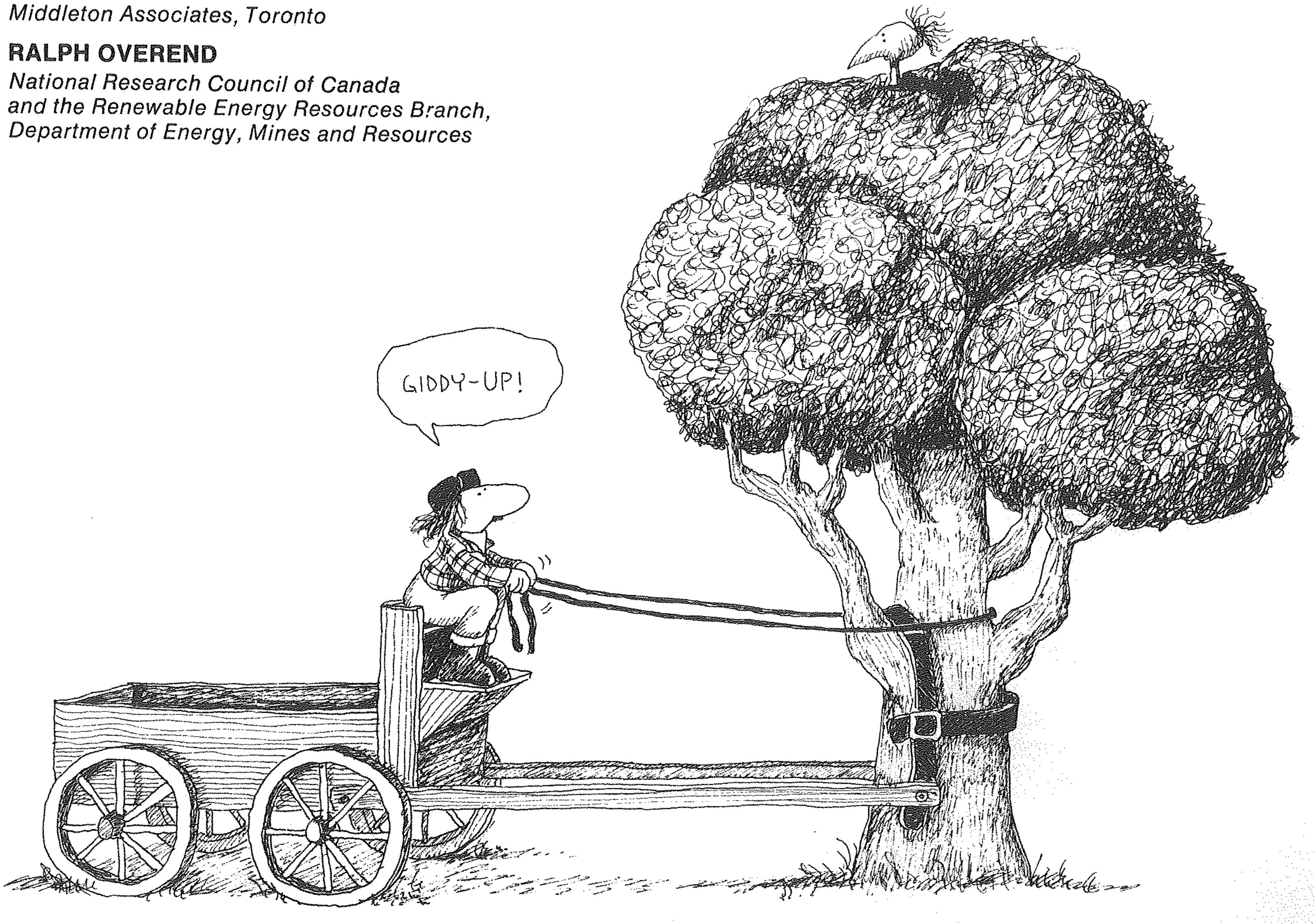

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"Wood is the historic renewable fuel"

"There is probably no other one subject which has during the life of the Fuel Administration monopolized more attention from the general public than that of the various aspects of the wood reserves of this country. The popular imagination was impressed with the fact that in the northern parts of Canada are immense areas of standing timber waiting to be cut. What was generally forgotten, however, was that the transportation and labour factors are quite as important to the accumulation of wood supplies as they are in the mining and distribution of coal.

In the crisis of our fuel problem through which we passed, it seemed difficult for our neighbours to the south, upon whom we depend for a considerable portion of our coal, to understand why Canada could not take care of her needs from her vast supplies of wood. Two principal reasons existed. First, Canada in the main has long since abandoned wood consuming heating equipment; secondly, a still more potent reason was the fact that Canada mobilized practically all her available wood choppers and sent them to Europe in connection with the forestry work there. An estimate of the services rendered by that force prepared by the Commission of Conservation indicates a "saving of ocean tonnage equivalent to feeding fifteen million people."

Wood supplies could and should be used in Canada as winter is approaching, and again in the early spring season. The question of unemployment is more or less serious in every country. For instance in Canada, the farmer requires additional help for a few months in the summer. The larger cities provide employment for large numbers during the same season, but what becomes of them all in the winter? Our wood problem is largely a question of mobilizing such labour. It means the co-operation of the municipality and its provincial Government, in those provinces, with large supplies of timber. By some such arrangement wood could be cut, cured and made available for use, as pointed out, at both ends of the winter. The whole plan should be part of a systematic programme of a reforestration scheme in the older sections of Canada. The timber resources of Eastern Canada are rapidly being exhausted, and the time is now at hand for the people to take greater interest in renewing our forest wealth. It seems proper to suggest that we are far too indifferent about this matter; as a people we should be keenly alive to the work of our Commission on Conservation and the National Forestry Association, both of which bodies have been very active in this direction."

Quote from The Final Report of the Fuel Controller Canada pages 48 and 49, Ottawa 1919.

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SUMMARY

Within the framework of a long range energy review to the year 2025, the potential contribution of renewable energy in the form of forest biomass is discussed. Because wood fuel does not presently contribute more than 4 percent of Canada's energy supply, an assessment of the maximum technical potential for the resource, conversion technologies and end uses was adopted.

To facilitate discussion, 3 reference cases are investigated: electricity generation, methanol production and low Btu gasification. The conversion technologies, i.e. direct electricity generation or cogeneration, gasification to synthesis gas catalytic conversion to methanol and low Btu gasification, are discussed and costs established, where possible.

End use other than for electricity and steam is difficult to define. The substitution of low Btu gas for natural gas and of methanol for liquid hydrocarbon is possible, although there are presently technical, economic, social and institutional obstacles to such substitution.

Data on the availability of the resource is severely lacking. When the annual increment of all species and ages is required for a definition of biomass production, the present data base in terms of the annual allowable cut for economically valuable species as fibre is inadequate. A variety of estimators are applied to suggest that the total annual productivity of the forest is about 400 x 10^6 ODt (oven dried tonne), equivalent in energy to 8 x 10^{18} Joule. The present wood harvest of 51 x 10^6ODt for all purposes has an energy content of about 1 x 10^{18} Joule. In order of cost and availability, forest biomass is available as mill residue, forest residue and by direct fuel wood harvest. The estimated quantities are respectively 7.5, 31, 72 ODt per annum.

A calendar of development for these resources is suggested. In the near term (1978-83), the mill residue could be utilized in the existing forest industries to substitute for fossil fuel purchases. Some technology development is required as is a change of attitude by utilities towards the purchase of cogenerated electricity.

The medium term to 1990 will realize more forest energy but will require changes in harvesting technology and forest management practice as well as development of conversion and end use technologies.

Over the longer term to 2025, the extensive forest and energy plantations could provide a large fraction of the carbon based fuel requirements. However a development program including extensive environmental assessment of the impacts of such large scale use will be needed. For example, the effect of collecting forest residue in the medium term and of plantations in the longer term could be to strip the soil of nutrients.

The report concludes with a recommendation to initiate a major resource assessment of the forest biomass as the highest priority towards realising this renewable energy source.

1. INTRODUCTION

The purpose of this document is to present a first round approximation of the potential contribution of forestry biomass to Canada's energy requirements to the year 2025 with discussion of the economic, technical, social, environmental, and institutional issues that may affect implementation. The principal objective is to explore the commercial attractiveness of energy recovery from forestry biomass between now and 2025, including a calendar of the important stages and components. The information and data contained in this analysis are based on a review of the current literature, a two-day panel discussion with fourteen Canadian experts in the field, and discussions with other experts.

A review of this nature requires, at the outset, a discussion of the current and projected energy picture as well as an indication of the social and economic setting of the analysis. However this is the task of other groups within the Long Range Energy Assessment Project (LEAP) of the Energy Review Group, and will be published elsewhere.

