

IDENTIFYING ENVIRONMENTALLY PREFERABLE USES FOR BIOMASS RESOURCES

STAGE 1 REPORT:
Identification of Feedstock-to-Product Threads

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Introduction

Canada is richly endowed with significant biomass resources. For example, the estimated thermal energy content of the annual biomass harvest in Canada is 5.1 Exajoules (1 EJ = 10^{18} joules or 1.4×10^6 GWh). This annual harvest is equal to 62% of the thermal energy derived from fossil fuel combustion (BIOCAP 2003). The development of this biomass resource, not just for energy but a variety of end uses, presents Canada with an opportunity to not only develop new and innovative industries but sustainable energy and raw material supplies while also reducing our reliance on non-renewable fuels and our greenhouse gas emissions.

This Phase 1 report builds on past studies to summarize the size of Canada's major biomass resources (forestry, agricultural, and municipal residues, landfill gas and energy crops) and for each sector identifies a number of possibilities and technologies that could be applied to this resource for energy and other potential commercial purposes. It also provides some initial information on regional concentrations of biomass. That information is required to select suitable feedstock-to-product processes or "threads" for analysis during the second phase of this work. Each thread will describe the processing steps to convert a biomass feedstock to a product that can be used for transport fuel, electricity, heat, fertilizer, and other products.

Reference to particular companies or specific processes in this report does not mean that the authors necessarily recommend these processes or companies or that they are commercially viable at current energy prices or greenhouse gas credit values. Rather, they are presented to demonstrate that such companies and processes exist and that literature is available for further investigation.

Five main ways to utilize biomass were identified:

1. **Biochemical Transformation** – this includes: fermentation to form alcohols such as methanol or ethanol; anaerobic digestion to produce methane (landfill gas); or chemical treatment of fats and oils to produce biodiesel. Biodiesel can be produced from vegetable crops, wood residue, and from liquid forms of waste biomass, such as animal fat or used cooking oil, as well as from wood (bio-oil, see point 3).
2. **Combustion** – this process uses the biomass directly to generate thermal energy, which can in turn be used to provide process heat, space heat, or can be used in a boiler system with a turbine to drive a power cycle to generate electricity. Combined heat and power units will deliver both useful heat and electricity and achieve a high degree of conversion efficiency.
3. **Pyrolysis** – this process produces a bio-oil liquid from which chemical products can be extracted, or which can be used as a transportation fuel or as a fuel for stationary engines.
4. **Gasification** – this process partially combusts biomass to produce a mixture of gases referred to as syngas in this report. This syngas can in turn be refined to yield hydrogen, converted into methanol, converted into various other chemical products, or it can be used to displace or replace fossil fuels to generate power in an engine, turbine, or boiler.
5. **Material uses** – this includes all of the other non-energy uses for biomass in addition to the energy and thermal conversions mentioned above. For example using the raw biomass, the extracted fibres and other compounds to produce: starch-based plastics, building materials (e.g. wood products, MDF or strand board); pulps and papers, yarns, fibres and fabrics; fertilizers, soil improvers and compost.

Research is on-going towards the so-called “biorefinery” concept, i.e. the extraction of multiple specialty chemicals from biomass. While these can improve overall process economics, making some of the above five options more viable, they have minimal impacts on climate change issues, and are therefore treated as a side aspect in this examination.

Figure I-1 traces the conversion of biomass through basic processes and intermediary forms to final energy products for combustion, gasification, and pyrolysis. There may be numerous intermediate products or energy forms but they are temporary in the cycle of source-to-energy use. Two of the noted final products, charcoal and coke, are intermediary forms themselves as they can both be used in further processing. In fact there are only three final products with respect to energy-related uses of biomass: electricity, heat and kinetic energy for transportation.

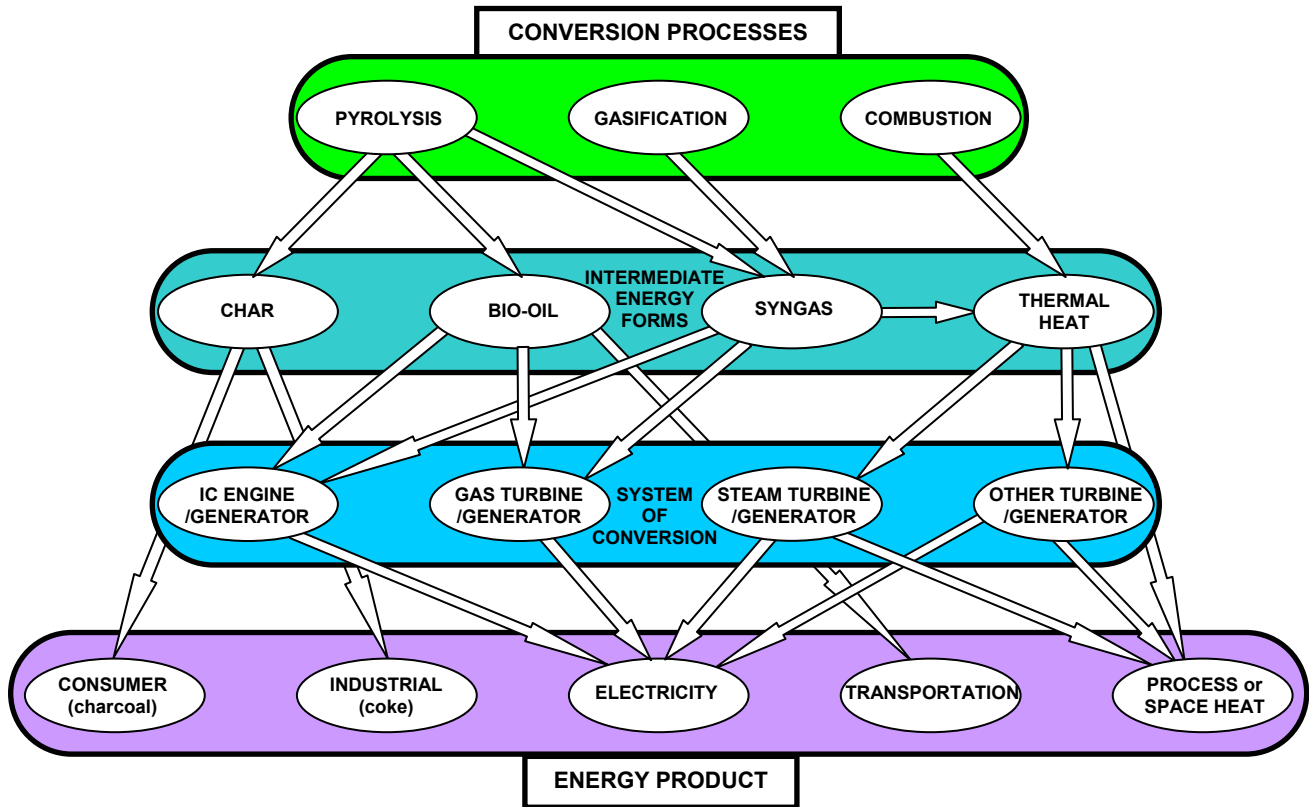


Figure I-1 Thermal Conversion Processes

Biomass contains a great deal of energy. Its energy density is lower than that of fossil fuels, but far higher than that of other “green” energy sources, such as wind, wave and solar. In addition, biomass is transportable and available for use on demand, i.e. it can be used as a firm power source, as opposed to intermittent renewable resources.

During the last century, electrical power production from biomass has been implemented in locations where high concentrations of available biomass allow for large systems to be built, as smaller, decentralised units could not reach the necessary economies of scale. In particular, pulp mills have become “integrated” to not only use recovery boilers to minimize chemical requirements but also to use hog fuel boilers to create additional steam and electrical power to minimize electricity purchases. However, much of Canada’s more dispersed biomass is not being utilized productively. This has sparked interest to develop new technologies for biomass

utilization that yield higher-value products than just steam and electricity, reduce costs, thus becoming viable for smaller quantities of biomass.

Many biomass conversion options are technically defined but are not commercially viable. In some cases, the market for the product is minor while in other cases the technology is too complex to compete with other sources. Some of the processes are relatively simple (i.e. the use of biomass as a soil improver or residential space heating) and others, such as gasification and subsequent chemical treatment, can be quite complex. **Figure I-2** illustrates the many ways in which syngas produced from biomass can be transformed, into a variety of process streams that can be used to replace petroleum-based products. Although the composition and therefore the treatment options for all biomass sources are at one level similar, the different physical and chemical structures, locations, and distributions of the various resources tend to favour feedstock-specific processes and uses.

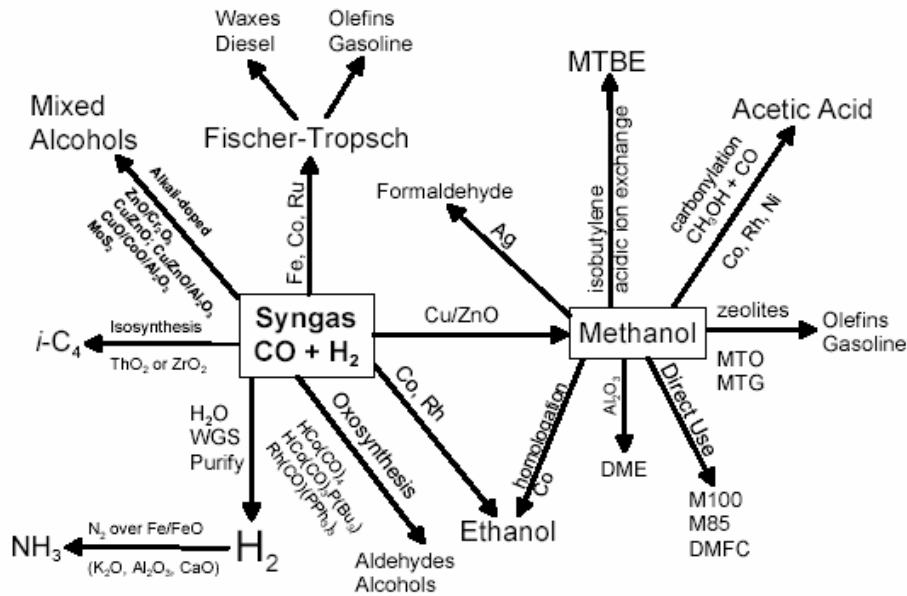


Figure I-2 Selection of Options to Use Syngas and Methanol for Products
[NREL 2003, p.14]

Feedstock	Treatment 1	Step 1 Product	Treatment 2	Step 2 Product
Wood	Combustion	Heat		
Corn stover	Fermentation	Power	Steam reforming	Hydrogen
Switchgrass	Composting	Ethanol		
Landfill gas	Shredding	Biodiesel		
Solid waste	Mixing	Pyrolysis oil	Catalytic conversion etc.	Methanol
Rape seed	Separation/cleaning etc.	Syngas etc.		Biobased chemical product
Etc.				

Figure I-3 1-Step and 2-Step Feedstock-to-Product Threads

Figure I-3 shows that the production of biomass-based products can take one or two processing steps: in the case of electricity production, biomass is burned in one step, possibly with some pre-treatment, such as shredding or sorting. Other products, such as hydrogen, are produced in a two-step process – and yet others could even require a third step. Each step will require additional energy and possibly other inputs which can reduce overall resource efficiency. It

should be noted that for fuels, such as hydrogen and methanol, engine efficiencies must be taken into account when comparing them to fossil alternatives.

A large number of “threads” were identified. By recognizing the modularity of different processing steps we can break down the “threads” into several processing steps, making the comparison of various options and feedstocks possible. Whereas many options to use biomass are presented here, a large number of initiatives and research projects are underway to use biomass in yet different ways, extract specialty chemicals, and to improve existing technologies to become more efficient and economically attractive. The field of biomass utilization is evolving rapidly, and new developments are published almost daily.

The **Phase 2** report of this study will not only relate to Canada’s particular situation, but will also extrapolate the results to other jurisdictions, concentrating on the U.S., Mexico and Western Europe. The situation in each country or region will differ, depending on the fossil fuels that biomass can replace and the specific emissions assigned to them, the electricity generation portfolio, and the availability of resources. For example considering wood, **Table I-1** shows that the use of wood as a fuel in Europe, North America and Mexico amounts to a few percent of overall energy use. However, per capita use of wood as a fuel is lowest in Europe and highest in Canada, indicating that the harvest of fuel wood is already high here as the resource is abundant. On the other hand, limited resources may be the reason for lower harvesting rates in much of Europe and Mexico. It is of interest to Canada that Finland used biomass to fill as much as 19.5% of its energy needs in 1991 [ARC 2003(1), p.26].

Table I-1 Use of Wood for Energy Purposes in North America and Europe
[IEA 1998, p.135ff.]

Country/ Region	Timber demand	Wood fuels demand		Ratio wood/ all energy	Per capita wood energy demand m ³ per capita/yr	Sources of Wood Fuels (FAOSTAT, in 1000 m ³ of fuel wood)			
	1000 m ³	1000 m ³	PJ	%		Fuel wood	Char-coal	Resi-dues	Black Liquor
Canada	182,388	34,538	345	4	1.17	5,319		600	30,673
USA	408,948	237,900	2,379	3	0.90	90,362	4,482		115,000
Mexico	6,060	32,775	328	6	0.35	15,574	840		634
Western Europe	145,377	91,310	913	2	0.25	28,377	1,268	18,025	15,636

Figure I-4 compares the current use of biomass in the supply of energy needs for North America and Europe. As can be seen, the USA and Europe have the lowest share of biomass in their energy portfolios, whereas Mexico covers more than 9% of its total energy needs from biomass (1998 data). Biomass has a large potential and it is estimated that it could cover as much as 20% of Europe’s energy needs, and in Canada, residual biomass alone could provide about 25% of the energy now obtained from fossil fuels [BIOCAP 2003].

Several scenarios may be necessary to provide a true picture of the environmental impacts of replacing fossil fuels with biomass in each country or region. As **Figure I-5** shows, the electricity background mix is very different for the three North American countries, as well as for Western Europe. There are also differences which also occur within each of the countries (e.g. the fuels used for electricity production vary between Canadian provinces). This variation needs to be

taken into account when making recommendations for the best use of biomass and may result in different results of the analysis with respect to emission reduction benefits.

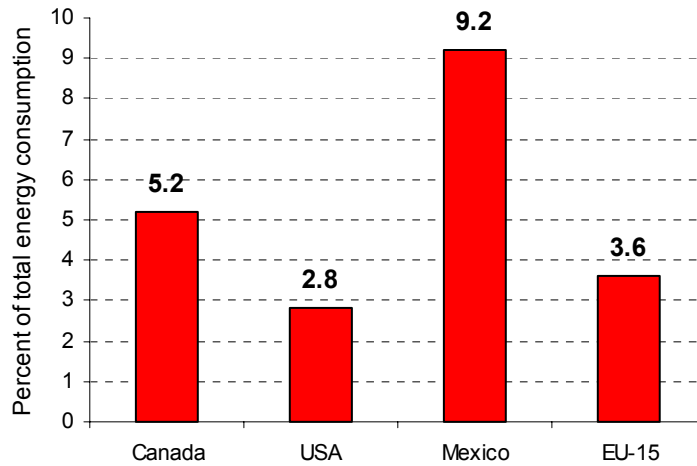
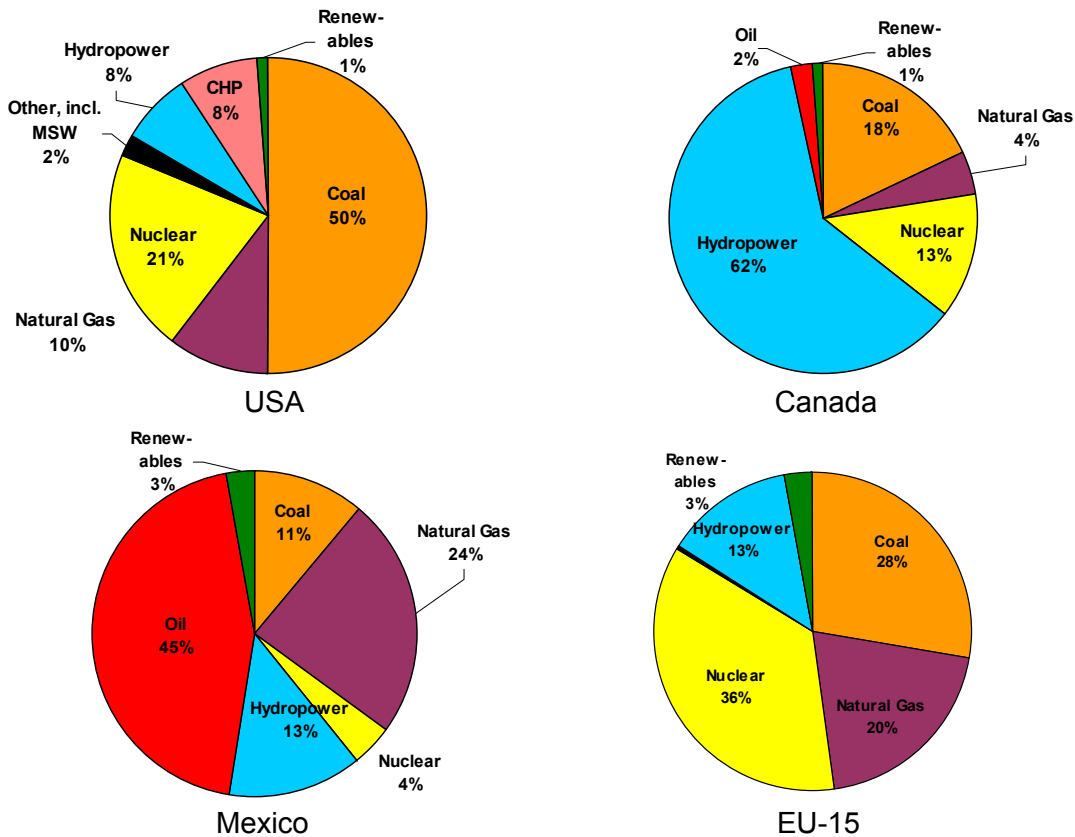