There are, however, two aspects of this issue that deserve particular attention(1).In 1974, 8.2 x 10^6 ODt (Oven Dried tonnes) of surplus hog fuel was generated with a recoverable energy content (65% efficiency) of 94 x 10^{15} J (89 x 10^{12} Btu)(2). The second factor which has some bearing on the future role of biomass as an energy resource is the expected shortfall in the supply of fossil (i.e. non-renewable) fuels over the long term. A number of experts see the production of liquid fuels (such as methanol) from wood for transportation purposes as playing an important role in supplementing the waning petroleum resource.

It should be noted that the latter argument ignores the substitutability of fuels. For instance, wood may best be used to replace natural gas currently used as a fuel in the pulp and paper industry with the replaced natural gas being available for long distance transmission for other uses including the synthesis of liquid fuels.

2. FORESTRY BIOMASS CONVERSION TECHNOLOGIES

2.1 GENERAL

Although it was the original intention of this investigation to confine itself to a consideration of the direct combustion of wood to produce electricity and gasification to synthesize methanol, a number of other options emerged in the course of this work. Some of these other options appear to be particularly suitable for certain types of forestry biomass (mill waste, residue left in the forest, dedicated biomass, etc.). This chapter thus presents a discussion of the principal conversion technologies possible based on various other studies in the area (3,4), with further specifications for three reference cases which appear to be the most opportune at this time, notably:

(i) Direct conversion to electricity
(ii) Gasification for on-site utilization
(iii) Gasification to synthesis gas for liquid fuel (methanol) production.

2.2 PRINCIPAL CONVERSION TECHNOLOGIES

2.2.1 DIRECT COMBUSTION

The most common method of recovering energy from wood is to simply burn the material in an excess of air and utilize the heat so produced. A great deal of energy is already being recovered from wood in the forest product industry through the burning of hog fuel (bark, branches, etc.) and spent kraft mill liquors to produce process steam, and, in some cases, electricity. In British Columbia, for instance, 33 per cent of the energy consumed by the pulp and paper industry is from hog fuel (2). Between 1,000 and 2,000 wood boilers are estimated to be in existence in North America, with 200 having been built in the U.S. in the last decade (5). The most common way to utilize hog fuel is to combust it in large, conventional boilers with heat recovery (as steam) from water-walled boilers. The three principal manufacturers of hog fuel boilers are Foster-Wheeler, Babcock-Wilcox, and Combustion Engineering. Fluidized bed incinerators, such as those available from Copeland Processes Ltd., are also being used to a smaller extent. Despite the current usage, the potential for greater utilization of wastes within the forest product industry is very large. Also significant is co-generation - the dual use of steam already generated to produce electricity for use within, and perhaps even outside, the forest product industry.

Outside the forest products industry, wood has been used as fuel by utilities such as Eugene Power and Light (Oregon).

Wood is also used to supply heat for homes and even some buildings using a wide range of equipment (including combination wood/oil furnaces). In fact, of all the roundwood harvested in the world in 1970, 46% was used as fuel, mostly in Asia and Africa (6).

2.2.2 GASIFICATION

Gasification, by partial oxidation, is a chemically complex process which takes place when heat is applied to organic matter with a deficiency of oxygen. The resulting gas will contain hydrogen, carbon monoxide, carbon dioxide and hydrocarbons with large amounts of nitrogen (if air is used as a feed instead of oxygen) the exact composition will depend on the temperature, pressure, time, and presence of catalyst.

A number of wood gasifiers, including the Westwood Polygas system installed in Clinton, B.C., are now in various stages of development. Most produce a low calorific content (4-6 MJ/m^3, or 100 - 150 Btu/scf) producer gas which is burnt on-site so that the sensible heat of the gas itself may also be used. As well, a number of solid waste gasifiers which may also be used to gasify wood are now under development. One system, the PUROX process developed by Union Carbide, uses oxygen instead of air which results in a gas which contains about 14 MJ/m^3. All of the known wood and solid waste gasifiers currently operate at atmospheric pressure. A good review of combustion technology for wood and wood wastes including some gasifiers is available from the Environmental Protection Service of the federal Department of Fisheries and Environment (7). It is generally felt that some of the systems are very close to full commercialization.

Producer gas is not well suited to chemical conversion since it contains a large excess of nitrogen which would need to be removed to create a synthesis gas.

Synthesis gas can be used to produce methanol through catalytic combination of CO and H_2, synthetic natural gas through methanation, or hydrocarbons through Fischer-Tropsch synthesis. Higher quality gas mixtures might be obtained by adaptation of processes being developed for coal gasification. As yet, coal gasification prototypes have not been tested with wood.

There may be other methods of using producer gas for power generation, such as its use in gas turbine engines, or even in internal combustion (spark ignition) engines. An alternative to conventional gasification is to alter the operating conditions of the gasification system in order to produce a combustible char (charcoal) rather than a gas.

2.2.3 PYROLYSIS

Pyrolysis is the physical and chemical decomposition of organic matter brought about by the action of heat in the absence of oxygen. Varying compositions of gases, liquids and chars are produced, depending on the conditions of the reaction. Most wood gasification systems commonly referred to as involving "pyrolysis" involve true pyrolysis as but one reaction in a multi-stage process with oxygen or air combustion being used to generate the necessary heat in another part of the reactor. Some have defined pyrolysis as any heat effect that converts organic material to gases, liquids, or solids. Thus gasification could be one form of pyrolysis.

The gas, liquid and char produced in pyrolysis can be used as fuel; the gas could also be used to produce synthetic natural gas, methanol, or liquid hydrocarbons.

2.2.4 CATALYTIC GASIFICATION WITH ALKALINE CARBONATE

The pyrolysis of wood and sodium carbonate mixture in a 13:1 ratio will result in the production of light hydrocarbons, principally methane. Relatively little is known about the process and it remains to be evaluated to assess its potential on a large scale.

2.2.5 STEAM REFORMING

Steam reforming is now commonly used to convert hydrocarbons, such as natural gas, to hydrogen and carbon monoxide, which can then be used to produce various products such as methanol. It could also be used to convert the various hydrocarbons produced in pyrolysis/-gasification processes to synthesis gas. This could then be used to produce methanol. However, this process is strongly endothermic and constitutes a serious loss of efficiency if used to upgrade methane contaminated synthesis gas from gasifiers such as Lurgi or Purox.

2.2.6 HYDROGENATION

Hydrogenation, also referred to as liquefaction or carboxylolysis, is a reduction reaction in which carbon monoxide reacts with cellulosic material at 250-350 C and pressures of 70-350 atmospheres. The resulting liquid fuel is similar to No. 6 Residual, but has a lower heating value of 30 MJ/kg.

This process, developed by the U.S. Bureau of Mines, is currently being tested in a process development plant in Albany, Oregon using wood. The process could probably be modified to produce fuel gas.

2.2.7 HYDROGASIFICATION

In this process, part of the biomass is first converted to hydrogen by gasification and the resultant gas is shifted to increase the hydrogen content. The hydrogen rich gas then reacts with the remaining biomass at a high temperature and pressure to yield a product gas with a high methane content which is then upgraded to pipeline quality synthetic natural gas (SNG). The hydrogasification reaction is highly exothermic, permitting biomass of high moisture content to be treated without the addition of extra heat.

A pilot hydrogasification plant has been successfully tested at Battelle Columbus Laboratories in the U.S.

2.2.8 ANAEROBIC DIGESTION

Anaerobic digestion is the conversion by bacterial action in the absence of oxygen of slurried organic material to a (70:30) gas mixture of methane and carbon dioxide. The process operates at 35 C and retention times can be as high as 15 days, thus necessitating equipment of a large volume.

Although the process is ideally suited for treatment of livestock wastes, a plant is currently being constructed in Florida which will process 100 tons per day of municipal solid waste. It should be noted that lignin in wood interferes with the process and thus may require removal beforehand, as is done in the manufacturing of paper products.

2.2.9 HYDROLYSIS

Cellulose can be hydrolysed into wood sugars including glucose through the action of either acids or special enzymes. Although both acid and enzyme hydrolysis have been used to some extent in the past, there is a resurgence of interest in these processes. Leaders in this field appear to be the U.S. Army Development Centre in Natick, Mass., and New York University.

The sugars produced by acid or enzymic hydrolysis can then be fermented, using enzyme containing yeasts, to ethanol or higher alcohols. Alternatively, the sugars can be digested anaerobically to produce a methane-rich gas (see 2.2.8). Such processes take considerable time for the liquors to be fully converted.

It is of great interest that Brazil has embarked on a huge program to promote the fermentation of cane sugar by products to produce ethanol which is blended with gasoline and used as an automotive fuel.(8)

2.2.10 BIOPHOTOLYSIS

The ability of plants to split a water molecule into hydrogen and oxygen through photosynthesis is quite remarkable. While direct photolysis would require very energetic ultraviolet radiation in a vacuum, the biological process uses red and blue light in a multistep process to perform the split with about 12 photons. The limiting efficiency of the natural process is 9% in part because the plant is producing a sugar for storage.