Figure I-4 Share of Biomass-Derived Energy in Overall Energy Consumption [IEA 2002(1)]



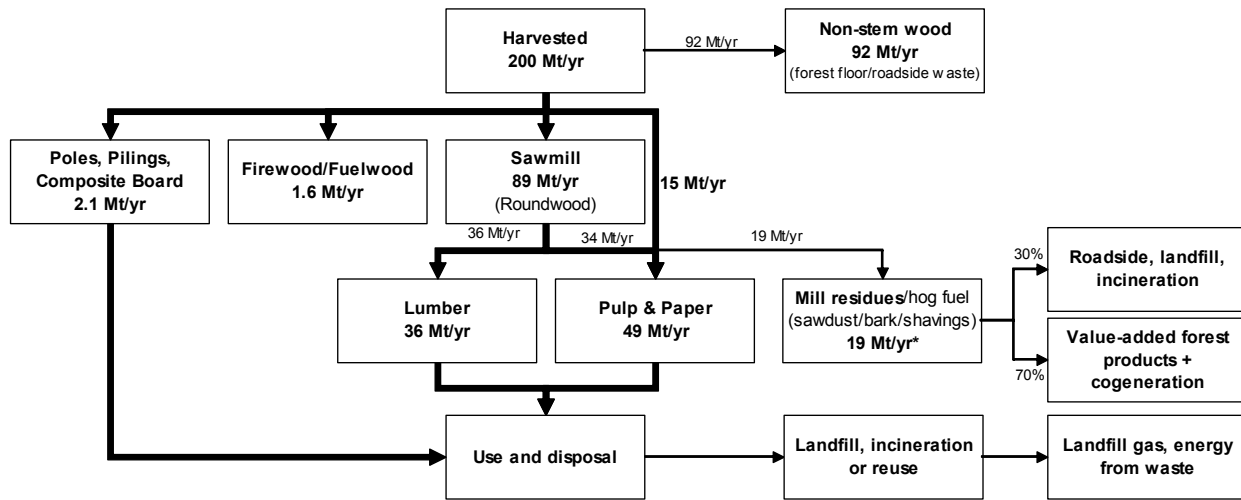
CHP = Combined Heat and Power; MSW = Municipal Solid Waste

Figure I-5 Electricity Production by Source in the U.S., Canada, Mexico and Europe [IEA 2002(2)]

Chapter 1 Forestry Residues

1.1 Forest Biomass in Canada

Each year, Canada’s forestry sector harvests more than 100 Mt of roundwood, and more than 90 Mt of non-stem biomass (treetops, branches and leaves which are left behind at or near the sites where the roundwood is harvested because it is uneconomical for use in sawmills). This harvest of roundwood and non-stem biomass alone has an energy content of about 3.1 EJ/yr, or approximately 36% of the current Canadian energy consumption provided from fossil fuels.



Based on Table 2.6 of BIOCAP 2003; 1 m³ of wood = 0.54 tons ODT

* the number in literature is generally somewhat smaller, i.e. 17-18 Mt/yr [CFS 1999]

Figure 1.1 Annual use of harvested forest biomass in Canada

Figure 1.1 shows how harvested forest biomass is currently being used. So far, most of the non-stem wood is not being used in North America although some is used to produce mulch for reclamation of logging landings. Some trial programs to collect this resource are currently being conducted in Europe, as preliminary estimates suggest that overall carbon emissions could be reduced by as much as 4-6% through its use [PA0923 2003]. A significant portion of the non-stem biomass could be available in Canada. Its energy content is 1.44 EJ/yr or about 17% of Canada’s current fossil fuel energy consumption [BIOCAP 2003, p. 16]. The non-stem wood category could be expanded to include other non merchantable forest biomass, such as tree thinnings (for disease control, scrub forest reclamation or forest fire mitigation), partially-burned/fire-damaged wood left after forest fires, diseased wood (bugwood affected by pine beetles), inferior tree species, and wood from community interface zones (a belt of about 3 km around inhabited areas to prevent forest fires from reaching settlements), and dry land sort wood waste¹ (an important stream of biomass, mainly bark, from sorting operations off rivers used for transporting wood) that could also be added to this category. According to the BC Ministry for Sustainable Resource Management, about 15 million m³ of bugwood are expected to be

¹ Contamination of this material with rock and grit is typically a challenge to its successful use as a fuel or use as a feedstock for another product.

available over the next ten years in the province [BCSRM 2003]. However, no estimates for the recoverable amounts from these sources have been found for this study.

Figure 1.1 also shows that much of the “hog fuel”, i.e. residues from milling operations, is already being used for energy generation. The hog fuel is mostly used wherever it occurs in sufficient quantities to make its economic utilization possible, i.e. at large saw and pulp and paper mills, where it is often used for combined heat and power generation. However, some 30% of this resource is still being landfilled, incinerated (sometimes in beehive or silo burners) without energy recovery, or simply left to decompose near roadside landings. All three ways of handling forest residues mentioned raise significant concerns: wood landfills have been shown to have a leaching problem that introduces pollutants into the environment. Incineration in uncontrolled beehive and silo burners produces excessive particulate and smoke emissions. Leaving residues in the forest “near the roadside” interferes with ecosystems, encourages insect infestations and can present a wildfire hazard. In addition, each of these practices has associated greenhouse gas emission profiles that can be improved.

This biomass is distributed and meaningful applications often require local utilization at the biomass production site to limit transportation costs. Some of the biomass is stockpiled, with some highly localized concentrations. For example, Saskatchewan has about 4 million tons of wood residue in landfills [AGB 2001, p.20] and BC has various woodwaste landfills. Technologies to utilize these resources need to be able to handle fuel with a high moisture content (50-60%).

Another resource derived from forest products is tall oil. Tall Oil Products such as Crude Tall Oil, Distilled Tall Oil and Tall Oil Fatty Acids are derived from Pine trees. They are by-products of the manufacture of paper and could be turned into bioenergy products, such as biodiesel. The Canadian tall oil production is estimated to be roughly 180 thousand tonnes per year [GCSI 1998, p.15]. Pulp and paper mills will often burn this residue in black recovery boilers to produce energy.

1.2 Geographical Distribution of Forest Biomass

Based on the National Atlas of Canada, sawmills can be found across the nation, with most activity going on in British Columbia, Northern Alberta, Eastern Ontario, Southern Québec and across the Maritimes (see Figure 1.2).

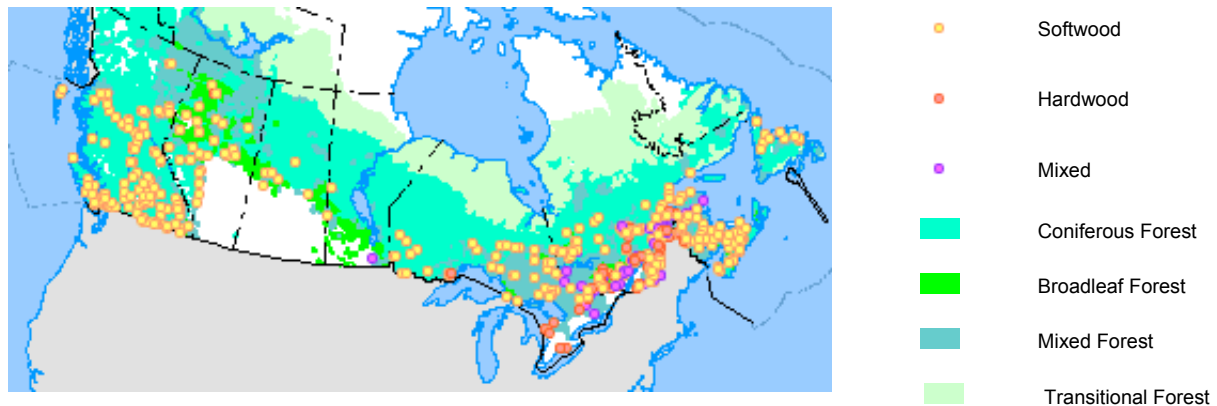


Figure 1.2 Location of Sawmills Across Canada [NAC 2003]

Apart from sawmills, pulp & paper mills and plywood mills will also be points where biomass residue can be found concentrated. Plywood production in Canada in 1999 was 1.9 million cubic metres, and 80 per cent of the total Canadian production came from British Columbia. With nearly half of Canadian softwood production also coming from BC, the province clearly has the largest wood and woodwaste resource among Canadian provinces. For pulp & paper mills, the picture is somewhat different: only 31.5% of pulp and 15.2% of paper were produced in BC in 1999 [COFI 2000]. Canada has 102 paper and board mills and 44 pulp mills. The paper and board production capacity is 22 million tons and the market pulp production capacity 12 million tons. Most of the pulp and paper mills are located in the Atlantic Provinces, Ontario and Quebec. [HUT 2002]

The next map (Figure 1.3) shows concentrations of timber productive land use, an indication of where Canadian forests are harvested most intensively. Therefore, the most intensely harvested forest biomass areas in Canada are located in:

- Ontario: along the St. Lawrence River, north of Greater Sudbury and the Thunder Bay
- Alberta: north and south of the Athabasca River and,
- BC: from the Columbia River valley up to the Prince George Area, the Queen Charlotte Islands and the western part of Vancouver Island in BC.

Local availability of biomass will depend on different factors. For example, if forestry is to be intensified for energy needs, areas that are currently not used extensively may be utilized. If forest residues are to be used, the highest quantities of non-stem wood will be available where forestry is most intensive. As a starting point for this project, it is important to account for current uses of forest biomass. Sawmill residues are already being used in some areas, and Table 1.1 shows the available amounts of all mill residues in each province. Their availability is highest in British Columbia, followed by Québec and then Alberta. Ontario, for example, seems to be using most of its mill residues already.

Table 1.1 Unused Mill Residues in Canada [CFS 1999]

Province/Country	Surplus [million BDt]
British Columbia	2.06
Alberta	0.90
Saskatchewan	0.05
Manitoba	0.02
Ontario	0.45
Québec	1.64
New Brunswick	0.18
Nova Scotia	0.06
Prince Edward Island	n/a
Newfoundland	0.02
Canada	5.4

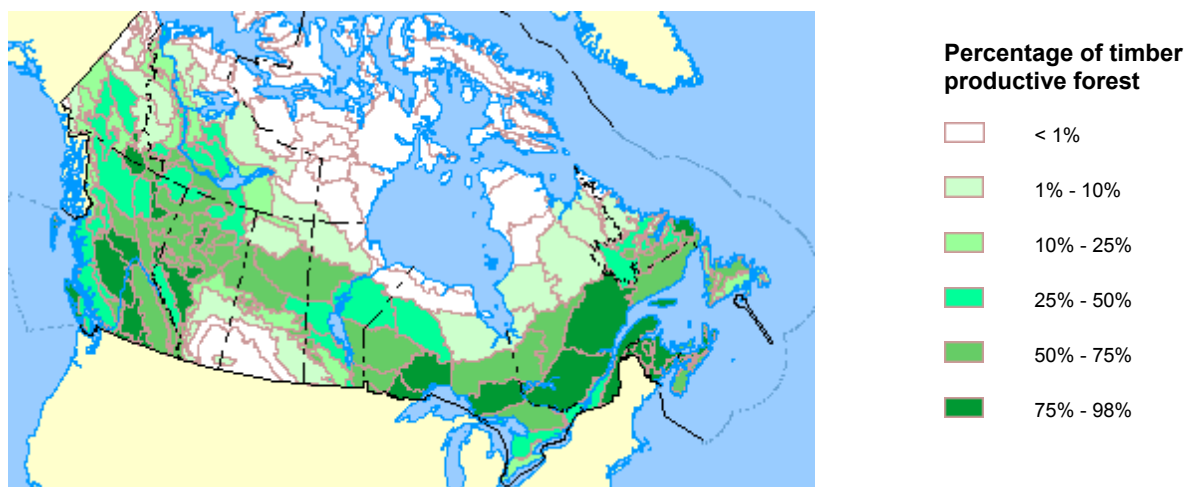


Figure 1.3 Timber Productive Forest [NAC 2003]

1.3 Possible Uses of Forest Biomass

1.3.1 General

There have been a number of developments of equipment designed specifically to combust biomass more completely and reduce fly ash emissions. These systems were developed because even the best large grate boilers showed significant inefficiencies. These boilers expelled carbon in the bottom ash as well as carbon, carbon monoxide and unburned hydrocarbons in the flue gas. These components represent unconverted potential biomass energy.

Combustion systems designed to fully convert biomass have generally followed one of several approaches: high temperature combustion systems use a refractory that reflects and re-radiates the combustion heat back onto the fuel bed to maintain temperature and ensures a complete burnout. Two-stage combustion systems use a gasifier chamber followed by a second refractory lined chamber where high temperatures complete the combustion. With lower moisture biomass the secondary combustion can be maintained by a scroll burner (or a similar system) without the need for the second chamber. (Gasification is also used by some systems to produce a syngas as an engine fuel, as will be discussed later.) Combustion systems are either operated at high temperatures to ensure full burn-out or they used a secondary “catalyst” to ensure full biomass exposure to sufficient heat. Refractory-lined combustion chambers are an example of the former. Fluidized bed combustors are an example of the latter, with hot sand acting as a “catalyst” to ensure the intimate mixing of the biomass fuel and full contact with high temperatures to ensure complete combustion.

High temperature combustors are an effective way to maximize the thermal energy produced from biomass while reducing unwanted emissions. To obtain the desired effects the combustion chamber must be refractory lined to capture the heat and maximize combustion temperature. This means that heat recovery must all be done from the hot flue gases and not from boiler tubing on the walls. Such combustors will typically minimize/eliminate carbon in the ash and flue gas. The particulate emissions are reduced, but not sufficiently to meet environmental regulations.

Gasifier two-stage combustion systems operate functionally similar to high temperature combustors. The partial combustion of biomass on the bed is desired for its reduced air supply, velocity and ash carrying ability. The potential advantage of gasifier two-stage combustion over high temperature combustion is reduced particulate emission.

Fluidized bed combustors have been shown to combust biomass very completely and also reduce/eliminate carbon. Both bubbling bed and travelling bed designs can be implemented. One advantage of bubbling fluidized bed boilers is that they can operate with boiler wall tubes in a design similar to traditional grate boilers. There are several disadvantages that are operationally significant. Some of the ash produced in the sand bed will fuse into clinkers which can be removed during operation. However, all of the remaining ash as well as worn sand particles (as they become small in size) are carried off with the flue gas. The fly ash loading often becomes greater than traditional boilers. In addition the worn sand particles that are carried in the flue gas, being silica, are abrasive. These two conditions put added operational stress on fluidized bed combustors.

Conversion of biomass using two-stage or high-temperature combustion systems is commercially used to produce heat to displace fossil fuels. These units can vary in size from

small residential fireplaces, to medium size units capable of converting all the biomass waste of a sawmill. They can be configured to convert all the hog fuel generated in several sawmills, and through heat recovery steam generators (HRSGs) to produce process steam in a pulp mill. Generation of heat from biomass is the least technology intensive conversion technology.

1.3.2 Electricity Production

- a) Large Combustion Systems. Traditional biomass conversion to electricity uses large scale boiler systems to create steam and turbine/generator systems to produce electricity. The reference to “large scale” is relative to the quantity of biomass consumed compared to quantities of biomass normally available in given locations. In fact traditional biomass boilers are considered “large scale” in the 35-MWe to 80-MWe range whereas traditional coal-fired boilers are an order of magnitude larger at 100-MWe to 1500-MWe.

Industrial biomass boilers are typically large cavity, “water-walled” combustion chambers with superheater, boiler and economizer tube banks in the outlet flue gas stream. The boiler section consists of a natural circulation design with a steam drum, mud drum and several boiler tube circuits. The wet-wall sides of the boilers, under-grate tubes and direct flue gas boiler tubes are all interactively connected in a relatively complex circulation pattern. Burning is done within the combustion cavity with a bed of biomass at the bottom fed with air from below. Typically the control strategy does partial combustion in the biomass bed with volatiles being driven off into the cavity. Over-fire air in one or more stages is used to complete combustion. Several grate systems have been implemented within this fundamental boiler design approach. Newer bubbling fluidized bed systems generally follow this same fundamental design. Travelling fluidized bed systems are less common and have design aspects more specific to their operational needs.

For production of electricity these boiler systems are integrated into power generation systems using steam turbines directly driving generators at line frequency. The fundamental power conversion uses steam in a Rankine cycle. In such a cycle the bulk of the energy is lost as unrecoverable latent heat of the steam which limits the thermal efficiency. The steam must be expanded to vacuum conditions to maximize the energy recovery and the result is very large equipment to handle both the high volume flow and the low pressure drop requirements. Typically the overall efficiency of large steam systems is limited to about 20%, electricity output from gross fuel energy content. With the addition of some added boiler efficiency enhancers, such as combustion air pre-heaters, the overall efficiency can be enhanced to exceed 25%.

Steam systems require operation by highly qualified and regulated personnel. This adds significantly to the operation cost and the cost of power generated. Handling of biomass fuel requires greater effort, storage area and equipment size compared to fossil fuels. In addition, heat rejection must be considered separately. Unless a source of cooling water (e.g., direct river water use) is readily available, heat must be rejected to the atmosphere. Due to the low temperatures of reject heat required to maximize cycle efficiency, evaporative cooling towers or cooling ponds must be employed. Such systems are large, require notable pumping energy, require maintenance support and are weather dependent.

Direct Combustion / Steam Turbine System

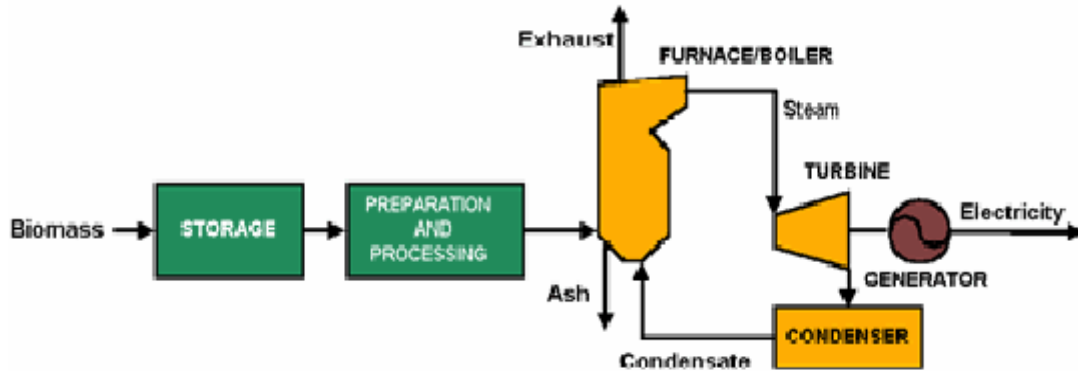


Figure 1.4 Generic Flow Diagram of a Direct Combustion System [Trillium 2002, p.22]

- b) **Small Combustion Systems.** Biomass is a distributed source of moderate energy content. There are only few situations where biomass is sufficiently concentrated to support large-scale boilers. Quantities that would combust to produce less than 100 MW_{th} (or 25-MWe) are generally insufficient to be converted to electricity economically when using traditional equipment. Concentrations of forest biomass, such as waste from roadside landings, log yards, land clearing, bush chipping, mill log yards, pulp mill woodrooms, sawmills and wood product plants, are generally smaller than what is required for a large-scale plant. In addition there are sources of biomass suitable only for energy production but located where large power generators would have no market. Such sources include bugwood from pine beetle infested forests, scrub forests and fire killed areas.

It has long been recognized that power generation from forest biomass on a small scale would open significant opportunities. Benefits could be realized in environmentally preferred methods of waste disposal, new power generation, displaced fossil fuel use, reduced greenhouse gas emissions and reduced particulate emissions. This has sparked efforts to address this potential market.

A number of attempts have been made to produce small biomass power systems using a steam Rankine cycle. Scaling effects and practical engineering requirements reduce the overall efficiency of such systems by a factor of two. As a result, the unit capital cost increases and makes this approach uneconomical. In addition, the requirement for highly qualified operating personnel makes the unit power cost of production prohibitive. Small steam systems on the market are generally project-designed with available equipment, rather than purpose-designed. Small co-generation systems are more accepted as the heat benefits enhance project economics.

A second approach has been presented using a closed Organic Rankine Cycle (ORC) that appears to be technically successful. An advanced version of the ORC offered by a European company (Turboden, srl) uses a synthetic oil working fluid and results in greater electrical conversion efficiency than the small steam approach. The coolant is rejected at a temperature sufficiently high for cogeneration purposes (80°C). A specific design feature of this system is an independent thermal oil loop to transfer heat from the flue gas to the working fluid. This bypasses the requirements for registered steam operators in most jurisdictions, reducing the unit power cost of production. It also imposes a second heat

transfer loop in series and reduces the heat extraction from the flue gas. The complexity of the system, the specially designed multi-stage turbine and the limited ability to extract flue gas heat results in a system that has a higher unit capital cost than large steam systems. However, the reduced operator qualification requirements reduce the operating cost significantly.

A third approach is being promoted using a new and currently unpublished power cycle. This system uses a Rankine cycle adaptation named the entropic cycle for a simplified small biomass power system. The implementation uses a single working fluid loop requiring only three heat exchangers and a power module. An expansion ratio less than 3:1 allows for a very small single stage turbine impeller. Coolant is typically used at 60°C and rejected at 90°C, making it fully available for cogeneration purposes. The system uses a heater/superheater rather than a boiler, so avoiding the need for registered steam operators. It produces slightly better electrical conversion efficiency than the European ORC system and recovers more energy from the flue gas, lowering the temperature sufficiently to allow direct baghouse cleaning. The fundamental benefit is a unit capital cost comparable to a large steam system and a reduced operating cost. A commercial unit of this system has not yet been implemented.

- c) **Gasification systems:** Syngas is generated through gasification and reduction processes. Biomass, such as wood, wood by-products or municipal waste, is converted to a synthetic gas in a high temperature, oxygen deficient environment. Volatile gases created are largely carbon monoxide, hydrogen and methane. There is typically also a significant quantity of non-volatile gases that include carbon dioxide, water vapour and nitrogen. In addition, there are particles of ash, char, tar and alkali compounds. These particles must be filtered from the syngas before it can be used as a fuel in an internal combustion (IC) engine or gas turbine. The filtering process, the need to remove water and the application in engines require that the syngas is cooled, resulting in an energy loss. Both IC engines and gas turbines require a relatively clean fuel for operation. Both engine types compress the fuel in operation, which causes a large temperature rise. To prevent uncontrolled detonation, the fuel must not be excessively hot initially.

The heat content of syngas varies greatly with the species and moisture content of the fuel feed and the conversion process employed. The common process uses air and results in a gas mixture of low gross calorific value (4-7 MJ/Nm³ dry). Special processes using pure oxygen would result in a gas mixture of medium gross calorific value (10-18 MJ/Nm³ dry). An exotic approach is being promoted using a plasma arc discharge gasification of biomass to produce a gas of even higher calorific value (20 MJ/Nm³ dry). However, this system uses 1 kWh of electricity to produce the energy equivalent of 1.93 kWh in the syngas, which would convert back to only 0.63 kWh of electricity. For comparison, natural gas has a calorific value of 35 MJ/Nm³.

Subsequent utilization of syngas is dependent on its production method, fuel properties and fuel consistency. Cooling and filtering is required to prepare it for use. Syngas can also be converted to methanol and other intermediary products. The low energy content of syngas affects the size of engines required to convert this energy. Generally, the physical size of an IC engine operating on syngas must be significantly larger than an equivalent fossil-fuelled engine. Larger engines are less efficient and more expensive to purchase, operate and maintain.

A technical extension of gasification is the Integrated Gasification Combined Cycle (IGCC)

system intended to produce a syngas to be fired in a gas turbine. Waste heat recovered from the turbine exhaust is input into a steam Rankine cycle. The intent is to increase the overall conversion efficiency over direct combustion, large steam systems. The capital and operating costs are intended to be mitigated by the increased efficiency. Such systems are most applicable to large sizes required to amortize capital and operating costs, although demonstration plants are in the 10-MWe size. IGCC gasification will continue for some time to be classified as a developing stage technology [Trillium 2002, p.24].

More information: <http://future-energy.np.def6.com/Silvagas.asp>

Many companies in Canada are developing new gasifier concepts. For example, Enerkem in Québec offers a gasification concept. The company claims their BIOSYN technology can process a variety of feedstocks, including sorted municipal solid waste, urban wood, agricultural residues, forest thinnings, sludges, as well as wastes from various industries, such as sawdust and pulp mill residues, spent oils, plastic-rich residues and rubber-containing wastes. Other companies like Nexterra, Modern Organics, Home Tech Farms, Gasifier, Vadir and SunGas are also developing small-scale gasifiers to convert biomass wastes into heat and power at the local scale. Some of these gasifier companies intend to produce syngas for engine applications and others perform an immediate combustion of gases to produce heat.

More information: <http://www.enerkem.com/>

- d) In coal **co-firing**, a portion of the coal used in a coal-fired plant is substituted with 5% to 15% biomass. This level of biomass can typically be tolerated by a coal-fired system without significant effects on the combustion process. The Oak Ridge National Laboratory, a DOE research and development laboratory, estimates that this biomass can be added at a cost less than US\$.005/kWh. Co-firing biomass is less expensive compared to dedicated biomass systems because no new or additional technology is needed to incorporate the biomass with the coal. Many large coal-fired boilers could benefit from co-firing by reducing their net greenhouse gas emissions (displacing fossil coal with green biomass) and/or increasing power production beyond current regulation limits. In addition, biomass acts as a reburning fuel and decreases NO_x emissions by up to 40 to 60%. With a lower sulphur content than coal, co-fired biomass also decreases sulphur emissions. Two Florida coal-powered boilers use biomass for co-firing. A pilot plantation with an area of 130 acres growing eucalyptus and cottonwood trees, which can be harvested every one to three years, has produced the target 55 green tons/acre of energy crop. The premium for this energy crop met the test target of \$1.76/million Btu compared to the current cost for coal of \$1.50 to \$1.75/million Btu. More than 10 demonstration projects in the U.S. have shown that NO_x emissions can be considerably reduced by co-firing biomass in the reburning zone. NREL estimates that co-firing biomass in U.S. coal plants will generate 20 to 30 GW by 2020 [FPT 1998].

1.3.3 Cogeneration and Combined Heat & Power (CHP) with Biomass

Cogeneration refers to the use of biomass-derived energy for multiple purposes. Probably the best example is in pulp and paper mills where biomass boilers produce a high pressure steam. The pulping and papermaking processes require this steam at a much lower pressure in a near saturated state. Reducing the high pressure boiler steam to process levels can be done through a turbine/generator. Thus the original fuel “co-generates” both electricity and process steam. In many mills excess steam is produced and expanded through condensing turbines to maximize power production and allow more efficient control in meeting process steam needs. These

applications are viewed more in terms of “extra benefit” from power generation than overall efficiency since the primary process steam needs must be satisfied independently of efficiency considerations.

Combined Heat and Power (CHP) is a specific implementation of cogeneration. It is recognized that many opportunities exist where both power generation and thermal energy is required. A single system used to meet both needs can show very high overall conversion efficiency. It should be recognized that electrical power generation is reduced to allow the cycle to reject heat at a higher temperature for thermal use. The loss of electrical conversion efficiency is significant but is accepted to create an increased overall efficiency of biomass energy utilization.

The first limitation of CHP systems is the amount of heat that can be recovered from the original biomass energy. In biomass combustion systems this is directly related to the outlet temperature of the flue gas. The second limitation is the energy loss associated with the conversion cycle. All conversion systems have associated parasitic and often unrecoverable heat losses. The final limitation is the form and temperature of the reject heat from the conversion cycle. Hot gases are the most inconvenient form of heat and have few direct economical uses. Saturated steam is a very useful form of thermal energy if it has sufficient temperature. However, steam must be used in close proximity to where it is generated as it cannot be “pumped”. Hot liquid is a useful form of heat if it has a sufficient supply temperature and a sufficiently high return temperature. The benefit of hot liquid is the ability to pump it distances for district heating purposes.

1.3.4 Conversion to Bio-Oil and Charcoal

Bio-oil is produced by condensing gases produced by pyrolysis. Generally the large, carbon based molecules produced by pyrolysis will condense along with water vapour while lighter hydrocarbon and carbon-oxygen molecules will remain vapour. Furthermore it has been found that large molecules will tend to break down to smaller non-condensable molecules if they are held at high temperature. Recognizing this, several groups have developed “fast pyrolysis” systems in which the pyrolysis gases are cooled and condensed quickly (<2 seconds) soon after being formed. Fast pyrolysis will maximize the yield of bio-oil and change the constituent molecules as compared to slow pyrolysis. Yields of bio-oil will vary with different technology systems, operating conditions and fuel feeds. Reviewing four alternate commercial systems shows similar production outputs for fast pyrolysis processes and a different output profile for slow pyrolysis.

Significant parasitic heat and power is consumed to dry and size the fuel in preparation for pyrolysis, as bio-oil production requires a fuel feed of very low moisture content. Any moisture in the fuel feed is captured as water content in the resulting bio-oil. Excessive water in bio-oil will reduce the heat content of the bio-oil, alter the combustion properties and cause separation into light and heavy phases. Bio-oil processes require a feed of <10% moisture, which is significantly below the moisture content of almost all available forest biomass. Even with this low level of moisture in the feed, the conversion process results in approximately 25% moisture content in the bio-oil. Most of this is due to the same amount of water being included in a lesser total volume of product. Some is due to the formation of water molecules from hydrogen and oxygen present molecularly within the original fuel.

The chemical mixture of bio-oil is relatively complex. There has been discussion concerning the extraction of useful, high-value chemicals from this mixture. However, with the exception of “wood smoke” flavouring chemicals and some glue precursors, there has been little progress

made on finding useful applications. Both of these products appear to have limited market potential. At this time it appears that heat energy conversion is the most promising application of bio-oil.

As a liquid with reasonably dense energy content, bio-oil appears to be suited as a transport fuel. On a volumetric basis, bio-oil has 55% of the volumetric energy content of diesel oil (40% on a weight basis). Contrary to diesel fuel, bio-oil does not produce SOx emissions during combustion and produces approximately half the NOx emissions in comparison with fossil fuels. However, combustion concerns include its acidic nature, particulate content and flame stability. The lower heat energy content requires larger equipment, especially for IC engines, for the same power output as fossil fuelled machines. Larger engines are less efficient and more expensive to purchase, operate and maintain. The high water content of bio-oil means the energy output is reduced as more energy is consumed in evaporation.

The unburned char from the process may have commercial applications. Non-condensable gases are recycled and produce approximately 75% of the energy required for the pyrolysis process.

More information: www.dynamotive.com - similar systems: www.ensyn.com; www.renewableoil.com

1.3.5 Ethanol and Lignin

Ethanol is produced by the fermentation of biomass, using bacteria, yeasts and enzymes. The carbohydrates of biomass are broken down and alcohol is formed. This process has been applied mainly to crops like corn that are rich in starch. The logen process is an enzymatic hydrolysis process for converting lignocellulosics (plant matter) to ethanol. The unique aspects of the technology include the steam explosion pre-treatment that was pioneered by logen, and the proprietary enzymes developed, manufactured, and marketed by logen. The block diagram for the logen process is shown in Figure 1.5.

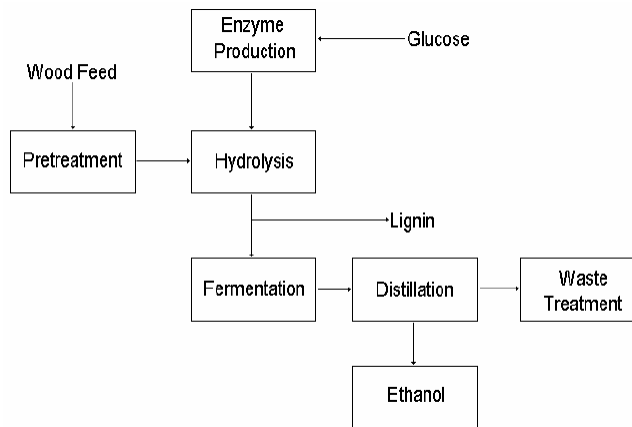


Figure 1.5 logen Enzymatic Process

The logen process is currently suitable for agricultural residues such as wheat straw and corn stover. Hardwood residues are also a suitable feedstock. A single step pre-treatment process for agricultural and hardwood residues can produce a material that can be efficiently hydrolyzed by the enzymes. However, the pre-treatment process is not as effective for separating the lignin of softwoods – a very interesting feedstock in British Columbia - from the cellulosic material and

thus the enzymes are not as effective. Much higher levels of enzymes are required and the production and capital costs are also much higher. The development of a pre-treatment process that produces both cellulose and hemi-cellulose that could be enzymatically hydrolyzed economically would allow the remainder of the logen process to be commercialized for softwoods.

The process will produce lignin as a co-product. The relatively mild pre-treatment process employed should provide a lignin that can be utilized as a starting material in other processes. If the lignin cannot be used in commercial applications, the alternative is to utilize lignin as a fuel to produce steam or electricity. This use yields a very low price for the lignin, no more than 5 cents per kilogram. Iogen Corp. has built a \$40-million pilot plant, and expects the technology to be fully matured with the first commercial facility to be operational in 2007.

Lignol Innovations Corp., together with BC Research, is commercializing a proven proprietary technology for refining many forms of woody biomass into their constituent chemical components. Their initial focus is on the production of ethanol and natural lignin from wood residues, such as sawdust & shavings. Lignol use a solvent (ethanol) to dissolve the lignin and then use an enzymatic process to convert the cellulose and hemi-cellulose into sugars. The key advantage of the Lignol process is that the lignin from this process remains natural and is not affected by the process. It can therefore be more readily used a substitute for industrial glues, such as phenol formaldehyde, than the lignin from the Iogen process. If a stable market for such products can be developed, this may improve overall process economics.