Some scientists believe that it may be possible to genetically alter certain enzymes so that hydrogen is produced, rather than a sugar molecule. It may even be conceivable to "graft" tumor-like bodies onto a plant which would convert sugars from the sap directly into hydrogen.

This conversion technology, if at all feasible, would be much further in the future than any of the others. The technique envisaged at present involves "gene splicing", a branch of recombinant DNA research causing considerable controversy.(9)

2.3 ENERGY FROM FORESTRY BIOMASS REFERENCE CASES

Of the many possible combinations of conversion technologies and end-products possible from wood, three have been selected as reference cases based primarily on the interest that has been expressed in them to date.

2.3.1 DIRECT CONVERSION TO ELECTRICITY

For the purposes of this reference case, a 50 MW wood boiler has been assumed as the most likely size. This size corresponds to the largest wood boilers that have been built to date (225 t/hr or 500,000 lb steam/hour), although it is recognized that much larger boilers could be designed. Procurement, transportation, and storage* requirements would appear to limit any one complex to 150 MW (about the size of a 1300 TPD Kraft pulp mill). It has been estimated that about 0.35×10^6 ODt (oven dry tonnes) of wood per year would be required by a 50 MW plant (100% load factor).

Although it is also possible, and perhaps even advisable, to use wood along with a fuel derived from solid waste as a fuel supplement to a coal-fired generating plant, insufficient information was available on this alternative for its inclusion in this document. Further investigation is warranted in this area.

The overall conversion efficiency for the generation of electricity from wood has been estimated to be 25%, based on a boiler efficiency of 69%, steam cycle efficiency of 39% and auxiliary power requirements of 9% of the delivered electricity (10). It should be noted that boiler efficiency has been found to vary between 45-75%, depending on the moisture content of the wood (11). This overall conversion efficiency is not expected to increase significantly in the future, although some process improvements may be possible in preparation and drying of the wood fuel and in the greater recovery of heat from flue gases.

The co-generation of steam for industrial processes or district heating is recognized as having cost and energy efficiency advantages and should be included wherever possible.

It is further assumed that each wood boiler would be equipped with a mechanical dust collector and bag filter to limit the emission of particulate matter to acceptable levels.

2.3.2 GASIFICATION AND ON-SITE UTILIZATION

The largest reactor that appears to be possible at the present time is about 320 ODt per day; this is restricted by the fact that the reactor's diameter cannot exceed 3 m if shop assembly rather than expensive field assembly is envisaged. For use in the forest product industry, a 54 ODt per day (2.2 t/hr) gasification module has been assumed. Such a unit should be able to produce approximately $10^5 m^3$ of low energy content gas per day.

The overall conversion efficiency for the production of low BTU gas from wood, including process energy, is generally reported as being between 65-75%, with some experts feeling that this could be much higher in the future. A figure of 70% will be used in this document.

There are three basic designs for gasification reactors: fixed bed, fluid bed, and suspension systems. Advantages of each have been cited by various experts. There also does not yet appear to be agreement on whether dry ash non-slagging systems are preferable to slagging ones.

The gas produced can be expected to have the following approximate volumetric composition: 20% H_2, 25% CO, 10% CO_2, 3% C_xH_4, 1% higher hydrocarbons, 40% N_2 with a higher heating value of 6 MJ/m^3. Note that if oxygen was used in the reactor instead of air, there would be (a) no nitrogen in the resultant gas, and (b) greater quantities of fuel gases, and (c) the gas would have a higher energy content of approximately 11 MJ/m^3.

2.3.3 GASIFICATION AND METHANOL PRODUCTION

This reference case is based primarily on two recent studies undertaken for Environment Canada (12) and the U.S. Forest Product Laboratory (13). The best gasifier for the production of synthesis gas (H_2 and CO) for methanol production is one which would use oxygen instead of air as an input to the reactor, such as the one developed by Union Carbide. The development of coal gasifiers (section 2.2.2) may result in improved wood gasification reactors for synthesis gas production.

A plant equivalent in size to a 1200 t/day Kraft pulp mill (cf. the 150 MW Electrical case) would require a battery

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* Wood requires about five times the storage volume of oil or coal on an energy basis.

of 11 gasifiers each consuming 222 ODt of wood per day to produce about 1100 t/day of methanol. This production corresponds to about 0.45×10^9 litre/-year (100×10^6 gallons) of methanol.

The overall conversion efficiency from wood to methanol, including all process energy, has been assumed to be 38 per cent. It may be possible to increase the methanol yield from a given quantity of wood by using various hybrid options, such as the addition of merchant hydrogen to the gasification process stream. Though such hybrid options will have lower overall efficiencies from an energy accounting viewpoint, they offer a means of integrating electricity production with biomass derived carbon to produce high energy density liquid fuels.

A number of proponents of wood derived methanol have also suggested that the output of a methanol plant can be increased by 5 - 10 per cent if small amounts of higher alcohols (with higher energy contents) are allowed in the mix (14). Although of potential interest, the reference case does not take this feature into account.

3. SUPPLY OF FORESTRY BIOMASS

One of the major limiting factors on the potential energy available from forestry biomass is, of course, the total amount of material that is available for energy recovery. Although it may be feasible to extend these amounts with other organic materials (municipal solid waste, agricultural wastes, pest and dedicated crops) or low grade fossil fuels (lignite and sub bituminous coals), these possibilities are not pursued in this document.

3.1 THE TOTAL RESOURCE

The Canadian total land area of 996,699,000 ha has the following land classification (15).

Land Type	Area/10^6ha	% of Total Area
Water	81.006	8.1
Wildlife (tundra, muskeg, etc)	519.105	52.1
Agricultural	67.344	6.8
Urban and Other	6.199	0.6
Forest	323.045	32.4
	996.699	100.0

The 32.4% of the land area that is forested can be further divided into areas which are defined as follows - primary, secondary and tertiary areas which are <80, <120, > 120km respectively from existing wood processing centres. Also some forest area is "reserved" or not available to forestry by legislation, e.g. water conservation areas.

Forest Classification	Distance km	Area 10^6ha	%
Reserved	infinity	13.141	4.1
Primary	<80	157.233	48.8
Secondary	>80 <120	19.849	6.0
Tertiary	>120	132.822	41.1
		323.045	100.0

The "productive" forest area is between 180 - 220 x 10^6 ha with a total growing stock of 24 x 10^9m^3. For comparison the average production (1969-73) was 0.124 x 10^9m^3.

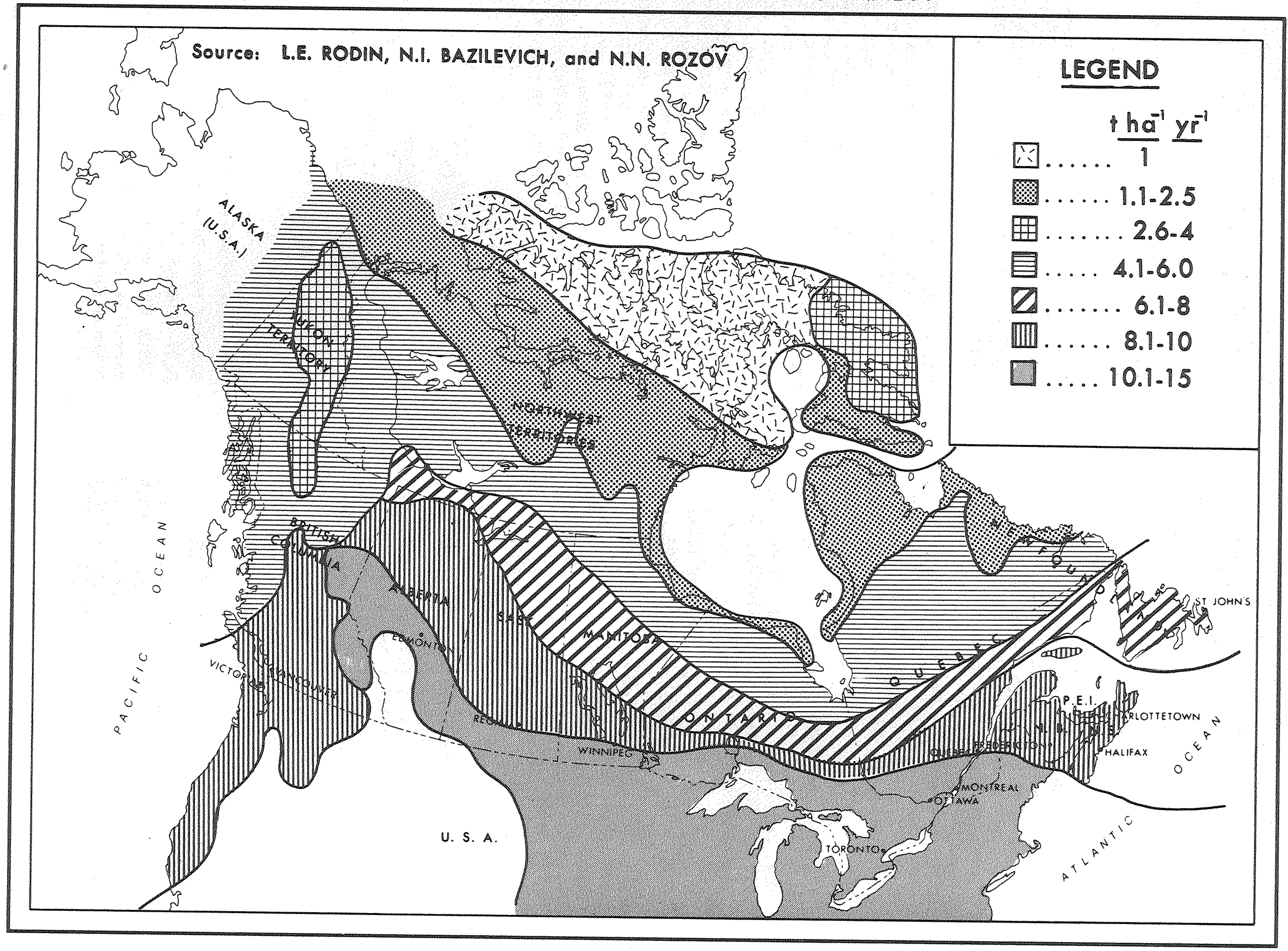
However the production figure is for merchantable boles only and is the Annual Allowable Cut (AAC) which is defined only for certain sizes (9cm diameter at breast height (dbh)) and commercial species (e.g., spruce, fir, pine, maple, etc.). As a result, the quantity of wood as biomass (i.e. independent of size or species) can only be estimated by applying "biomass correction factors". These factors are: - correction factor from merchantable bole to whole tree (ex root) including branches, bark and leaves of 30 to 60 per cent - correction factor to include non-marketable species and all sizes of tree (as whole tree (ex root)) of 130 to 230 per cent. The figures for the AAC for the year 1974 are given in units of 10^6m^3 and in brackets in units of (10^6ft^3) (15).