By a different process, ethanol can also be made from biomass through gasification. Figure I-1 in the Introduction identifies this process. Some argue this process bears the potential to be more cost-effective than the enzymatic routes discussed above [Klass 1998].

More information: www.iogen.ca www.lignol-innovations.com

Other concepts: BC International Corporation; Arkenol (Southern California); ACOS (Acid Catalyzed Organosolv Saccharification process; Dr. Laszlo Paszner of the Faculty of Forestry at UBC); a wood gasification system is offered by Brightstar Synfuels Company of Texas and a biological syngas to ethanol process was developed by Bioengineering Resources, Inc. (BRI) of Arkansas.

Fermentation routes to fuel ethanol have been used in most research studies and commercial developments to date. However, an alternative approach is gasification: the biomass material is gasified to a mixture of carbon monoxide and hydrogen. In the presence of the appropriate metallic catalyst, this mixture is converted to ethanol. This approach can utilize biomass materials such as bark, which are not suitable for ethanol production by fermentation methods. In Canada, this route has been explored by Ethopower (Kelowna, BC), in conjunction with the University of British Columbia, and by the Saskatchewan Research Council [CARC 2003, p.54f.]. Ethopower no longer exists, but the gasification concept is still being pursued by Nexterra in Vancouver, as well as Draco Energy Systems, in conjunction with Hybrid Fuels Inc. (geared towards animal waste). The technology is still at a conceptual stage, with a suitable catalyst being the main challenge for ethanol production.

More information: <http://www.hybridfuels.com/html/080903.html>

1.3.6 Methanol

Most of the methanol produced in the United States today is made from natural gas. But methanol can also be produced from other feedstocks including coal, biomass, and residual oil. Biomass for the production of methanol includes crop residues, forage crops (grasses), forest residues, short-rotation tree crops, and more than half of the municipal solid waste and industrial waste streams. An important opportunity for Canada seems to exist in terms of the large amounts of black liquor produced in the pulp & paper sector, which could also be used to make methanol. From presently 24 million tonnes of black liquor generated annually in Canada methanol could be produced in the same order of magnitude as current ethanol production in Canada (see Table 5.2) [CARC 2003, p.55].

A thermochemical conversion process can be used to produce fuels like methanol, ETBE and MTBE. The first conversion step to produce Methanol from biomass is gasification. The biomass is subjected to elevated temperatures and pressures (in some processes) to form a synthesis gas (syngas). The syngas, composed mainly of carbon monoxide and hydrogen, is conditioned to remove impurities such as tars and methane, and to adjust the hydrogen to carbon monoxide ratio to 2:1. In a second step, the syngas reacts over a catalyst at elevated temperatures and pressures to form methanol.

Methanol is a liquid transportation fuel that can be produced from fossil or renewable domestic resources. In the United States, it is most commonly used as a chemical feedstock, extractant, or solvent, and as a feedstock for producing methyl tertiary butyl ether (MTBE), an octane-enhancing gasoline additive. It can also be used in pure form as a gasoline substitute, or in gasoline blends such as M85 (85% methanol and 15% gasoline). Pure methanol can be used in existing vehicles; however, engine modifications are required to facilitate cold starts and to replace materials that can be corroded by methanol and M85. Methanol has a higher octane rating than gasoline, which helps reduce engine “knock.” It can also deliver greater fuel efficiency if the engine’s compression ratio is properly adjusted [NREL 1995]. Because methanol carries more hydrogen by weight than liquefied hydrogen, it is also seen as a possible synthetic fuel for fuel cells.

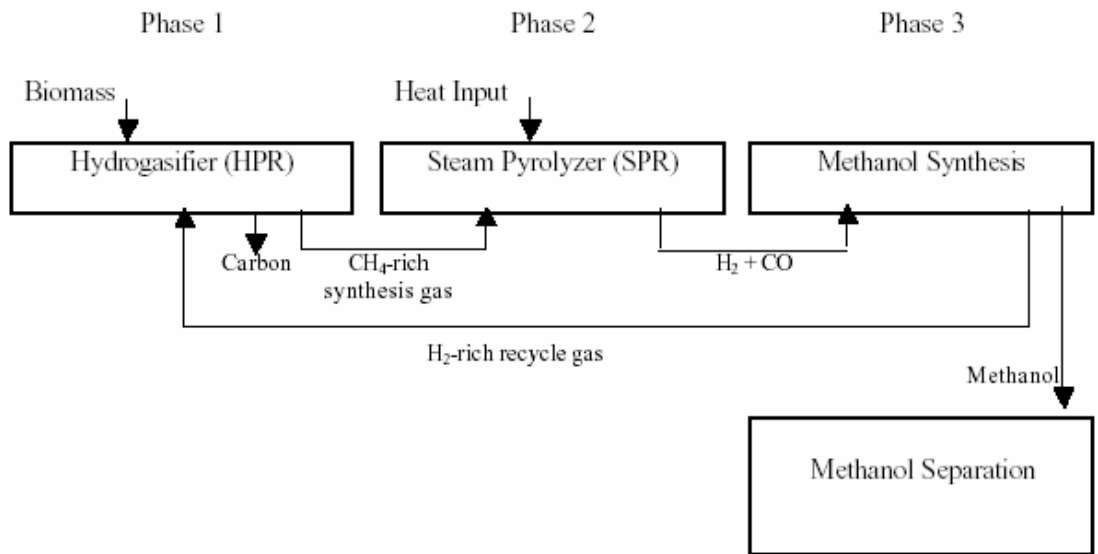


Figure 1.6 Hynol Process Flow [EPA 2000]

One of the concepts considered for the production of methanol is the Hynol Process. It originated at the Department of Energy’s Brookhaven National Laboratory as a method for increasing the yield of

fuel from conversion of biomass. Originally conceived to operate with a coal feedstock, the process has been adapted to biomass. The process produces methanol with a carbon conversion efficiency of 87%. Unconverted biomass is withdrawn from the reactor with ash in the form of char, which can be used as fuel or sequestered.

The Hynol Process involves three phases: (1) Reaction of biomass in a hydrogasifier, also referred to as a hydropyrolyzer (HPR); (2) Steam pyrolyzation of the resulting gas, which produces a synthesis gas; and (3) Methanol synthesis, which leaves a recycle gas that can be returned to the HPR and waste heat that can be returned to the steam pyrolyzer.

1.3.7 Hydrogen

In addition to the direct production of hydrogen from gaseous hydrocarbon feedstocks, such as gasified coal or natural gas, hydrogen can be produced from liquid energy carriers such as ethanol and methanol as well as from ammonia. Methanol reforming ($CH_3OH + H_2O \leftrightarrow CO_2 + 3H_2$) is practised in Japan and to a small degree in Europe where there are no economical sources of syngas. Currently, there are about a dozen companies that are involved in building plants to produce hydrogen from methanol or ammonia. [NREL 2003, p.19]

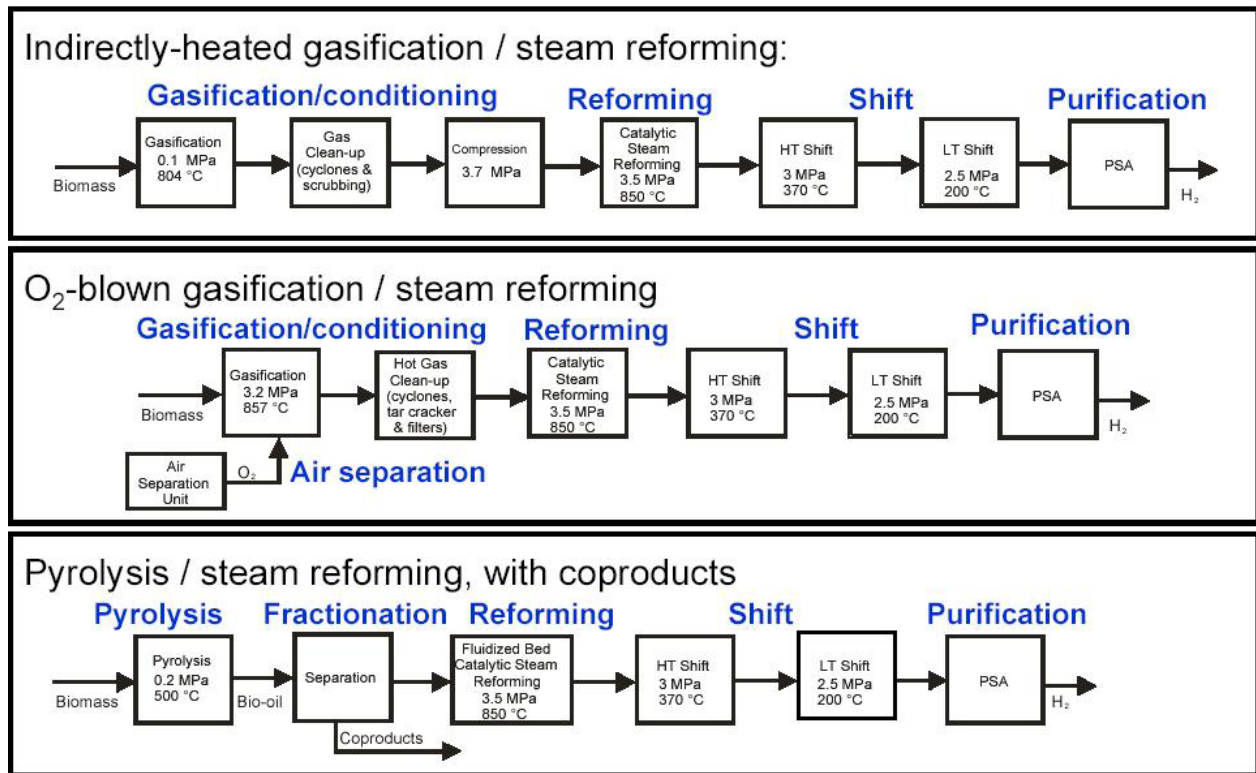


Figure 1.7 Flow Diagrams for Biomass-to-Hydrogen Pathways [NREL und.]

The production of hydrogen from biomass follows the same general process as that of coal to hydrogen. The biomass is first gasified, the gas is treated to increase the hydrogen content and then the hydrogen is purified. The syngas produced from biomass gasification can contain a number of contaminants including particulates, tars, sulphur, and chlorine compounds. The syngas may also contain significant quantities of methane, which must be reformed to more syngas, depending on the composition of the feedstock and the type of gasifier used. A report prepared for the US Department of Energy identified bubbling fluid bed gasifiers as the

technology of choice to make hydrogen from biomass [E2S 2002]. Apart from gasification, pyrolysis is also being explored as a pathway to hydrogen from biomass (see Figure 1.7).

Merchant hydrogen prices vary considerably depending on the volume and form of delivery. For large volume users, pipeline is the most economical followed by bulk liquid hydrogen delivery. For gaseous hydrogen produced from natural gas at a large-scale, central production facility at a pressure of around 400 psi, the plant gate price is about \$5-\$8/GJ. In general, contract prices for delivered hydrogen are not publicly available and they vary a great deal depending on the type of delivery, quantity required, and delivery distance. SRI International, a California research institute, states that liquid hydrogen list prices have been around \$45/GJ, but that the average transaction prices are considerably below this. A typical price range for large-volume, bulk liquid consumers is \$18-\$24/GJ. [NREL 2003, p.23]

1.3.8 Composting

Composting is an aerobic treatment of biomass. Whereas CO₂ is produced through partial decomposition of the biomass during the process, no methane is produced, as would ensue if the biomass was landfilled and allowed to decompose under anaerobic conditions. The resulting compost can be rich in nutrients and displace artificial fertilizer, which in turn leads to emission reductions from the fertilizer production process and its bacterial decomposition in the field, which results in N₂O emissions.

Composting wood residues poses two challenges: 1) the particle size must be reduced if too large (1/8 inch diameter) in order for the micro-organisms to access it as a substrate, and 2) a nitrogen source must be added. Conversely, the best potential use for woody debris is to mix it with other residues. For example, wood can be used as a bulking agent for nitrogen-rich and water-rich feedstocks, such as manure, biosolids, food waste, or grass. The potentially large particle size can help increase pile porosity and aeration.

Most wood residues, apart from sawdust and wood shavings, have to be shredded in order to facilitate composting. A tub grinder is most often used for shredding or grinding woody materials destined for composting. A tub grinder is a hammer mill with a round rotating hopper (tub) which feeds the materials into a hammer chamber. The composting process takes about six weeks. [CERWA 1998]

Chapter 2 Agricultural Residues

2.1 Crop Production Residues

2.1.1 Availability in Canada

Agricultural crops can be classified as [BIOCAP 2003, p.19]

- a) starch crops (cereal grains: wheat, barley, oats, rye; and grain corn): represent 54% of total dry tonnage produced in Canada
- b) Seed oil crops (canola, soy beans, flaxseed): represent 9% of dry tonnage produced in Canada
- c) Forage crops (tame hay and fodder corn): represent 36% of dry tonnage in Canada.

Forage crops are harvested nearly intact, and hence are considered to have a harvest index of 100%, meaning that only unused portions of it are available for other uses (estimated to be about 5%). In contrast, reported harvests of cereal grains and seed crops represent only about 50% of the total plant mass. The difference between the whole plant yield and the crop yield is considered to be crop residue, consisting of straw and chaff of cereal crops, stover of corn and unused fodder crops [BIOCAP 2003, p.20].

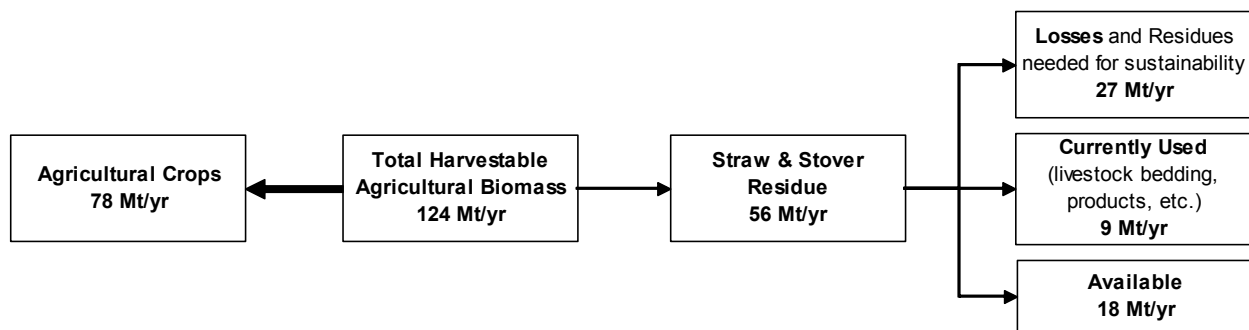


Figure 2.1 Agricultural Biomass from Field Crops in Canada

Figure 2.1 shows the mass flows of agricultural biomass for Canada. About 45% of agricultural biomass is available as residue and thus potentially available for energy and other uses. However, to warrant soil fertility and the sustainability of agricultural operations, a minimum of 20% of crop residues should be left on-site [STUMBORG 1996]. In addition, not all remaining residues can be harvested due to technical limitations (e.g. weather). Discounting amounts that are already being used for other purposes, such as straw needed as livestock bedding, insulation, mulching, etc. leaves about 15% of agricultural biomass available for the purposes discussed here.

2.1.2 Geographical Distribution

Table 2.1 shows the regional availability of agricultural biomass throughout Canada. The totals based on the REAP 2002(1) report are somewhat higher than those given in BIOCAP 2003, which confirms them as fairly conservative. Figure 2.2 shows the same facts graphically, agricultural activity is concentrated in the Prairies, mainly in Eastern Alberta, Saskatchewan and Western Manitoba, with additional, but smaller, activity in Northwest Alberta, Southern Ontario and in Québec, along the St. Lawrence River.

Table 2.1 Availability of Agricultural Residues in Canada, in tonnes x 1,000 [based on REAP 2002(1), Table 1]

	BC	AB	SK	MB	ON	QC	Atlantic	Total
Corn Stover	-	-	-	110	1,900	1,115	6	3,131
Straw*	23	6,218	9,246	2,940	615	310	125	19,477
Hay	-	~220	~220	~220	220	210	52	482
Canola straw	11	627	833	463	14	-	-	1,948
TOTAL	35	6,845	10,079	3,513	2,749	1,635	183	25,039

Data for western provinces extrapolated from Ontario data, based on annual yield data as given in [PP 2002, Table C2] and [CCoC 2003] for canola. REAP 2002(1) assumes that 20% of straw, 50% of corn stover and 29% of canola residues remain on the field to maintain sustainability. Of the sustainably recoverable residues, a large proportion is already allocated to other uses, such as straw for livestock bedding. 35% of the recoverable straw, 100% of corn stover, 5% of hay and 100% of canola is left for other uses, such as energy production. These are the numbers given in this table.

* The long-term total of straw available in ON was estimated to be about 1.4 million tonnes per year, after harvesting and storage losses. How much of this would be available for energy purposes depends on alternative uses, such as bedding, its price (to be \$50 or less a tonne to be economically viable), and how much can actually be collected from farms. REAP Canada estimated that only 20% could be collected, which would result in a total of only 230,000 tonnes, as opposed to the above 615,000 tonnes [AAFC 2004].

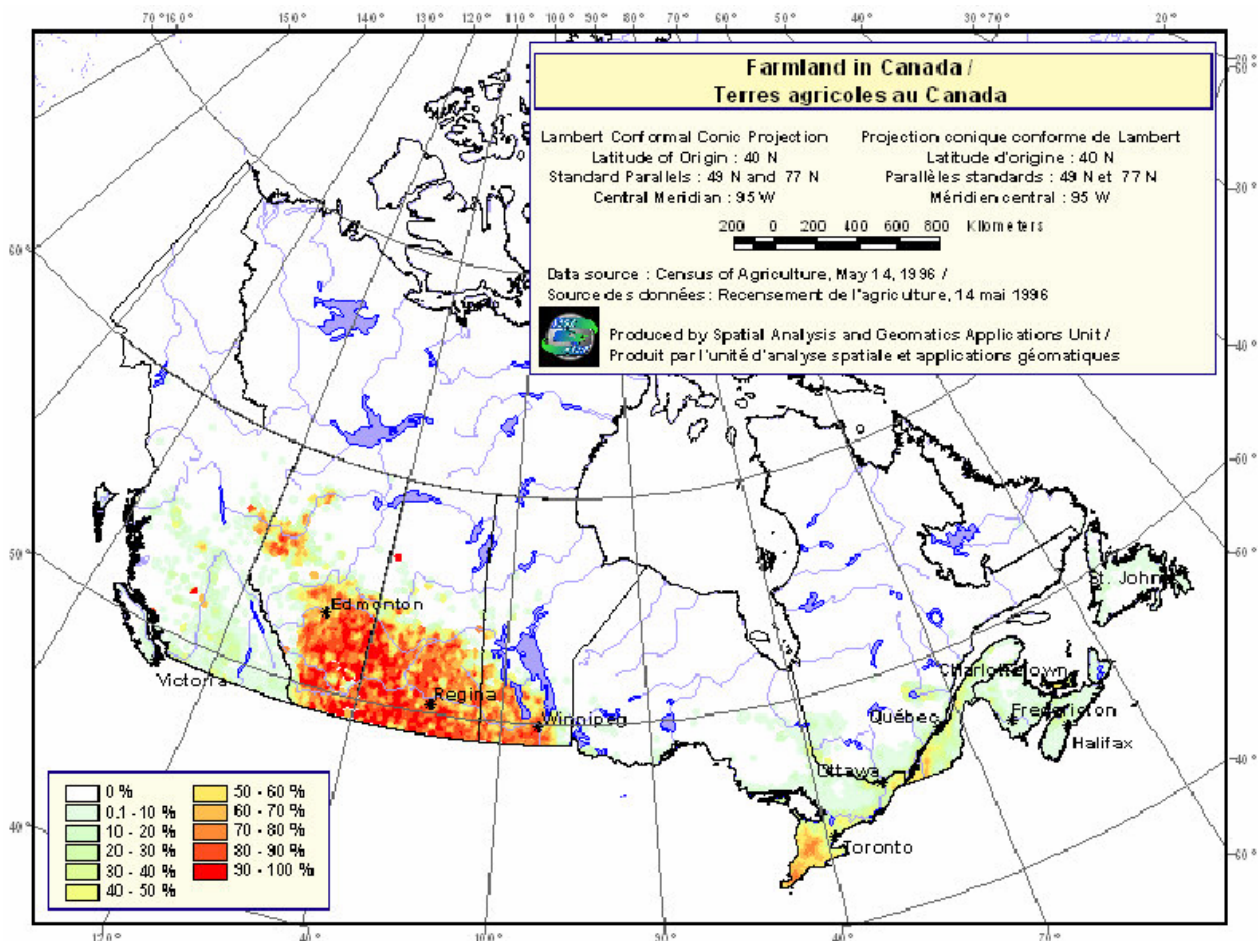


Figure 2.2 Concentration of Farmland in Canada [Statcan 2001, App. D]

2.1.3 Possible Uses for Field Crop Residues

Current Usage

In Eastern Canada, approximately 65% of straw residues supply existing markets, but the distribution of usage is very different in the Western provinces. In Manitoba for example, 93.5% of barley straw is committed to livestock bedding, but only 6.7% of wheat straw is used for livestock bedding. A further 6% of the straw is used for the production of strawboard in the Elie plant just west of Winnipeg. By comparison, there is virtually no demand for the 600,000 tonnes of oat straw produced per year. Only 25.8% of the total 4.7 million tonnes of straw available in Manitoba supplies dedicated usage, and burning in the field eliminates a considerable fraction. [BIOCAP 2003, p.21]

Ethanol, Distiller's Grain, and CO₂

Conventional ethanol production involves fermenting the starch-derived sugar from grain like wheat and corn. Research is now being conducted to produce ethanol from products that are now considered waste, like the sludge from pulp and paper production, waste paper, grass, straw (logen Process, see chapter 1.3.4), leaves and other solid landfill wastes that contain cellulose, or plant fibres.

Ethanol is a high-octane, water-free alcohol that is usually produced from renewable resources such as corn, wheat, straw and other biomass. Only the starch component of the grain is converted to ethanol leaving the fibre, protein, minerals, carbon dioxide (CO₂) and vitamins. Traditionally, grain-based plants produce two products in addition to ethanol – distiller's grain, either wet or dry, and CO₂. Wheat distiller's grain is high-protein, palatable by-pass protein, and high fibre that improves gut health in pigs and poultry. Sale of distillers' grain and CO₂ in addition to ethanol can result in production plant savings of 4 cents a litre. [AGRI 2003]

Total ethanol production in Canada is about 238 million litres a year, with most being used as fuel and the rest going to industrial uses. Industrial ethanol is used as a solvent in products such as toiletries, cosmetics and medications for external use. In Saskatchewan, the PoundMaker ethanol plant at Lanigan has a production capacity of about 13 million litres per year. This plant is integrated with a feedlot. Beef cattle are fed the distiller's grain, which is a by-product of the ethanol production process. Ethanol production in the United States is considerably higher - about 6 billion litres are produced each year.

Ethanol made from wheat is created through the process of fermentation. Fermentation is a series of biochemical reactions, using micro-organisms like yeast, which yields ethanol. Several different types of wheat can be used, including durum, hard red spring and hard red winter wheat. The process begins with cleaning and milling of the whole wheat kernel. Then a special enzyme (a naturally occurring substance), which can withstand high temperatures, is added, and the wheat is cooked at 95°C. This process of enzyme treatment and cooking breaks down the starch in the wheat. Then the mash is cooled to 30°C, the temperature at which fermentation can take place. Another enzyme, called amyloglucosidase, is added, along with yeast (*Saccharomyces cerevisiae*).

The enzyme and the yeast work together to ferment the wheat mash. The enzyme slowly releases glucose, a sugar. The glucose is immediately used by the yeast, and the process of fermentation occurs. The fermentation is usually complete in 56 hours. Ethanol is recovered through distillation. Water is removed from the ethanol, either through filtration or treatment with

a chemical. The mash that is left over from the fermentation process can be fed to beef cattle as distiller's grain. Use of the by-product in this way reduces the need for cattle feed production, reduces the cost of ethanol production and helps produce a valuable consumer product. [Agwest 1998]

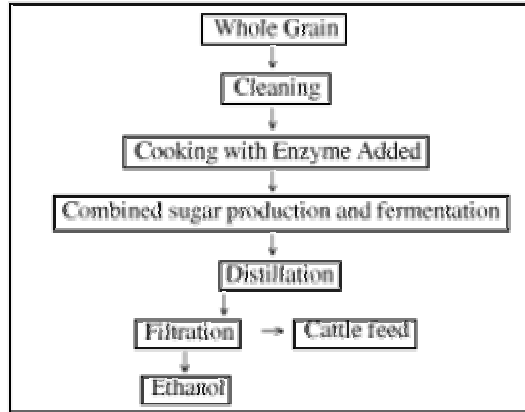


Figure 2.3 Production of Ethanol from Grain [Agwest 1998]

Many ethanol production technologies are currently experimental and have not yet been demonstrated on a large scale. This would include the production and collection of some of the feedstocks as well as the production of ethanol from lignocellulosics, like wood [Levelton 2000].

Biomass Fractionation into Cellulose, Hemicellulose and Lignin

PureVision in Lupton, Colorado, pursues the separation of the major components of biomass, converting these into cellulose, hemicellulose and lignin. The feedstock can be agricultural crop residues (wheat straw, corn stover and sugarcane bagasse), small diameter trees and forest thinnings, energy crops (switchgrass, hybrid poplar, willow, etc.) or other wastes, including organics and paper from municipal solid waste and paper mill and municipal sewage sludges. The process includes three steps (see Figure 2.4):

1. Pre-treatment;
2. Production of a purified cellulose product and separated wash streams containing the lignin and hemicellulose from biomass; and
3. Preparation of the purified cellulose fraction for enzymatic conversion into sugar, which can then be converted to ethanol.

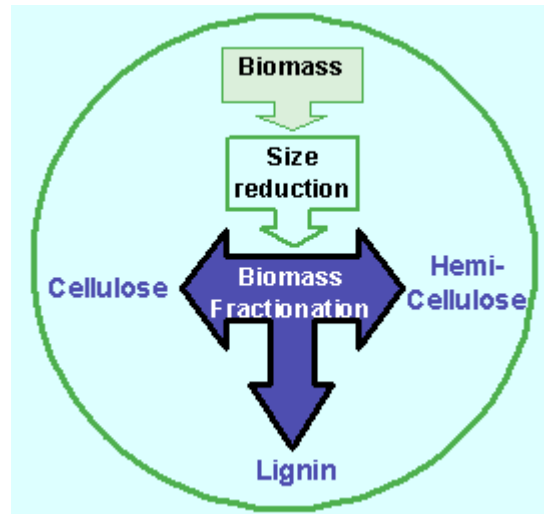


Figure 2.4 PureVision Fractionation Process [PV 2003]

The PureVision technology uses enzymes to convert diverse biomass feedstocks into sugar streams, a process known as enzymatic hydrolysis. Both xylose (a 5-carbon sugar, from hemicellulose) and glucose (a 6-carbon sugar, from cellulose) are produced from renewable biomass in the PureVision process. The technology has been proven at bench-scale and provides a critical process to effectively convert cellulose and hemicellulose into sugars in

biorefineries. Once the cellulose, hemicellulose and lignin are separated in the fractionation process, they become feedstocks for producing a wide range of bio-products for many industries, including but not limited to energy, transportation, agri-business, textiles, building products, pharmaceuticals, bio-plastics and paper industries. Table 2.2 provides an overview of the numerous possibilities for use of the three output streams from the fractionation process. Potential markets for the fibres include substitutions for wood pulp, non wood pulp and synthetically processed cellulose pulp in commercial applications. These pulps are used in all forms of papers as well as a wide range of other materials including dissolving pulps for producing rayon, lyocell and cellulose acetate fibres used in both textile and technical applications, fibre for automotive composites, and building products. The lignin fraction can be combusted in a boiler to produce electricity. Higher value applications could include the use of lignin as an asphalt binder or in construction materials.

Table 2.2 Utilization Options for Output Streams of the PureVision Process [PV 2003]

Output from Process	Primary Market	Products
Cellulose to glucose, then fermented into alcohol	Fuel ethanol for transportation markets	Transportation applications include oxygenates added to gasoline in blends of 10%, 20%, and 85%, aeroplane fuel and fuel cells.
Cellulose converted into glucose	Glucose processed into speciality chemicals for food and health care industries.	Fermentation sugars, gluconic acid, glucose, mannitol, sorbitol.
Hemicellulose	Fermentation sugars and/or conversion to methane in a bio-reactor to feed co-generation	Fermentation sugars for producing ethanol, xylose, xylitol, furfural, furfuryl alcohol, furan, bioplastics, etc. Energy
Purified cellulose fibres	Pulp for paper making and fibre filler in the building/ construction and automotive industries.	Bio-based cellulose derivatives include fibre and pulps for paper and building products, rayon, cellophane and cellophane flake.(delete colon here)
Lignin	Fuel for co-generation (energy)	Combustible fuel Future uses include making adhesives

More information: www.purevisiontechnology.com; see also: <http://www.oit.doe.gov/agriculture/factsheets/fractionation.pdf>

Manufacture of Composite Board

Dow BioProducts Ltd. produces “Wood Stalk” fibreboards from agricultural residues in its factory in Elie, MB. The fiberboard is made from harvested wheat straw fibre and a formaldehyde-free polyurethane resin. Before being offered the alternative of selling the straw, many Manitoba farmers were burning off the straw in the field.

Other products, such as particleboard or MDF, are often made from both waste wood and whole tree resources. Another traditional material, Lauan plywood, is commonly made from trees harvested from tropical rainforests.



Wood Stalk is used in the same applications as traditional fibreboards, and have some superior features, such as lighter weight, moisture resistance, and reduced tool wear.

More information: <http://www.cargilldow.com/corporate/index.asp>

2.2 Livestock Residues

2.2.1 Availability in Canada

Livestock manure from dairy, beef, poultry and swine is a readily available source of waste biomass in Canada. It is an under utilized resource, with most manure currently landspread with little or no pre-treatment. The Alberta Research Council estimated that 780 MW of electricity and 1040 MW of thermal energy could be produced in Canada from the wastes of the livestock industry [ARC 2003(1), p.28]. The utilization of manure for energy purposes would also alleviate other problems associated with direct application of manure to soils including bacterial contamination of surface and groundwater supplies, over-enrichment of soils with nitrogen or phosphorus and nuisance odours. In addition, manure produces methane gas and nitrous oxide, two potent greenhouse gases.

Not all livestock manure can be used for energy purposes. For example, manure from field grazed animals is considered lost due to difficulties in collection (but has a useful purpose to fertilise the soil). The numbers in Figure 2.5 represent a conservative Canadian average, but actual recovery rates could be much higher on individual farms.

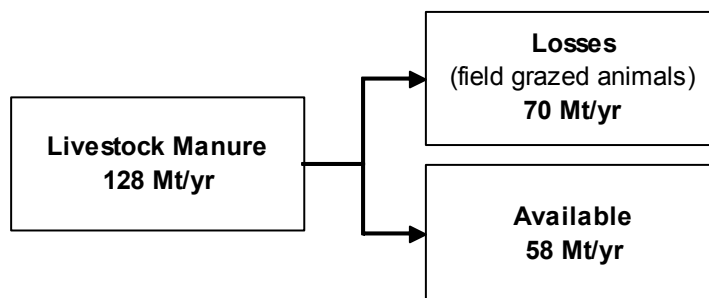


Figure 2.5 Availability of Livestock Manure in Canada

2.2.2 Geographical Distribution

Table 2.3 shows the regional availability of livestock manure throughout Canada. The totals based on the REAP 2002(1) report (close to 80 million tonnes a year) are somewhat higher than those given in BIOCAP 2003 (58 million tonnes a year), which confirms the latter as fairly conservative.

Figure 2.6 provides a graphical view of livestock concentrations in Canada. Although overall livestock numbers are also highest in the Prairies, the highest local livestock concentrations can actually be found in British Columbia (various locations) and along the St Lawrence River in Québec, as well as in Southern Ontario. This means that transport distances to central facilities may be higher in the Prairies, which could influence decisions to utilize these resources for energy production purposes.