10^6m^3(10^6ft^3)

	AAC		Actual Cut		, Surplus	
Softwood	195.9	(6916)	108.7	(3838)	(87.2)	(3078)
Hardwood	32.6	(1152)	8.6	(306)	23.9	(846)
Totals	228.5	(8068)	117.3	(4144)	111.1	(3924)

The conversion of the AAC to weight of biomass therefore is 228.5 x 10^6m^3 x 0.37 ODt m^3 = 85 x 10^6 ODt to yield 194 x 10^6 ODt at 130 per cent Biomass Factor or 280 x 10^6 ODt at 230 per cent Biomass Factor.

BIOMASS PRODUCTIVITY– ZONES IN CANADA



Source: L.E. RODIN, N.I. BAZILEVICH, and N.N. ROZOV

Another means of obtaining the annual yield of biomass is to use a figure of 0.25 cord/acre/year = 0.56 ODt/ha/yr for sustained yield of merchantable boles (cf. the AAC) and apply this to the productive forest area of 200 x 10^6ha to yield 110 x 10^6 ODt or

225 x 10^6 ODt at 130 per cent Biomass Factor

360 x 10^6 ODt at 230 per cent Biomass Factor.

Yet another means of identifying the annual yield is to use productivity data from various studies. The most systematic study is that of the Brookhaven National Laboratory (17) on a pine-oak forest in Long Island yielding 5.5 t/ha/yr with a stand of 26.5 t/ha.

The State of Vermont (10) in a study of woodland productivity arrived at the same conclusion with a yield of 5.5 t/ha/yr with a standing phytomass of 124 t/ha. Comparable intensive studies have not been performed on the Canadian boreal forest. However, estimated productivities (18) (hereinafter called the RBR data) are shown in Figure 1.

For comparison the RBR data for the Brookhaven and Vermont region shows 8 - 15 t/ha/yr or 4-7 t/ha/yr of above-ground yield which is close to the 5.4 t/ha/yr biomass accumulation rate reported in the Brookhaven study.

Thus the major forest zones appear to have productivities of between 4.1 - 8 for a weighted average of 6 t/ha/yr of phytomass. If one is to consider harvesting, leaving the below ground portion then the productivity will be close to 3 t/ha/yr.

The total annual yield therefore will be 320 x 10^6x 3 t/ha/yr = 1000 x10^6t/yr. If only the accessible component of primary and secondary forest zones (no more than 120 km from existing wood conversion centres) of 180 x 10^6 ha are are considered (as they are in the determination of the AAC), then there are 520 x 10^6 t/yr.

Estimates of yield of the Primary and Secondary forest regions totalling 180 x 10^6 ha are summarized:

Estimation Technique	Yield/10^6 ODt/year
1974 Annual Allowable Cut	85
with 130% Biomass Factor	194
230% Biomass Factor	280
"Rule of thumb" 0.25 cord/-acre/yr	110
with 130% Biomass Factor	255
230% Biomass Factor	367
Estimates from primary productivity from RBR	520

For the purposes of the LEAP study it is proposed that a total annual productivity of 400 x 10^6 ODt be assumed to be the limit for the forest when managed extensively. This represents a vast energy supply of the order of 8EJ (8 x 10^{18}) J per annum. For comparison, the total Canadian basic energy demand in 1974 was 8EJ with the liquid fuel sector accounting for about 1.5EJ. Only part of this vast supply will ever be available for energy; the present forest withdrawals for pulp and paper and lumber are equivalent to 0.8 - 1.0EJ of primary energy.

3.2 SOURCES OF SUPPLY

3.2.1 MILL RESIDUES

Large amounts of wood residues (mainly bark, but also other presently unusable wood by-products) are currently generated by the forest product industry in lumber and pulp mills. Some wastes, such as the chips produced by sawmills, can and often are being used by the pulp and paper industry in the production of pulp. Some of the remaining wastes, referred to as hog fuel, are now being used by the industry to produce process steam and, in some cases, electricity.

In the first instance, better use should be made of the mill wastes which are already being used to produce process steam by using back pressure steam to produce electricity. It has been estimated that 200-250 MW of electricity could be produced on the west coast of Canada using back pressure steam (19), and this represents 40 per cent of the west coast industry's current consumption.

The most accurate figures available on the amount of mill waste that could be used for energy recovery are from a recent survey (11) which found that of the 28.8 x 10^6t of bark and wood waste generated by the Canadian forest products industry, 14.5 x 10^6t are being disposed of by incineration, landfill or other means. The total amount of 28.8 x 10^6 agrees favourably with calculations of the waste produced based on a generation of 0.22 ODt (or 0.5 as received with 50% moisture) of bark and wood waste per cunit, which results in waste production of over 27.2 x 10^6 t per year.

It is particularly important to note here that these wastes are available in relatively concentrated amounts in a limited number of locations; this is not the case with the other sources of forestry biomass.

3.2.2 FOREST RESIDUES

A great deal of wood residue remains after a tree has been harvested and transported to a lumber or pulp mill. The material left in the forest would include the top, foliage, and branches, also referred to as the crown and slash.

A number of estimates are currently available on the quantities that would be involved in Canada. One recent report concluded (12) that between 16-50 per cent, of the merchantable volume of timber could be recovered in the form of bark (13 per cent), branches, foliage, and top. Based on their assessment of the current state-of-the-art, they used a 30 per cent biomass factor in their base case. More recent estimates, however, suggest that this figure is too conservative and that a 60 per cent "leave" is the minimum that should be used (20).

In 1974, the total roundwood requirement of the Canadian forestry product industry was 117 x $10^6 m^3$ or 43 x 10^6 ODt (16). This, using a 60 per cent leave factor, means that about 26 x 10^6 ODt of wood residue are cut and left in the forest each year in Canada.

It should be noted that although the residue is currently available, it must be collected and transported before it can be used.

Further, some assessment must be made of the environmental impacts of "full" tree (less stump) removal. The important question is, to what extent can organic and nutrient levels and soil structures be maintained, in northern Canadian forest soils, under a cyclical "whole tree" harvesting regime?

3.2.3 UNUTILIZED TREES IN CURRENTLY LOGGED AREAS

Most logging operations only harvest trees that have a diameter at breast height (dbh) of 9 cm (3.6"), commonly referred to as "merchantable". Also, most logging operations will leave certain uneconomic species standing because they are unsuitable for the required industry.

For energy recovery systems, smaller trees and trees of any species are equally useful. For instance, it has been estimated that, for jack pine on a medium site in Ontario, the volume of trees over 1.5 cm dbh is 1.4 times the volume of trees over 9 cm dbh (21). If this factor were taken as being representative of other species, 20 x 10^6 Odt of trees between 1.5 - 9 cm dbh could have been harvested from currently logged areas in Canada in 1974.

Limited estimates are available on the additional amount of wood from trees of species considered useless for traditional forest products that could have been harvested from currently logged areas.