Table 2.3 Availability of Livestock Manure in Canada, in tonnes x 1,000 [based on REAP 2002(1), Table 1]

	BC	AB	SK	MB	ON	QC	Atlantic	Total
Dairy	1,913	2,167	641	1,106	8,205	8,636	1,367	24,035
Beef	2,062	14,022	8,810	4,199	3,037	1,236	462	33,828
Swine	199	2,694	1,593	3,154	4,338	4,991	499	17,468
Poultry	475	288	98	137	939	684	210	2,830
Turkey	79	63	29	48	307	168	46	739
Sheep	3	9	5	3	11	10	2	43
TOTAL	4,730	19,243	11,177	8,646	16,837	15,725	2,586	78,943

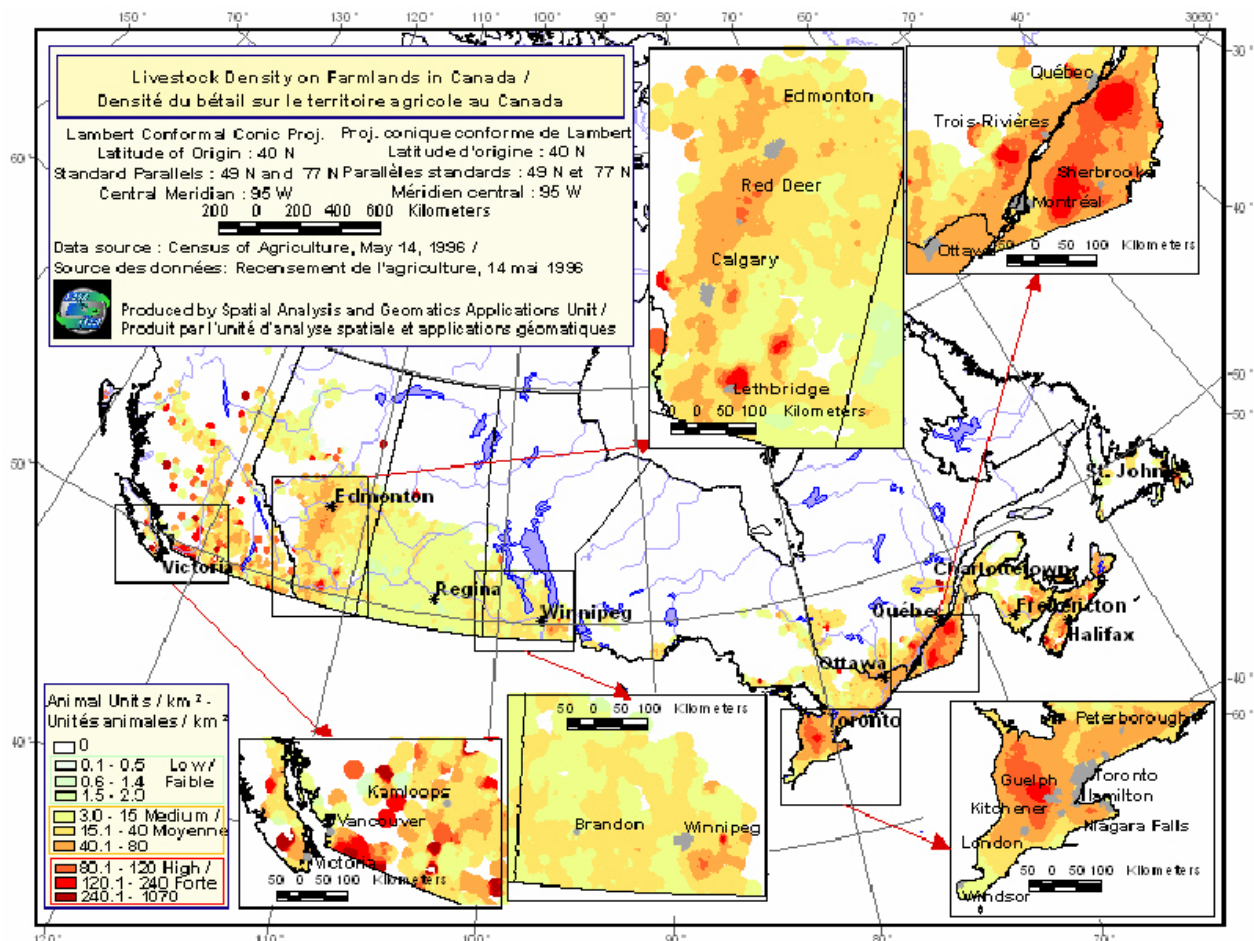


Figure 2.6 Livestock Density in Canada (1996) [Statcan 2001, p.13]

2.2.3 Manure Utilization Options

Power, Heat and Fertilizer (anaerobic digestion)

The treatment of manure in anaerobic digestion systems, with simultaneous biogas production, could meet typical household electrical demands of an average dairy farm, while also producing a nutrient-rich fertilizer and providing a renewable energy resource.

In a digester, anaerobic bacteria break down or "digest" organic material in the absence of oxygen and produce "biogas" as a waste product. Biogas produced in anaerobic digesters consists of methane (50%-80%), carbon dioxide (20%-50%), and trace levels of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen, and hydrogen sulphide.

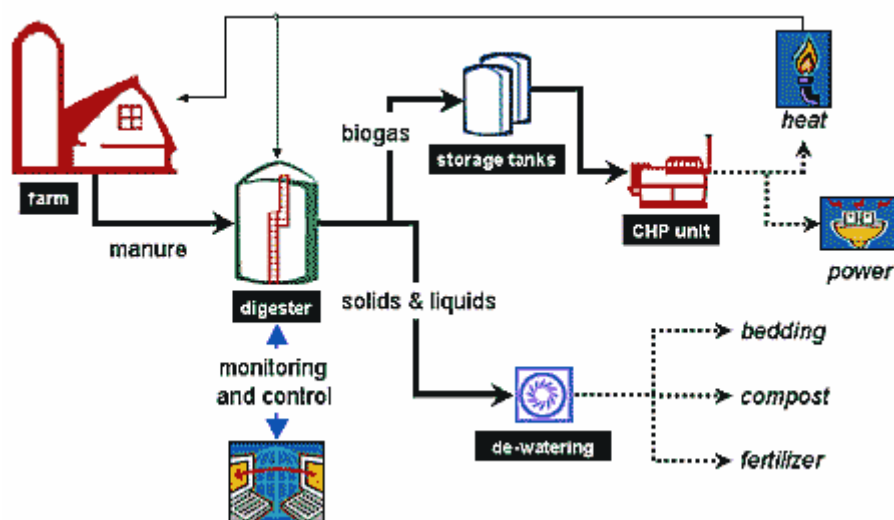


Figure 2.7 Anaerobic Digester Facility [Microgy 2003]

There are two basic types of digesters: batch and continuous. Batch-type digesters are the simplest to build. Their operation consists of loading the digester with organic materials and allowing it to digest. The retention time depends on temperature and other factors. Once the digestion is complete, the effluent is removed and the process is repeated.

In a continuous digester, organic material is constantly or regularly fed into the digester. The material moves through the digester either mechanically or by the force of the new feed pushing out digested material. Unlike batch-type digesters, continuous digesters produce biogas without the interruption of loading material and unloading effluent. They may be better suited for large-scale operations and have been commercially successful in Europe, where they were developed.

To optimize the digestion process parameters in the digester need to be controlled: the digester must be kept at a consistent temperature, as rapid changes will upset bacterial activity; digester pH and rapid changes in temperature can upset bacterial activity in the digester. In Canada, digestion vessels require some level of insulation and/or heating. The trade-offs in maintaining optimum digester temperatures to maximize gas production while minimizing expenses are somewhat complex. Studies on digesters in the north-central areas of the country indicate that

maximum net biogas production can occur in digesters maintained at temperatures as low as 72°F (22.2°C).

Biogas can be used for heating and to operate an internal combustion engine or microturbine for electric power. For engine applications, it may be advisable to scrub out hydrogen sulphide (a corrosive and toxic gas). Very large-scale systems/producers could sell the gas to natural gas companies, but this may require scrubbing out the carbon dioxide. More frequently, the electricity generated from biogas is sold into the public power grid. In Brooklyn, New York, fuel cells are being used to convert digester gas into electricity: the New York Power Authority has installed eight 200 kW fuel cells that will use digester gas from local biosolids treatment plants as the feedstock to produce electricity.

The material drawn from the digester is called sludge, or effluent. It is rich in nutrients (ammonia, phosphorus, potassium, and more than a dozen trace elements) and is an excellent soil conditioner. It can also be used as a livestock feed additive when dried. Any toxic compounds (pesticides, etc.) that are in the digester feedstock material may become concentrated in the effluent. Therefore, it is important to test the effluent before using it on a large scale. This is important for low temperature digesters, which may not be as effective in killing all the pathogens.

The availability of inexpensive fossil fuels has limited the use of digesters solely for biogas production. However, the waste treatment and odour reduction benefits of controlled anaerobic digestion are receiving increasing interest, especially for large-scale livestock operations such as dairies, feedlots, and slaughterhouses. Where costs are high for sewage, agricultural, or animal waste disposal, and the effluent has economic value, anaerobic digestion and biogas production can reduce overall operating costs. Biogas production for generating cost effective electricity requires manure from more than 150 cows.

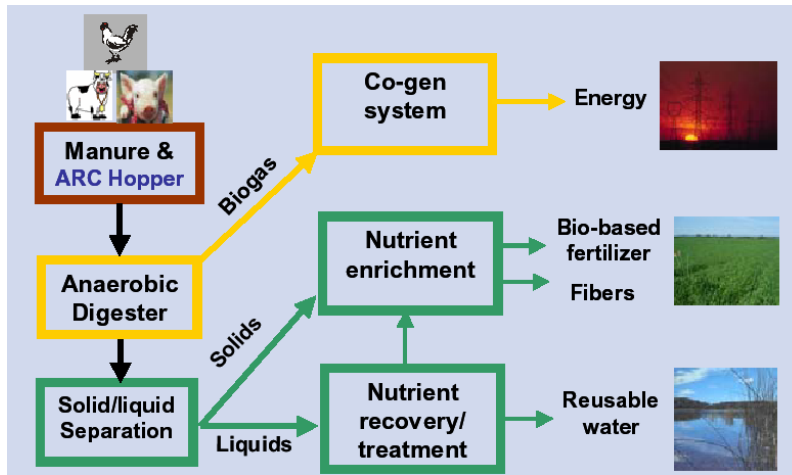


Figure 2.8 IMUS Digester Concept [ARC 2003(3)]

Highmark Renewables and the Alberta Research Council are working on a digester concept to turn manure into energy, bio-based fertilizers and reusable water. The technology, called Integrated Manure Utilization System (IMUS), will be tested at pilot scale in Vegreville, producing one megawatt of electricity from the manure of 7,500 head of cattle. It is scheduled for completion in June 2004. Figure 2.8 shows the process flow of the plant. The temperature of the anaerobic digesters is maintained at 53°C to 55°C in order to create optimal thermophilic

bacterial growth. Under these conditions hydraulic retention time is shortened, over 99 per cent of pathogens present in the raw material are destroyed, and biogas production is maximized. The unique nutrient recovery system treats the centrifuged liquid through physical and chemical processes to recover nitrogen and phosphate and produce reusable water. The solid, combined with a nutrient enrichment process, is used to produce solid bio-based fertilizer with balanced nutrients [ARC 2003(2)]. A low temperature plug-flow type digester is being demonstrated in Manitoba (BioTerre).

More information: <http://www.arc.ab.ca/whatsnew/newsreleases/imus.asp>

Superior Fertilizer (aerobic biotransformation)

Agronix Inc. is a US-based company that has developed an aerobic treatment process for manure and other organic waste. The process is an accelerated composting process, but has the advantage of preserving many of the fertilizer values of the organic material, as opposed to a normal composting process, which will lose much of the nitrogen.

The BCR (Bio-Conversion Reactor) system takes organic residues such as animal manures, sewer sludge and industrial food production waste and converts them through a natural process into fully bio-converted high quality agri-products like organic fertilizer and growth substrates. The conversion is completed in 12-14 days in a scientifically controlled in-vessel system. Through the combination of different kinds of manure, rather than just one (e.g., cow manure, as in the case of decentralised digesters), the composition and value of the end product as a fertilizer is improved. The fertilizer is pelletised and can be applied like inorganic fertilizer. All pathogens are eliminated during the treatment process. As the nutrients are bound up into an organic matrix, they are not leached from the fertilizer and can be absorbed by the plants to 100% - whereas a large percentage of inorganic fertilizer is lost due to leaching and bacterial denitrification.

The plant is a centralised facility and would regroup the organic residues from several farm operations, including livestock manure, slaughterhouse residues, or agricultural residues. The process prevents the loss of nutrients that are lost through leaking or evaporation of ammonia and methane in other processes and produces a more consistent product with defined, stable features, and nutrient contents. The process also transforms any heavy metals present in the biomass into oxides, which radically reduces their toxicity and bioavailability.

The BCIR (Bio-Chemical Integrated Recycling) system is a more specialised version of the BCR process and is in its final commercialization stage of process engineering. The process involves a step-wise sequence of controlled chemical reactions designed to extract whatever end-product(s) are desired from the manure or other biomass. The process has undergone intensive laboratory testing on a wide variety of organic residues. Although it is not an organic process, it has near zero environmental impact, according to Agronix.

It can transform all organic wastes including sewer sludge into more than 1,000 identified chemical commodities. At present, Agronix has successfully extracted 65 chemical commodities for use by industry as polymers, surfactants, lubricants, de-icers, adhesives, alternative fuels, agro-chemicals and fertilizers. Some more recent testing has been focused on the extraction of alternative fuels (ethanol) from various organic wastes and for the paper industry, long-fibre cellulose from bagasse (sugar cane waste).

More information: <http://agronixinc.com/GO.html#BCR>

Manure and Animal Residues to Bio-Oil

A University of Illinois research team is working on turning pig manure into a form of crude oil that could be refined to heat homes or generate electricity. The thermochemical conversion process uses intense heat and pressure to break down the molecular structure of manure into oil. It's much like the natural process that turns organic matter into oil over centuries, but in the laboratory the process can take as little as a half-hour. The process is currently only working in small batches, but further development could lead to an oil product that could be used to fuel smaller electric or heating plants, or to make plastics, ink, or asphalt.

A similar process is being used at a plant in Carthage, Missouri, where tons of turkey entrails, feathers, fat, and grease from a nearby Butterball turkey plant are converted into a light crude oil.

More information: <http://www.age.uiuc.edu/faculty/yhz/index.htm>

Chapter 3 Landfill Gas

3.1 Resource Availability

In Canada, most waste disposal on land occurs in well over 10,000 municipally managed or privately owned landfills [Levelton 1991]. The generation of methane from landfills has increased since 1990. However, more landfill gas is now being captured and combusted. Residential, institutional, commercial, industrial, construction and demolition wastes are disposed of in MSW landfills [EC 2003]. About 23.5% of Canada’s methane emissions come from landfills. As such, landfills are Canada’s fifth largest source of CO₂ equivalent greenhouse gas emissions.

Wood waste landfills are privately owned and operated by forest industries, such as saw mills and pulp and paper mills. These industries use the landfills to dispose of surplus wood residue such as sawdust, wood shavings, bark and sludges. Landfill gas capture increased by almost 40% between 1990 and 1999, but is not practised at wood waste landfills [EC 2003].

Landfill gas, which is composed mainly of methane (55%) and carbon dioxide (45%), is produced by the anaerobic decomposition of organic wastes. The first phase of this process typically begins after waste has been in a landfill for 10 to 50 days. Although the majority of the methane and carbon dioxide is generated within 20 years of landfilling, emissions can continue for 100 years or more.

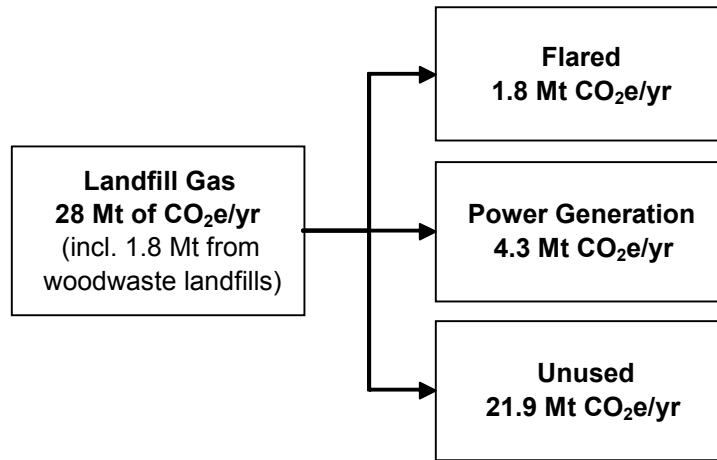


Figure 3.1 Current Usage of Landfill Gas Emissions in Canada [EC 2002]

In Canada, 5% of waste is centrally composted and the balance is landfilled. At the landfill, 7% of the landfill gas is captured and flared and a further 17% is captured and used as an energy source [Woodrising 1999].

3.2 Possible Uses of Landfill Gas

3.2.1 Flaring

24% of landfill gas in Canada is captured, but not all of it is currently being used in generators for power production. In some cases, the low calorific value of the gas or erratic volumetric flow rates does not make energy recovery economical. Pumping of the gases can entrain air, which could lead to spontaneous combustion in the landfill. About 7% of landfill gas is flared, which turns methane (a potent greenhouse gas) into carbon dioxide, reducing greenhouse gas emissions. Carbon dioxide emissions from biomass in landfills are not counted as emissions under the Kyoto Protocol, as it is assumed that they are derived from non-fossil plant matter, which is constantly regrown such that the same amount emitted through landfills is sequestered again.

As methane is 21 times as potent as carbon dioxide as a greenhouse gas, a large reduction in emissions can be achieved by flaring. Further reductions would be possible if the energy were used to heat buildings or as process heat, or to produce electricity. However, landfill gas capturing systems are expensive and are currently only installed on the larger landfill sites.

3.2.2 Power and CO₂ Production

The anaerobic decomposition of biomass in landfills produces methane, which can be used as an energy source. Wells can be drilled to release the methane from the decaying organic matter. Then pipes from each well carry the gas to a central point where it is filtered and cleaned before burning.

Methane can be used as an energy source in many ways. Most facilities burn it in internal combustion engines to produce electricity. Two new ways that are being explored include the use of microturbines and fuel cells. Microturbines have outputs of 25 to 500 kilowatts. About the size of a refrigerator, they can be used where there are space limitations for power production. Methane can also be used as "fuel" for a fuel cell. Even low BTU gas from landfill sites can be used in a modified microturbine. The fuel is premixed and the use of a catalyst allows it to continue making power from low-quality gas.

A major barrier to widespread commercial utilization of landfill gas (LFG) is reliable, economic removal of contaminants. Ohio company Acrion markets a process to remove contaminants from landfill gas using liquid carbon dioxide obtained directly from LFG [Acrion 2003]. A stream of contaminant-free methane and CO₂ is produced. Contaminants are concentrated in a separate small stream of CO₂ for incineration in the landfill flare. The contaminant-free methane and CO₂ stream can be used as medium Btu fuel gas, as a hydrogen source for the fuel cell or as feedstock for chemical synthesis, for example to produce methanol. Alternatively, it can be further processed to separate CO₂ from methane to produce pipeline methane or transportation fuel (compressed or liquefied), and liquid CO₂. Natural gas fleet vehicles are a potential steady market for methane recovered from LFG.