It was estimated that an average Vermont woodlot may have 30-50 per cent cull material.(10) This estimate was not considered appropriate for the Canadian situation, so no national estimate of the amount of all material has been attempted.

The estimate of unutilized trees in currently logged areas is 20 x 10^6 Odt. This does not take into account non-merchantable species growing in the managed forest so that this estimate is fairly conservative. Combined with the discussion of "leave" under section 3.2.2, the biomass correction factor is therefore probably much greater than 30 per cent and is likely to be between 130 - 230 per cent.

3.2.4 WOOD AVAILABLE IN AREAS CURRENTLY NOT LOGGED

In 1974, the annual allowable cut of roundwood in Canada was 228 x $10^6 m^3$, and the roundwood requirement of the forest products industry was 117 x $10^6 m^3$. Thus, the InterGroup report (12) assumes an "indicated surplus" of 110 x $10^6 m^3$ of merchantable boles, 41.3 x 10^6 ODt of wood. The same report identified twenty locations in Canada where surplus biomass could be used for the production of methanol (22). This study estimated that a total of 29 x 10^6 ODt of wood were available available at these locations, based on a 30 per cent biomass factor to include bark, branches, foliage, and top. Using a 60 per cent biomass factor gives a total of 35 x 10^6 ODt of wood, and using a 130 per cent biomass factor (including other sizes and species) gives a a total of 52 x 10^6 ODt of wood.

The economics of operating in some areas not now used by the forest products industry may be quite different from the economics associated with areas currently logged.

Two other studies have attempted to predict the future Canadian demand for roundwood by the traditional forest product industry (16,23). These studies have been recently reviewed but their estimates for growth in the industry were considered too optimistic. They indicate, however, that the total roundwood requirements of the forest products industry will be just about equal the allowable cut in 2000 (24). Other experts have concluded that there will be a surplus of 64 x $10^6 m^3$ or 24 x 10^6 ODt of forestry biomass in excess of the 215 x $10^6 m^3$ projected for consumption by the forest product industry in 2000 (25).

3.2.5 ENERGY PLANTATIONS

There has been considerable debate in the last few years about the possibility of the intensive cultivation of special hybrid plants to generate energy (26,27,28,29,30). Recent work in this area includes a study for ERDA by the Mitre Corporation and Georgia Pacific Corporation. Preliminary results from this study indicate that, with intensive management, using high growth hybrids (poplar, or red alder, for instance), cropping on a 6 year rotation with replanting every 30 years, proper irrigation and fertilizers, a recovery of 25-54 ODt $ha^{-1} yr^{-1}$ is possible (3). If successful, such crops would be able to increase by 5-10 times the amount of biomass currently recoverable. In Canada, stands of red alder grown in the Pacific rain forest have been found to produce 37 ODt/ha/yr but it is not known how applicable this may be across Canada (31) since its biome is presently only on the west coast. However, other species with high yields suitable for other forest regions may exist.

The major advantage that accrues to the plantation concept is the reduction in the area necessary to provide fuel to an energy converter. This area is in inverse proportion to the productivity. The traffic factor (i.e. mass carried x distance), which will be a measure of the transportation costs of harvesting will be proportional to the square root of the area.

$$\text{mass x distance} \propto \sqrt{(\text{productivity})^{-1}}$$

The potential contribution of genetic improvement of "biomass" tree species is evident since higher annual growth rates combined with more rapid rotations will combine to yield higher productivities. At some point however the potential will be limited by either nutrient or water supplies and some energy will have to be returned to the plantation in the form of chemicals and irrigation power.

Also, as crop rotations become more rapid approaching those of agriculture, many of the disadvantages of intensive monoculture such as high fertilizer and insecticide inputs may occur. Overall this concept would appear to have considerable benefits but would require a great deal of careful study before an extensive commitment is made.

3.3 HARVESTING TECHNOLOGY

The harvesting technology currently used by the traditional forest product industry is designed to recover merchantable boles, not to maximize the recovery of all forest biomass. The system involves the manual or mechanical cutting of trees of the as a liquid fuel which are briefly summarized below. Many of the comments concerning methanol would also be appropriate for other alcohol fuels, such as ethanol.

It is also important to note here that there is a distinct possibility that the natural gas currently flared in the Middle East will be converted to methanol and exported. Likewise large coal deposits may also be used for methanol production in the future. Both these sources of methanol may prove to be more economical than wood, and would thus be implemented before wood. This could mean that by the time wood is to be used to produce fuel grade methanol, large scale uses may already have been established.

4.4.1 TRANSPORTATION FUEL

Methanol has been used as a fuel in cars both in mixture with gasoline (5-30%) and alone in numerous tests. Although the results of most of the tests to date do not indicate any serious problems with its use, difficulty in starting on cold mornings and phase separation of gasoline/methanol blends caused by methanol's high solubility in water are known to occur. In the severe winter conditions of Canada many technical precautions would be required.

Certain changes are required to the carburetor, but these do not appear to be significant. Experimental results at Exxon suggest that engines developed for pure methanol could be 25-45% more efficient than gasoline engines. Should fuel injection be widely introduced, as some believe it will be in five years, the fuel makes much less difference to the performance of the engine, though the phase separation problem would still require attention. Due to methanol's solubility in water, changes would be required to the current method of using water bottom tanks to transport and store gasoline. One of the first uses for methanol would therefore probably be for controlled fleets.

A further question is Canada's ability to unilaterally change to methanol as an automotive fuel, given the close ties of the country and the auto industry with the USA. ERDA in the USA is examining alternative fuels and large experiments with methanol/gasoline mixtures have taken place in FRG and Sweden. However alternate fuel utilization is not being considered on any time scale less than the middle 1980's.

Full discussion on the use of methanol as an automotive fuel can be found in various reports (33-36).

The problems of methanol compatibility with existing distribution networks and automobile practice could be avoided if a new process developed by Mobil (37, 38) to convert methanol to a synthetic gasoline becomes available. This process, using a special Zinc/Zeolite catalyst, will selectively produce a highly aromatic (high octane number) gasoline which could be blended with existing gasolines. The energy efficiency defined as the theoretical gasoline: methanol heats of combustion will be about 70 per cent and an estimate of the added cost is (Mobil fuel) ¢/gal = 5¢ + (2.4 x Methanol Cost per gallon). On an energy equivalent basis, the cost 7-12 cents per gallon of gasoline equivalent due to the more than doubled energy content of gasoline over that of methanol. This process presently funded by ERDA will be tried on a pilot plant scale in the near future. The important parameters such as cost and catalyst lifetime should then be available.

4.4.2 TURBINE FUEL

Methanol has also been discussed as a possible fuel for stationary gas turbines producing electricity and has been found to provide more power than No. 2 oil, while producing less nitrogen oxide pollutants (39,40,41). Such turbines are often used for supplying peak electrical energy by utilities.

4.4.3 BOILER FUEL

Tests have been conducted on the use of methanol as a boiler fuel and the results indicate that where a boiler is equipped with gas and oil burners, the oil burners can be successfully modified to use methanol. Boilers designed to burn gas only can have a methanol burner added for occasions when natural gas is not available, as the burner modification required for methanol firing is relatively simple. When methanol is to be used as a supplemental fuel to oil, a separate fuel handling system is necessary (40).

4.4.4 FUEL CELLS

Methanol can be used in fuel cells which convert chemical energy to electricity with very high efficiencies. At least one company is known to be developing a platinum catalyst fuel cell for methanol and another fuel cell has been developed that gives more than 30,000 hours of continuous operation on methanol using tungsten carbide and charcoal as electrodes and sulphuric acid as electrolyte (41). Although hydrogen is somewhat simpler to use in a fuel cell, methanol can be stored and shipped much more easily than hydrogen.

5. MAXIMUM TECHNICAL POTENTIAL

One of the most important functions of this document is to attempt to estimate the maximum potential amount of energy that could be technically produced from forest biomass. Unfortunately, the data necessary to make any solid approximations are not available. However, an attempt has been made to use the available information to arrive at an order of magnitude estimation. Table I included in the conclusion calculates the energy that could be generated from four of the five identified sources of forestry biomass for the three reference case conversion technologies. No estimate was possible at this time for the potential associated with energy plantations in Canada.

The figures in this table should be treated as the very rough approximation that they represent. It should also be noted that each column of figures applicable to a particular technology represents an absolute maximum potential energy, assuming all the available biomass is used for that one conversion technology.

6. IMPLEMENTATION

The technical potential for energy recovery from forestry biomass discussed in the previous chapter is only a theoretical maximum. The principal pre-conditions which must be addressed before any of the potential can be tapped are briefly discussed in the following chapter. As well, the factors which will affect the rate at which energy recovery from forestry biomass is implemented are also reviewed.

6.1 INSTITUTIONAL FACTORS

One of the main reasons why there is not a better utilization of the electricity potential already within the forest product industry appears to be due to the rate structure set by the utilities and their reluctance to buy surplus generated electricity from industrial and process energy producers. The declining rate associated with increased consumption can, it is argued, make it uneconomic to recover electricity although, in fact, a net benefit may accrue to society. It has been estimated, for instance, that the marginal price of electricity is at least 50% higher than the average price usually charged by a utility (42). More importantly, the utility's reluctance to buy off-peak electricity and the very low prices offered when they do buy it are serious constraints to the utilization of the forest product industry's current capacity to produce electricity "economically".

A second important institutional limitation is the apparent lack of a solid pro-biomass constituency in Canada, as exists with nuclear power, oil, or even solar energy. Of even greater importance is the apparent absence of an integrated organization with the knowledge, ability, and interest to carry out the large schemes assessed in this document. It may be that some combination or consortium of public and private institutions may be necessary to bring any of the larger projects to fruition. It is worth noting here that the forest resource is a provincial responsibility and that future development may require extensive Federal-Provincial coordination.

6.2 EQUIPMENT DEVELOPMENT

The implementation of the reference case conversion technologies is being restrained, to a greater or lesser extent, by the incomplete development of four types of equipment, described below.

6.2.1 HARVESTING EQUIPMENT

Although advances have been made in the development of full-tree chippers in the last few years, further work appears to be warranted to optimize the chipper for different sizes of trees in order to reduce energy consumption and cost. Certainly in the area of transporting full trees and in whole tree utilization, much will be learned by further research, design, and development. An opportunity may exist to develop a Canadian industry and expertise in this field.

6.2.2 GASIFICATION OF WOOD TO PRODUCER GAS

Although a number of wood gasifiers are currently at the prototype and demonstration stages, operational problems remain to be ironed out. Optimization of truly commercial gasifiers will only be possible after experience has been gained with the successful operation of the demonstrations over a period of years.

6.2.3 GASIFICATION OF WOOD TO SYNTHESIS GAS

Although some gasifiers, such as that designed by Union Carbide using oxygen, currently do produce a medium energy synthesis gas that could be converted into a variety of products (ammonia, methanol, methane, or hydrocarbons), these processes appear destined to suffer significant inefficiencies because they operate at atmospheric pressure. Some experts feel it would be better to have a system operating at high pressure in order to realize the full potential that this technology holds (43). A program to bring this technology to the commercialization stage was estimated to require about 15 years and $20-30 million (43).

6.2.4 SYNTHESIS GAS PURIFICATION

Due to the lack of experience in the purification of synthesis gas produced from wood, certain unique problems can be anticipated. Certainly the testing currently planned by Union Carbide and Coyne Chemical Company regarding the use of synthesis gas from solid waste to produce ammonia in Seattle will be helpful.

6.3 DISTRIBUTION SYSTEMS

The distribution of steam is limited by the distance over which steam can travel economically, the high capital cost associated with the installation of district heating systems, and the current lack of any method to store steam.

Producer gas is likewise limited by the fact that it cannot be transported over long distances or stored economically, since the heat content does not justify compressing the gas and all the sensible heat of the gas would be lost.

As mentioned previously, certain problems are associated with the distribution of methanol/gasoline blends through the existing water-bottom gasoline distribution system, due to methanol's solubility in water. Also, the use of methanol or methanol/-gasoline blends for automobiles requires certain adjustments which, although not difficult technically, pose problems regarding large scale introduction into the Canadian market. Of course conversion of methanol to a synthetic gasoline (4.4.1) would overcome these problems.

6.4 ENVIRONMENTAL AND SOCIAL IMPACTS

At various points in this report, comments are made on items of environmental concern. Above all, the item of greatest concern must be the ecosystem from which the biomass is drawn. A renewable resource must be considered to be renewable in perpetuity. The forest ecosystem is vast and complex. The standing forest can be likened to capital in the bank; the annual harvest, a function of the standing forest and the year's solar input is, by analogy, the interest earned on that capital. The cycle of regeneration and growth to maturity in the extensive forest takes 50 to 400 years, a time period that far exceeds the response time of many of man's institutions. Thus, all demands made on the system should take into account the long-term needs of the ecosystem rather than short-term expediency which, summed over time, can become a gross insult to the environment. It is therefore reasonable to assume that man's impact will reflect the amount of biomass harvested coupled with the conversion and end-use technologies. It must be pointed out that industry today such as pulp and paper industries, generate water and air pollution, both of which are however, being attacked in a concerted fashion by industry and government. Current harvesting is recognized to be by no means an environmentally secure technology. Forest management has been poor in some regions with the results that the "renewable" resource may not be restored at a reasonable rate. Artificial regeneration is being practiced, though for the northern boreal forest the technique is still in its infancy. Using this experience, what do the energy schemes classified by results in Table 1 promise for environmental impact?

6.4.1 MILL RESIDUE

Frequently the unutilized mill waste is a pollution source whether it is landfilled or incinerated. Technologies such as gasification or combustion in steam raising boilers would turn a hazard to benefit and with prudence in developing these technologies, the environment will be improved.

The social benefits will include more employment in the new plant and a lesser investment by society in centralized power generation and distribution systems.

6.4.2 FOREST RESIDUE

Logging residue is presently considered by some to be a major fire hazard and by others as an essential means of returning fibre to the soil ecosystem. In western Canada, the normal practice is to fire the slash by prescribed burning. The benefits are held to be reduction in fire hazards along with fire scarification of the soil for natural or artificial regeneration. Only about 30 per cent of the slash is consumed with the thick trunks and branches eventually decaying to the soil ecosystem. Whether the existing slash is burnt in situ or allowed to decay slowly, it is evident that the mineral components of the wood are returned to the forest floor. Harvesting of slash could diminish a risk of fire but may thereby cause significant nutrient and fibre loss. This requires intensive study.

The increased traffic factor from existing regions could increase the transportation, pollution and road hazards in the form of fire risk and erosion, as well as disruption of wildlife habitats.

The conversion technologies will generate their own burden; thermal electric generation and co-generation will increase the amount of ash disposal as well as increase air pollution potential. Also, there will be increased demands for water for cooling purposes in these processes. Gasification and chemical or fuel synthesis technologies would have the potential to distribute extremely toxic compounds to the atmosphere and hydrosphere. Environmental protection of the type required for petroleum refining and pulp and paper will be required at the outset for these technologies. The "traditional" approach of retrofit control technologies will be totally unacceptable for industries which rely on a flow concept of production since it must be stressed that renewable energy is dependent utterly on the vitality of the complex ecosystem from which the harvest is taken.

The social consequences will mainly be in the form of increased employment in harvesting and transportation along with the staff required to operate conversion technology added to existing plants. The extension of existing plants will have regional benefits in the sense that increases in prosperity of communities will in turn improve the social infrastructure (for example, hospitals, education and social facilities).

6.4.3 LARGE SCALE ENERGY PROJECTS

The resource base for these projects can be considered to be new green forest plants situated in regions presently not exploited or in the creation of special plantations in either forest regions or more likely, on existing farmland.

Immediately one can recognize that competition for land use will arise. The InterGroup report (12) referred to frequently here was predicated on starting new forest operations, generally in the southern margin of the boreal forest. The land use competition is illustrated by the Reed Paper controversy (44) in northern Ontario. A conflict with the InterGroup proposal would also occur, since the very tract of land claimed by Reed for softwood centred on Red Lake would provide hardwood to a projected methanol plant. The land is the homeland of native peoples under Treaty No. 9 since 1905. In 30 communities, of which only one is accessible by road, approximately 15,000 Cree and Ojibway lead a trapping and hunting existence, as well as occasional employment for wages. Treaty No. 9 bands are arguing for a halt to the Reed program mainly because they believe the northern boreal forest is too fragile to recover from the impact of present wood harvesting practices. Other objections include the changes in their lifestyle by the southerners who come to construct the pulp and paper mill at Red Lake. The mercury disaster of the English and the Wabigoon River systems is also held up as another reason to prevent this project.

Given that the actual impacts of clear-cutting, and road construction in other areas are beyond dispute, can more modern techniques be guaranteed to prevent poor regeneration, silting of rivers and loss of soil? The environmental impact statement for the large-scale extensive forest schemes and the effect on native rights will require immediate investigation before any further consideration of these schemes is contemplated.

The other variant - plantation culture, will generate other environmental considerations (45,46). The maximum yields will come from plantations on marginal or even prime agricultural land. This could present a potential land use conflict if food production was to assume greater importance later in the century. The fuel requirements of a 100 MW facility at 50 per cent load factor with an average harvest of 106 t/ha on a 5 year rotation implies a plantation of 13,160 ha (51 square miles).

The plantation concept requires inputs of herbicide, fertilizer and water. Each of these has an energy and environmental cost. There high risk in maintaining large areas of single species monoculture. The inputs of insecticide and/or fungicide that may be required to meet a "natural" threat to the plantation could become extremely hazardous to water supplies and the ecological balance of the region in which the plantation is situated. A concern affecting both the immediate and the long term productivity will be the loss of humus, nitrogen, phosphorous and minerals from the soil.