The resulting stream of methane is pure enough to be used in fuel cells instead of a generator in order to produce electricity.

Acrion's technology also allows for the commercial use of most of the CO₂ in landfill gas. The CO₂ not used for the wash is drawn off as a 99.99 percent pure liquid CO₂ stream that can be

used in a variety of commercial applications, from making dry ice to carbonating soft drinks. One option Acrion is examining is to pipe the CO₂ to Burlington County's R&D Greenhouse and Resource Recovery Complex, where "Jersey Fresh" tomatoes and other plants would benefit from the CO₂-enriched environment. Acrion is also providing samples of the pure liquid CO₂ to distributors and consumers for analysis and testing in commercial applications.

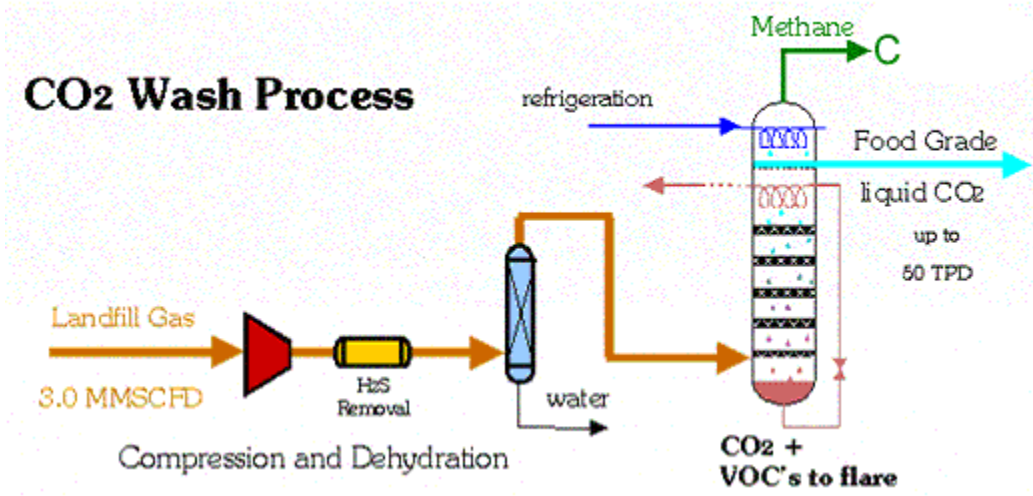


Figure 3.2 The CO₂ Wash Process [Acrion 2003]

More information: www.acrion.com.

3.2.3 Methanol and CO₂

Figure 3.3 shows the treatment of landfill gas in the Acrion process in order to obtain methanol. A small, modular add-on "refinery" produces methanol from landfill gas, using a stream of methane that is also produced on-site using the CO₂ Wash Process.

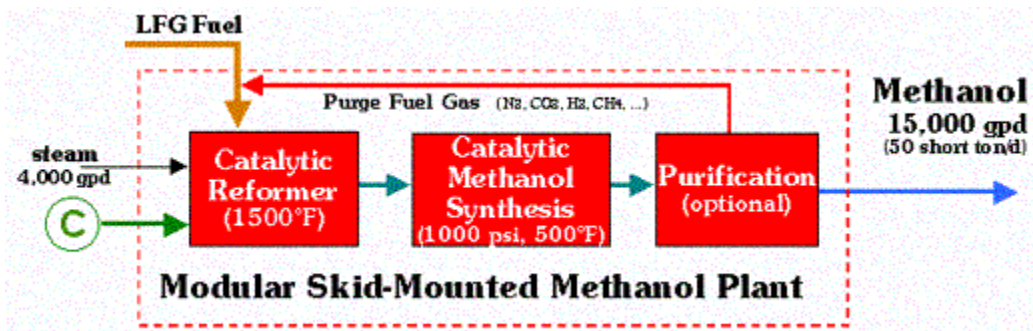


Figure 3.3 Acrion's Modular Methanol Synthesis Process [Acrion 2003]

3.2.4 Hydrogen and CO₂

Instead of methanol, the landfill gas can also be turned into hydrogen in a shift reactor.

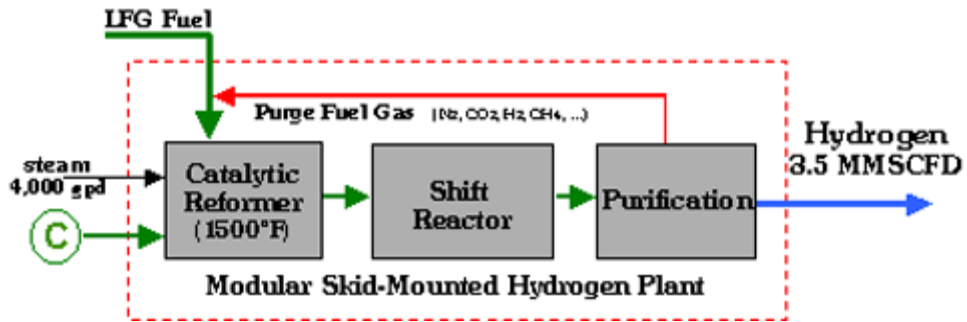


Figure 3.4 Acrion’s Modular Hydrogen Synthesis Process [Acrion 2003]

Chapter 4 Municipal and Industrial Residues

4.1 Organic Waste Resources

4.1.1 Municipal Solid Waste

Municipal solid waste (MSW) may be considered to fall into three categories:

- urban or residential wastes - generally picked up at the curb or transported directly by the producer to landfill;
- industrial, commercial, and institutional (I, C & I) wastes - from commercial enterprises, temporarily stored on-site in bulk-lift containers before haulage; and
- demolition, landscaping and construction (DLC) wastes - usually trucked directly to landfill.

In Canada, approximately 1 tonne per person of municipal solid waste is generated each year, about a quarter of which is recycled [BIOCAP 2003, Tables 4.1 & 4.2]. Of the 25 million tons per year total, 1.2 million tons are incinerated with energy recovery [NRCan 2002, p.17]. The remainder is either recycled or landfilled.

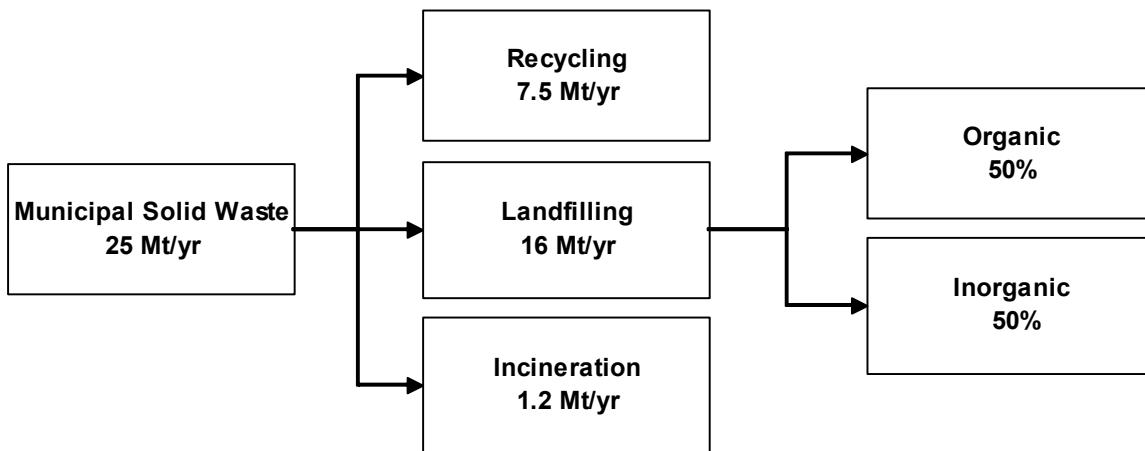


Figure 4.1 Municipal Solid Waste Management in Canada

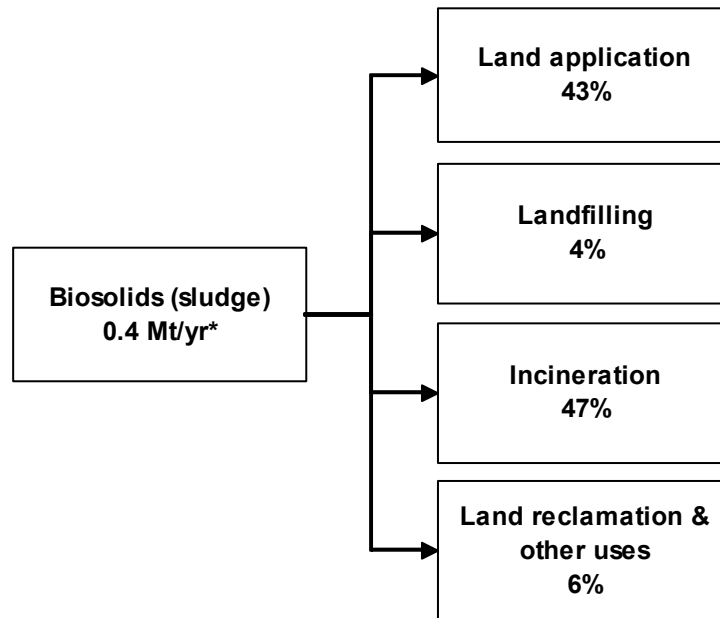
MSW contains on average 85% combustible materials from which energy may be derived by a variety of methods. This would include plastics and other artificial materials derived from fossil fuels. No definitive analysis over the organic content of landfilled waste could be found, but it can be safely assumed that it is at least 50%. Combustion, pyrolysis, gasification and the production of biogas through aerobic or anaerobic fermentation are methods to derive energy from waste. Pyrolysis and gasification require pre-drying of the waste, but offer great potential both for the capture of energy and the production of specific bio-products.

4.1.2 Sludge

Municipal sewage sludge, or biosolids, from wastewater treatment does contain biomass and can be used for energy and other purposes. In Canada, approximately 388,700 dry tonnes of biosolids are produced every year. About 43% are applied to land, 47% are incinerated and 4% are sent to landfill, with the remainder used in land reclamation and other uses. Land application has been increasing in recent years as many municipalities move away from incineration and

landfill disposal due to environmental concerns with these processes. By comparison, the United States and Europe apply approximately 60% and 34%, respectively, of their biosolids to agricultural land. [EMS 2001]

The usage of biosolids varies substantially from province to province. In BC, 90% of municipal biosolids are land applied (land reclamation: 70%, agriculture: 25%, compost: 5%). Most wastewater facilities in Manitoba use holding lagoons, some of which are only pumped out every nine years. Biosolids in Manitoba can be land applied at a one time use of 55 tonnes per hectare. In Québec (1999), 80% of biosolids were incinerated, 12% landfilled and 8% or 0.5 million tonnes were either land applied or composted. In Alberta and Saskatchewan, regulations specify a maximum biosolids application rate of 25 tonnes per hectare. Biosolids cannot be applied to land used for root crops, vegetables, tobacco or dairy grazing. [ES&E 2000].



* dry tonnes

Figure 4.2 Current Uses of Biosolids from Water Purification in Canada

Unlike forest residues, chemical conversion of biosolids offers several challenges irrespective whether combustion (incineration), gasification, or even pyrolysis is used. Heavy metals contained in the biosolids can be transported with the flue gas and filtered out if the proper air pollution equipment is in place; some heavy metals can remain in the ash. The ash must then be disposed of accordingly.

4.1.3 Animal Fat and Liquid Organic Waste, Canola Oil

Fats and oils have high energy contents and can be transformed into transport fuels (biodiesel). West Coast Reduction of Vancouver has a virtual monopoly on the prairies in terms of the commercial collection and rendering of yellow grease (used cooking oil), beef tallow and pork lard. This appears to be particularly the case for yellow grease. In the case of tallow and lard, the large animal processors manage and process most of their own material. [IAG 2002, p.6]

Most of Canada’s exportable canola supplies are purchased by Japan. The remainder of the crop is crushed for domestic consumption or export, primarily to the United States. Biodiesel

production in Canada would require displacement from higher priced food uses. There is potential for the use of lower quality canola oils from seed that was overheated during storage without any ill affects on the quality of the biodiesel. However, the amounts of heat damaged seed available each year varies greatly, and ranged from 100 tonnes to 3,200 tonnes per year between 1996 and 2000 [IAG 2002, p.9]. This volatility in supply makes rape seed at best a supplementary feedstock in addition to more stable source of supply, such as yellow grease.

4.2 Clusters of Animal Fat and Liquid Organic Waste in Canada

4.2.1 Municipal Solid Waste

Table 3.1 provides an overview of waste generation per province in Canada. Solid organic waste can be expected to occur where large agglomerations of people are present, i.e. in the big urban centres of Canada. Waste is often transported over hundreds of kilometres to remote landfills, which implies significant emission reductions if the waste can be used in the vicinity of large cities.

Table 3.1 Disposal of waste¹ by province and territory (Preliminary estimates for 2000) [Statcan 2002]

	1996	1998	2000	1996	1998	2000
	Waste disposed			Waste disposed per capita		
	Metric tonnes			Kilograms per capita		
Canada	20,673 903	20,840,883	23,109,369	690	688	750
Newfoundland and Labrador	372,324	366,280	409,599	670	671	760
Prince Edward Island	x	x	x	x	x	x
Nova Scotia	553,638	502,577	432,487	590	537	460
New Brunswick	505,957	468,571	472,612	670	623	630
Quebec ²	5,491,000	5,537,465	6,912,000	750	755	940
Ontario	6,913,786	6,988,157	7,615,923	620	612	650
Manitoba	947,884	964,726	938,624	840	848	819
Saskatchewan	900,210	848,408	828,359	880	827	811
Alberta	2,435,884	2,527,817	2,750,004	880	869	910
British Columbia	2,413,528	2,458,484	2,592,191	620	614	640
Yukon, Northwest Territories and Nunavut	x	x	x	x	x	x

x Confidential to meet secrecy requirements of the *Statistics Act*.

¹ Total amount of waste disposed of in public and private waste disposal facilities. Does not include wastes disposed in hazardous waste disposal facilities or wastes managed by the waste generator on site.

² Figures are derived from the results of surveys conducted by the province.

Note: Figures may not add up to totals due to rounding.

4.2.2 Yellow Grease

As yellow grease originates in food frying operations, most of this grease can be collected in Canada’s metropolitan areas, such as Toronto, Montréal, Vancouver, Calgary and Edmonton. A commercial-size biodiesel manufacturing plant with a capacity of 20-30 million litres a year could be run in virtually any province (see Table 3.2).

Table 3.2 Annual Production of Biodiesel Feedstocks in Canada, million litres (extrapolated from Alberta data [IAG 2002, p.10])

Feedstock	BC	AB	SK	MB	ON	QC	Atlantic	Canada
Yellow grease ¹	24	18	6	7	70	43	13	180
Beef tallow ²	12	90	41	22	31	20	4	221
Pork Lard ³	1	11	7	15	20	24	2	79
Canola oil*	0.06	3	5	2.5	0.05	-	-	11
TOTAL	36	123	59	47	121	86	19	491

* Based on 2003 Canola Harvests [CCoC 2003]

¹ Based on population statistics (Statcan, 2003)

² Based on heads of beef per province (Statcan, 2003); a number of 200,000 tonnes per year is also confirmed in [GCSI 1998, p.15]

³ Based on heads of hogs per province (Statcan, July 1, 2003)

NOTE: According to [CARC 2003, p.v], yellow grease production in Canada is 240,000 tonnes per year, and animal fat production is 640,000 tonnes, which exceeds the above extrapolated values considerably. However, the report then goes on to say that only a small fraction of these amounts is available for new uses, such as biodiesel production.

4.2.3 Animal Fat

Table 3.4 identifies high-density livestock regions in Canada. Table 3.2 already shows that Alberta, Saskatchewan, Ontario and Québec are the provinces with the highest production of beef tallow and pork lard. For beef tallow, the best regions would be the Central St. Lawrence, Upper South Saskatchewan, North Lake Erie and East Lake Huron. For pork lard, the best regions are the Central St. Lawrence, Lower St. Lawrence and North Lake Erie. This indicates that the regions in Québec and Ontario probably have the best overall resources, as they combine both beef tallow and pork lard.

Table 3.4 High Livestock Density Areas (May 1996) [Statcan 2001, p.14]

Province	Sub-Basin	Cattle (Animal Units)	Pigs (Animal Units)
Quebec	Central St. Lawrence	270,347	170,570
Ontario	North Lake Erie	237,669	89,400
Ontario	East Lake Huron	231,890	40,952
Quebec	Lower St. Lawrence	183,828	98,346
Alberta	Upper South Saskatchewan	253,058	10,347
B.C.	Fraser	126,393	13,407
Alberta	Red Deer	102,567	8,454
Alberta	Battle	76,759	6,723
Ontario	Lake Ontario	13,808	2,150

4.2.4 Canola

Significant rape seed (Canola) harvests are brought in only in the Prairies, with Saskatchewan having the largest share, followed by Alberta and then Manitoba.