Conversion and end-use technologies pose the same environmental hazards of those described above (6.4.2) though with greater effect due to the greater extent of development implied.

Very large scale extensive harvesting of or intensively managed forest may have consequences for the management of fresh water supplies. The transfer of nutrients from the soils to watersheds may take place or in irrigation schemes changes may occur in the water table and the salivity of ground water.

The social and employment benefits will depend on the strategy chosen. Under the extensive management options new plants in the boreal forest may be on land subject to native treaties. The new plants will occasion new settlements that may require incentives to be given to prospective employees. The intensive management scheme of plantations will almost certainly encroach upon marginal and better farm lands thereby displacing historic communities. Both schemes would create sizable employment opportunities often in "have not" regions of Canada.

6.4.4 HEALTH AND SAFETY ISSUES

Persons working in the forest and the conversion plants are exposed to many hazards; of these, noise deserves particular attention. Mechanization and industrial processes generate incredible noise, a hazard to hearing that only becomes apparent in later life.

Generally, chemical and pulp and paper plants have good safety records. The activity in the woods is, however, extremely dangerous with the forestry mortality rate being second to that of mining. The 1966-75 averages (47) for annual fatalities per 100 workers were: Mining, 0.133; Forestry, 0.124; Fishing, 0.087. For comparison, manufacturing and public administration rates were 0.012. Where an accident injury breakdown is available from a Workmen's Compensation Board (48), it is evident that the majority of forestry accidents are in the category "struck against, by, falls, caught in, on or against", with 414 out of 492 claims in this class. This is of course contrary to the popular myth retailed by many foresters that chain saws are very dangerous!

Any expansion of forestry for energy purposes would require more attention to safety aspects though presumably, with more mechanization, the protection of the worker will increase and the social costs thereby will be diminished.

6.5 FACTORS AFFECTING THE RATE OF IMPLEMENTATION

A number of factors have been identified as affecting the rate at which the maximum technical potential summarized in the previous chapter would be realized. The first area of importance relates to the cost availability, insurance of supply, and importance of self-reliance of other forms of energy, particularly liquid fuels. Also of importance are the future markets and uses for the product currently produced by the forest products industry. For instance should Canada become unable, for any number of reasons, to maintain its high level of export of newsprint, much larger amounts of forestry biomass might be available for use as an energy source. Even should Canada decide to make a commitment to greater utilization of its 220 x 10^6 ha forest land for energy, real limits would be imposed by the amount of land that could be brought under intensive forest management practices in one year, with 8 x 10^6 ha/yr as a reasonable upper limit. And finally, the large-scale utilization of Canada's forest land as an energy source may conflict with the Canadian public's views on how a resource that has played and continues to play such an important role in our heritage should be treated.

7. COSTS

The following chapter attempts to estimate the costs that may be expected to be associated with supplying forestry biomass for energy purposes and representative costs for each of the three reference cases.

7.1 COSTS ASSOCIATED WITH SUPPLY OF FORESTRY BIOMASS

Each of the five different sources of forestry biomass will have different costs or cost ranges. A brief discussion of each follows.

7.1.1 MILL RESIDUE

Many mill residues generated at lumber mills, such as chips, shavings and sawdust, are often utilized in pulp mills. Their replacement value was estimated to be $18/ODt in 1974 (compared to roundwood at $32/ODt). For comparision, the value of residues as a fuel was estimated to be $8/ODt (49). Other studies have assigned a negative value to wood wastes of $1.4/ODt (50). The value of the residues which will, of course, be entirely dependent upon the other uses that are available in the particular location where they are generated.

7.1.2 FORESTRY RESIDUE

The cost of collecting and transporting wood waste to a central location for processing was recently estimated to range between $14-33/ODt, compared to the delivered price of pulp of $36-55/ODt (51). An earlier study estimated the cost to vary between $10.50-$20.2 for four locations across Canada (52). Both these estimates are somewhat confusing because it is not clear how much mill residue, if any, are being included in the cost figures. One recent estimate was that slash could be brought in from the forest for $2-20/ODt, with $8/ODt having been experienced by one mill (53).

7.1.3 UNUTILIZED TREES IN CURRENTLY LOGGED AREAS

One study has estimated that the cost of collecting timber residues, cull trees, and dead trees in conjunction with, but as a separate operation from, conventional harvesting is $7.60/green Ton ($14.3/ODt) (54). No estimates were available for the cost of harvesting small trees in conjunction with an existing harvesting operation.

7.1.4 WOOD AVAILABLE IN AREAS CURRENTLY NOT BEING LOGGED

The best estimate of the total costs associated with wood procurement in surplus areas, contained in a recent study for Environment Canada, is $45 ODt, ranging from $36 - $48 ODt depending on the method used for capital cost amortization (55). Another study estimated the cost associated with harvesting, chipping, and transporting wood to a central location in Vermont as being $14.91/green Ton in 1980 or approximately $30/ODt (56). It is not helpful that while on-site chipping has been reported to reduce harvesting costs by 23 per cent (57), other studies have found that this increases the cost by 9 per cent (55).

7.1.5 ENERGY PLANTATIONS

A study on silviculture energy plantations currently underway in the U.S. has estimated the production costs of such operations (including planning, land lease and preparation, roads, planting, irrigation, fertilization, weed control, harvesting, tractors, loading, transportation, interest, taxes, return to investor and salvage value) to range between $18.6 - 38.1/ODt for 10 different sites (58). Similarly, Weyerhaeuser estimated the total cost of producing, harvesting, and transporting short-rotation forestry biomass to be $33/ODt (7 year cycle Cottonwood) and $44/ODt (10 year cycle pine) (59). It has also been estimated that the use of short rotation hybrid poplars in southeast Ontario would result in cost reduction of $10-20/ODt due to reduced transportation distances (60).

7.2 COSTS ASSOCIATED WITH REFERENCE CASES

7.2.1 DIRECT CONVERSION TO ELECTRICITY

No estimate was made of the cost of installing electricity generating capacity into an existing pulp and paper mill with excess heat available.

The total capital costs of a 50 MW wood-fueled power generator appear to be in the order of $40 000 000, based on three separate estimates (10,50,54). Operating and maintenance costs, excluding fuel, are similar to those of a coal-fired plant, or about $700,000/year according to a recent report (61).

The breakdown of the per unit cost of electricity for a 50 MW wood-fired plant was estimated to be 44.8 mill/kWh (62) based on:

	MILLS/kWh	$/TON
Annual Operating Cost	22.57	--
Operating and Maintenance	2.32	--
Fuel Cost		
Processing	0.67	0.50
Harvesting	14.24	10.65
Chipping	2.68	2.01
Transportation	2.34	1.75
Sub Total	19.93	
TOTAL	44.82	14.91

For comparison, the cost of producing electricity using low sulphur coal was estimated to be 49.15 mills/kWh. The use of larger sized wood boilers would be expected to reduce the boiler costs by 25-30%

7.2.2 GASIFICATION AND ON SITE UTILIZATION

Detailed cost data on wood gasification systems are not yet available at this stage in the development of the process. Based on information from three gasifier manufacturers (Union Carbide, CIL and Westwood Polygas), capital costs appear to be in the range of $10,000-25,000 per ODt/day with higher values associated with units equipped with an oxygen plant. One recently published estimate of the costs associated with a 179,000 ODT/year (500 ODT/Day) gasifier with a steam boiler and turbo-generator were estimated to be $22 150 000 with an annual operating cost (including capital at 5% over 20 years) of $3 300 000. If this gas were sold at $2/MCF and the electricity at 15 mills, the disposal charge for the wood waste would work out to $4.2/Ton (63).

7.2.3 GASIFICATION AND METHANOL PRODUCTION

Two recent studies have provided cost estimates of methanol plants. Katzen (64) estimated capital costs of $64 000 000 and $169 000 000 for 50 and 200 million US gallons per year respectively. InterGroup (65) estimates $59 300 000 and $139 000 000 for 50 and 200 million Imperial Gallons per year respectively.

Katzen estimates (using 30 per cent profit before taxes and 14 per cent depreciation, maintenance taxes and insurance) the production cost to be 58¢ and 38¢/US gallon exclusive of wood cost for the 50 and 200 million gallon per year cases.

InterGroup (assuming 15 per cent DCF before tax) instead of after tax arrived at 30¢ and 24.6¢/US gallon exclusive of wood cost for the same two cases.

Katzen's estimate of cost per gallon (US) for the 50 million gallon plant with wood costs of $34/ODT is 96¢ at a time when chemical grade methanol was selling at 38¢/US gallon (1975).

A comparison from the data of InterGroup is not available since final cost estimates are only presented for novel methanol plants using much less wood per ton of methanol than the base case comparisons. By making technology assumptions and essentially a utility financing structure the InterGroup report concluded that wood wastes at about $20/ODt would provide methanol at a competitive price.

TABLE I
ENERGY AVAILABLE FROM FOREST BIOMASS IN CANADA PER YEAR

				CONVERSION TECHNOLOGY**		
Source of Supply	Amount Forest Biomass Available per Year 10^6 ODt	(ODT)	Gross Energy Content 10^{18} J (10^{15} BTu)*	Electricity Production 25% Efficiency 10^{18} J (10^{15} BTU)	Producer Gas Production (70% Efficiency) 10^{18} J (10^{15} BTU)	Methanol Production (38% Efficiency) 10^{18} (10^{15} BTU)
MILL RESIDUES	7.5	(8)	0.14	0.04	0.10	0.05
RESIDUES FROM FOREST OPERATIONS	31	(34)	0.58	0.15	0.41	0.22
UNUTILIZED TREES IN CURRENTLY LOGGED AREAS	20	(22)	0.37	0.09	0.26	0.14
WOOD AVAILABLE IN AREAS NOT CURRENTLY BEING LOGGED (WITH 130% ADDITIONAL BIOMASS FACTOR)	52	(57)	0.97	0.24	0.68	0.37
TOTAL	109.5	(121)	2.06	0.52	1.45	0.78

* 10^{18}J = 10^{15}Btu = 1 Quad.

** The efficiencies quoted are process efficiencies and do not include other energy losses such as harvesting.

NB: The volume of wood harvested by current forest operations total $139 \times 10^6 m^3 (4.9 \times 10^9 ft^3)$ or 51×10^6 ODt (56×10^6 ODT) equivalent in 1974.

8. CONCLUSIONS AND RECOMMENDATIONS

A major conclusion of the panel was that the biomass resource base was not properly quantified, be it mill wastes or total forest productivity. The resource must be quantified on a high priority basis particularly for the large scale schemes. However, despite the lack of a definitive resource data base, it was estimated that something in the order of 110 x 10^6 ODt of forest biomass are available for energy conversion per year in Canada. This represents a maximum technical potential of between 0.5-1.5 x 10^{18} J of energy, depending on the conversion technology. Table 1 gives the estimated quantities of resource available.

The following is a list of programs and their benefits that would expedite the use of the renewable energy contained in the forest areas of Canada. The programs are identified in near (1978-83), medium (1990), and long (2025) time horizons.

8.1 NEAR TERM ENERGY SUBSTITUTION OPTIONS

There are forest areas where a wood waste disposal problem exists along side the use of a premium fuel for kilns and process heat. This can be rectified by thermal steam/electric generation from the waste or gasification technology to produce producer gas. The LEAP discussion identified the interior B.C. forest industry as a prime candidate for the replacement of natural gas by hog fuel use with 64 per cent of the B.C. forest industry in 5 regions containing 66 per cent of the surplus hog fuel. The energy substitution of 26 trillion BTU of natural gas represents about 22 per cent of B.C. natural gas usage (1974) (2).

The construction of thermal power stations fueled by harvested wood and wastes was also advocated particularly in the case of combined saw mill/pulp and paper/power station applications where the co-generation of process steam and electricity could easily be arranged.

Specific projects that could be instituted would therefore be the estimation of existing steam capacity in pulp mills and the costs of generating electrical power for on site needs as well as possible integration with electricity utilities.

Another option would be to bring producer gas technology up to commercialization so as to replace the natural gas firing of kilns and driers in the forest products industry. In the Maritimes this technology has been proposed in conjunction with internal combustion engines to generate electricity in small units (2 MW). Thus the technology investment would have application in all provinces having an adequate resource base, a base which could also include many agricultural wastes such as straw and some peat deposits.

The provision of space heating in Northern and Maritime areas could be served by modern wood stoves with local harvesting of wood. To this end a Canadian industry could be aided by the establishment of suitable standards of safety and efficiency ratings of wood heating appliances. The industrial base exists today with 15,000 - 20,000 units of wood/oil combustion furnaces produced and sold in Canada and the U.S.A. Second generation stoves are being developed which can be fed wood chips to take advantage of modern mechanized harvesting techniques. This intermediate scale technology would be particularly important in rural areas where the cost of oil and gas has become especially onerous.

While relatively small scale in proportion to the total availability of wood energy, these steps indicate a significant substitution potential at relatively low investment. Moreover the returns on investment should attract private sector support relatively easily in several areas.

8.2 LARGE SCALE USES OF THE FOREST BIOMASS IN ALL TIME FRAMES

8.2.1 ELECTRIC POWER GENERATION

The direct production of electric power from wood grown intensively would be close to economic today (62). A regional experiment on Vancouver Island or in Eastern Ontario would give an opportunity to test and identify those areas of harvesting technology, resource management, environmental protection systems and power generation costs that require development. For example senior governments might sponsor a 150 MW demonstration targeted for the medium term, with studies in the areas identified as requiring more work starting in the near term.

8.2.2 CHEMICAL FEEDSTOCKS AND FOODSTUFFS

This is an area of energy and petroleum resource substitution and was not considered in detail here. The task is one of reviewing the economic potential of possible end products from wood. This task, already undertaken to some extent by previous studies, (3,13,49) would result in a list of products which may have potential as economic substitutes for petroleum products. This may include any of glucose, phenol, benzene, methanol, ethanol, etc. This would be a near term task with the possibility of pilot plant studies and in the medium term full scale production of chemicals identified as economic by the earlier feasibility studies.

Animal feed potential from poplar and aspen is very high and current initiatives such as "STAKE" technology should be encouraged so far as is economically feasible as a substitute for high energy grain crops.

8.2.3 LIQUID FUELS FROM BIOMASS

Ultimately renewable energy will be almost the sole source of power. However in the time frame of LEAP to 2025 it is very difficult indeed to predict how the biomass resource will be utilized. The case studied was a synthetic fuel, methanol, produced by the synthesis gas route by gasification of wood.

The study recognized the possible shortfall in the medium term for premium liquid fuels for transportation but was unable to recommend either the best synthetic fuel or the most significant end use. Therefore in the near term more rigorous surveys of the applicability of synthetic fuels and the best synthesis route to these from biomass should be undertaken. This would entail bench scale evaluation of <u>all</u> processes close to technical realization along with demonstration at the pilot plant scale. End use by sector should also be examined for demand and economic feasibility. In the case of methanol, the effects of the Canadian conditions on blends such as M-15 should be evaluated in selected vehicle pools to demonstrate in the near term whether or not such blends are compatible with cold winters and Canadian fuel distribution practices.

Since methanol is also a possible product of coal gasification and has been proposed as a transport medium for Arctic gas, it may very well be that the renewable and fossil options will be complementary in the near term. Even in the present technology for gasification of solid waste with oxygen, the gasifier technology owes a lot to coal gasification. During the study, an argument for the development of medium or high pressure gasification (as against the atmospheric Purox type process) was made on the basis of coal experience. So far, experience with coal processing by gasification has shown little improvement in thermal efficiency but capital investment savings of 15% have been realized with the decrease in size of plant for a given throughput. The question of whether or not to develop a pressure gasifier independently within Canada is still open and before engaging in an expensive program (estimated at $20 - 30 000 000 over 10+years) a careful study of possible benefits should be undertaken.

In any case, the technology for converting synthesis gas (CO/H_2) to synthetic fuels should be monitored very closely world wide whatever the synthesis gas feedstock may be. One interesting area is catalytic conversion of methanol to synthetic gasoline (Mobil process); perhaps this could be made to occur directly from synthesis gas.

8.3 THE ROLE OF THE FEDERAL GOVERNMENT

Using federal resources such as remote sensing with the cooperation of provinces in ground based observations, the total biomass resource should be evaluated. This could entail satellite imagery, aircraft photography and radar altimetry and direct field measurements of productivity.

The environmental impact of increased use of forest biomass should be assessed not only for productivity but also for the impact on Canada's fresh water resource.

The total energy analysis of the large scale schemes (electricity, liquid fuels) should be determined at an early stage using the Statistics Canada facilities which have used an altered version of the input/output economic model to determine the net energy efficiency of large scale projects such as CANDU and the tar sands (66).

For all synthetic fuels, especially those produced from biomass the Federal government might wish to weigh the benefit of a non-interruptible supply against the inevitable poor economic status of synthetic fuels today. To be specific, a reasonable investment in Research, Development and Demonstration (R, D & D) in the near term would enable an intermediate scale, widely dispersed biomass/liquid fuel industry to be rapidly put in place if dictated by the medium term energy supply situation. The areas needing direction and funding of R, D & D are indicated above.

For those options identified as having near term energy substitution potential, the major influence of Provincial and Federal governments would be in providing economic incentives, through either fixed regimes (such as rapid capital write-off) or encouraging utilities to alter rate structures to promote the greater utilization of forestry biomass for energy. This will be particularly important within the existing pulp and paper industry where a large co-generation potential appears to exist.

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