4.3 Utilization Options

4.2.5 Animal Fat, Sub-food-grade Vegetable Oil and Cooking Oil to Biodiesel and Glycerine

Animal fats are used in lipo-chemistry, for energy production, instead of gas or mineral oil, and also in the production of biodiesel. Biodiesel is a methyl diester product made by a chemical reaction between methanol and either vegetable oils (e.g. substandard vegetable oil or recycled cooking oil) or animal fats. Currently three common types of biodiesel production technologies are available, and the selection will depend on feedstock quality and the state-of-art of a facility. Commercially used processes for biodiesel production are as follows:

- Base catalyzed transesterification with refined oils
- Base catalyzed transesterification with low free fatty acid greases and fats
- Acid esterification followed by transesterification of low or high free fatty acid greases and fats.

Each of these processes typically utilizes methanol (ethanol has been considered as well) in the presence of a base catalyst such as sodium or potassium hydroxide to produce mono-alkyl ester-based oxygenated fuel (methyl or ethyl esters) commonly known as biodiesel, and glycerine as a by-product.

Canadian biodiesel technology has focused on the hydro-treating method using a conventional refining process similar to the petroleum industry. This method produces cetane (used as a booster for diesel fuel), naphtha (used as a gasoline supplement), and other products (usable as power burner fuels). The high cetane portion (super cetane), when blended about 5 to 10 percent by volume with diesel, enhances engine performance in diesel the way octane does in gasoline. Super cetane may find a potential market as a replacement for commercial nitrate-type diesel fuel additives [CRFA 2003(1)]. A German biodiesel plant blends its animal fat-based biodiesel with rape seed oil for better lubricity during the cold months [Render 2002].

In Canada, since May 2001, Biox Corp. is using new technology to run a 250,000 litre per year pilot plant in Oakville, Ontario, which can handle any feedstock, with yellow grease provided by a Canadian renderer as the primary stock. The BIOX Process is a new commercial scale biodiesel production process in which fatty acids and triglycerides are sequentially converted to methyl esters by acid catalysed esterification and base catalysed transesterification. Dr. David Boocock, Past Chairman of the Chemical Engineering and Applied Chemistry Department, University of Toronto, has transformed the production process using inert co-solvents, such as tetrahydrofuran or methyl tertiary butyl ether, to achieve the reaction at low pressure in one phase and increase the rate of methanolysis reaction. The reaction is over 99% complete in seconds at ambient temperatures, compared to previous processes which required several hours. Continuous processes are now feasible and proven.

Most of the solvent can be recycled, and so the enhanced performance results in lower costs – Biox wants to produce ASTM D6751 grade biodiesel at a cost of 7 cents CAD per litre, plus the cost of capital and feedstock, thereby making biodiesel cost competitive with petroleum diesel. BIOX plans to commission its first commercial scale biodiesel production facility (60 million litres per annum) in Toronto during Spring, 2004.

More information: www.bioxcorp.com

Whereas biodiesel production will most likely not grow to cover the entire diesel consumption in Canada (to compare, all U.S. soy crops could only cover 13% of U.S. diesel consumption), using biodiesel as an additive may result in emission reduction benefits: the addition of 1% biodiesel to diesel fuel increased fuel efficiency by 5% - 13% [CRFA 2002]. With Canada's annual diesel consumption of 22.6 billion litres, 1% addition of biodiesel as a fuel additive could reduce CO₂ emissions by 2.8 to 5.6 Mt of CO₂. Reductions as a result of fuel savings would close 1.1% to 2.3% of Canada's Kyoto gap of 240 Mt.

The CANMET Energy Technology Centre in Ontario, Canada, has proven at lab scale a process to convert yellow grease and/or tallow and/or poultry fat into a valuable low-sulphur, high cetane premium diesel blending stock. The process used is based on a refining technology called hydrotreating. Figure 4.3 describes the necessary equipment and the material flows. The principal output is a diesel blending stock called AGTANE (for AGricultural ceTANE, or also SuperCetane) in English speaking countries (e.g. Australia, United Kingdom, United States, etc.), and BIOZOLE in French speaking countries. Production could be readily implemented in major urban areas where large rendering operations are located within 50 miles of petroleum refining facilities

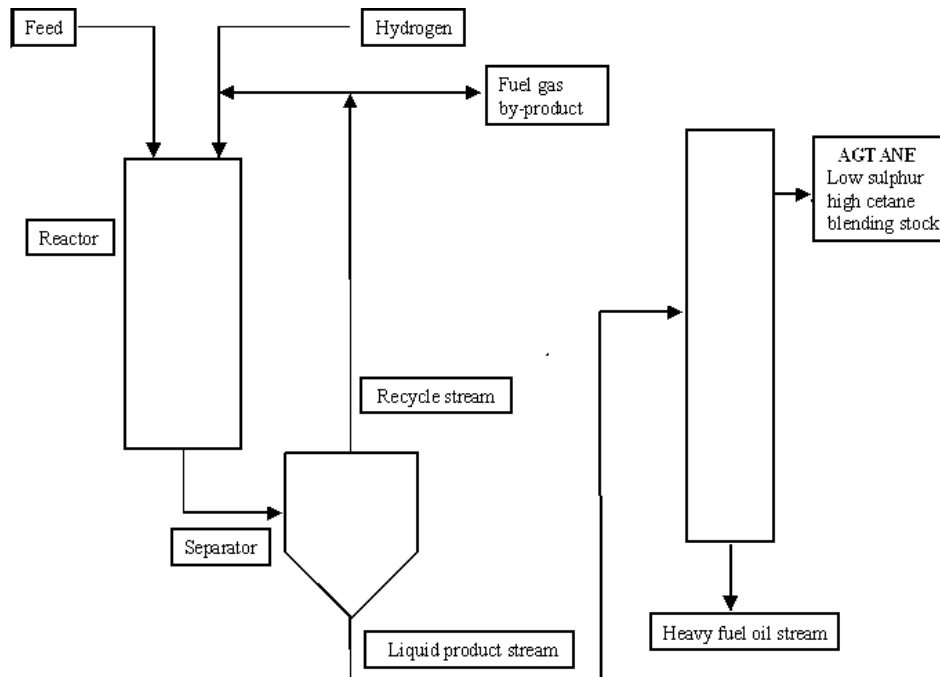


Figure 4.3 AGTANE Process Flow Chart

AGTANE, a collection of long-chained paraffins, is a premium diesel blending stock - it is not biodiesel (biodiesels are esters). Conservative economic models indicate that for mass production plants (>750,000 gallons/year), yellow grease can be profitably converted to AGTANE. AGTANE blended diesel will not require fuel suppliers to increase the use (and cost) of algae and/or bacteria killers (biodiesel blends typically require more algae and/or bacteria-killing additives than regular diesels). Being a collection of long-chain paraffins, AGTANE has a field tank storage life equal to or superior to currently commercialised diesel fuels. Modern fuel injection diesel engines were designed to burn fuels that include paraffins, which are included in AGTANE but no in conventional biodiesel fuels. AGTANE has been repeatedly shown to have cetane values of over 100, before blending, and have excellent physical and chemical

characteristics that make it an ideal blending stock. Typically, biodiesels have cetane values between 50 and 60. Unlike biodiesel, there are no engine emission trade-offs. No water is needed to produce AGTANE (water is needed to make biodiesel).

More information: <http://www.mhr-viandes.com/en/docu/docu/d9000137.htm> or
http://www.canren.gc.ca/tech_appl/index.asp?CaID=2&PgId=1083

4.2.6 Land Application of Sludge

In Canada, a large portion of biosolids (43%) are currently used in agriculture because they contain high concentrations of essential crop nutrients, primarily nitrogen and phosphorous. The nutrients are recycled into crop production and are used in place of inorganic fertilizers [EMS 2001]. Similar direct uses of sludge include its application to fertilise forests, in land reclamation projects, or the revegetation of mine spoils.

The main concerns about land application of biosolids are their content of contaminants, including heavy metals, and pathogens. For this reason, many municipalities incinerate the sludge in order to eliminate pathogens.

Composting is a possibility of pre-treatment for sludges. The sludge is dewatered to increase the solids content to around 20%, and is then mixed with a high-carbon organic material, such as sawdust. This mix is composted under aerobic conditions at temperatures of at least 131°F for several days during the composting process. This also eliminates some of the pathogens.

4.2.7 Anaerobic Treatment – Methane and Biosolids

Anaerobic treatment in digesters is one of the most widely used methods to treat water purification sludge. The sludge is held in the absence of air for 15 to 60 days at temperatures of 20°C to 55°C. Anaerobic bacteria feed on the sludge, producing methane and carbon dioxide. In some treatment plants, the methane is collected and burned to maintain the treatment temperature.

An example of an anaerobic process is the U.S. ODI 2PAD System (see Figure 4.4). It separates the acid and methane-forming digestion phases (acidogenesis and methanogenesis), increasing the efficiency of both, and combines this with high temperature, destroying pathogens to below detectable limits. The system has been proven during a two-year pilot study.

An anaerobic sludge treatment facility in Tampa, FL recovers about US\$700,000 worth of electricity each year from the methane produced. This is equivalent to approximately US\$65 of net electricity per dry ton of volatile biosolids removed from the digester. Tampa also uses the heat removed from the electrical generators to provide more than 95% of the warmth needed for the digesters. All but 10-15% of Tampa's digested biosolids are heat-dried and marketed for between \$85 and \$120 per dry ton. The balance is being land applied in dewatered form [EPA 1994, p.17].

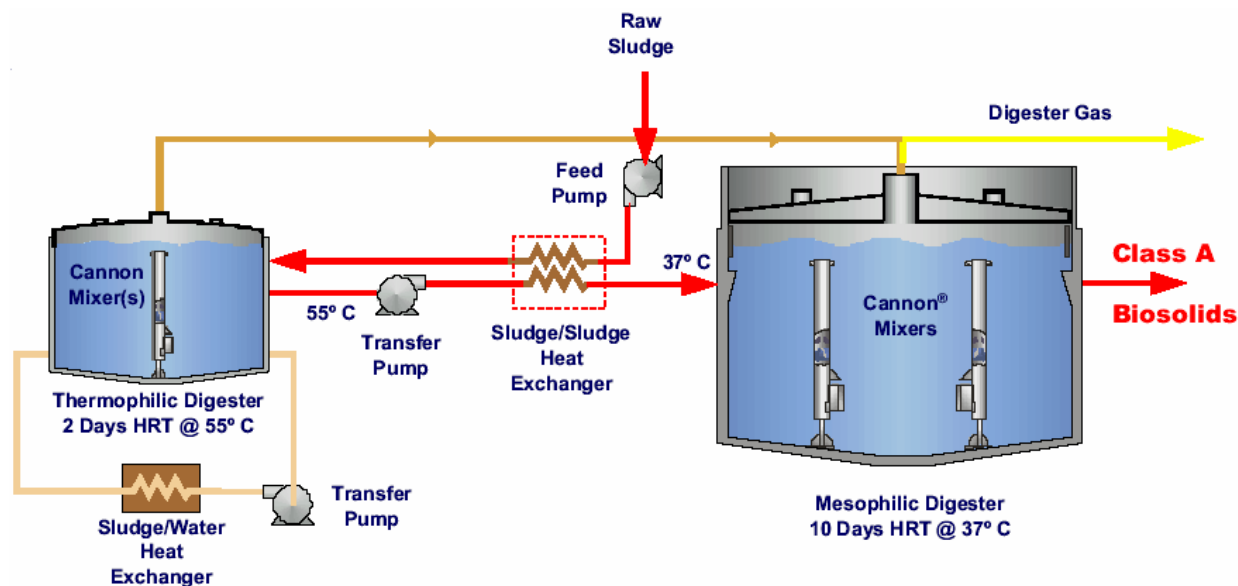


Figure 4.4 Two-Phase Digestion Process (ODI 2PAD System) [ONDEO 2002]

As an option for further improvement of the digestion process, a fuel cell can be used to generate electricity. A fuel cell at the Columbia Boulevard Wastewater Treatment Plant in Portland, Oregon, already converts digester gas into electricity. The digester gas is first cleaned to remove impurities and then enters the phosphoric acid fuel cell. Impurities are principally hydrogen sulphide, halogens (fluorine, chlorine and bromine), moisture, bacteria and solids. Biogas also contains carbon dioxide, which cannot be removed easily. The gas-cleaning system at Columbia Boulevard uses a potassium hydroxide impregnated activated carbon filter to remove the hydrogen sulphide. The fuel cell began producing power in July 1999 and produces an estimated 1,400,000 kilowatt-hours of electricity each year.

More information: www.energy.state.or.us/biomass/FuelCell.htm

4.2.8 Incineration

Sewage sludge incineration reduces the volume of the material to be disposed of, completely destroys pathogens, decomposes most organic chemicals, and recovers the small amount of heat value contained in sewage sludge. Figure 4.5 shows the incineration technology by Danish company Krüger as an example. The residual ash is a stable, relatively inert, inorganic material that has just 10 to 20% of the original sludge's volume. Most trace metals in the sewage sludge become concentrated in the ash (a five- to tenfold increase in concentration). This material most commonly is landfilled, although it potentially could be used in construction materials. Incineration can release volatile pollutants, such as cadmium, mercury, lead, or dioxins into the atmosphere. Incinerator operation requires sophisticated systems to control temperature, residence time, and the removal of fine particulate matter (fly ash) and volatile pollutants from stack gases. This makes incineration one of the more expensive options for sewage sludge disposal. As with landfilling, the potential benefits from organic matter and plant nutrients in sewage sludge are lost. [PSU 1999]

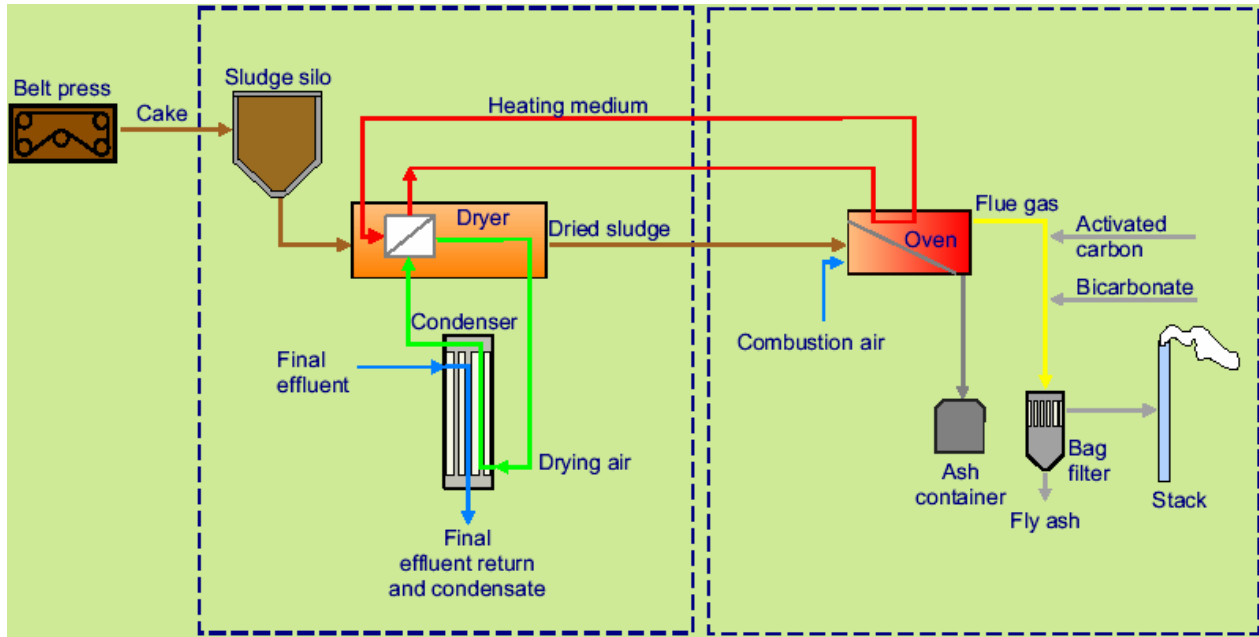


Figure 4.5 BioCon System for Sludge Incineration [Vivendi]

4.2.9 Pyrolysis: Waste to Liquid Fuel

Pyrolysis is almost exclusively applied to the manufacture of liquid-fuel end products like ethanol and bio-oil. Pyrolysis occurs when biomass is heated in the absence of oxygen. Through this process, the biomass is converted into a liquid called pyrolysis oil (bio-oil), which has a heating value nearly half that of a conventional fuel oil – typically 16–18 MJ/kg, and a pH of 2.5. The density of the liquid is very high at around 1.2 kg/litre, compared to light fuel oil at around 0.85 kg/litre. This means that the liquid has about 42% of the energy content of fuel oil on a weight basis, but 61% on a volumetric basis [PYNE 1999]. A biopower system that uses pyrolysis oil is currently being commercialised.

Fast pyrolysis, while related to the traditional pyrolysis processes for making charcoal, is an advanced process, which is carefully controlled to give high yields of liquid. It is a high-temperature process in which biomass is rapidly heated in the absence of oxygen. As a result it decomposes to generate mostly vapours and aerosols and some charcoal. Cooling and condensation forms a dark brown mobile liquid, the pyrolysis oil, also termed “bio-oil”.

The essential features of a fast pyrolysis process are:

- Very high heating and heat transfer rates, which usually requires a finely ground biomass feed with a low moisture content.
- Carefully controlled pyrolysis reaction temperature often exceeding 500°C in the vapour phase, with short vapour residence times of typically less than 2 seconds.
- Rapid cooling of the pyrolysis vapours to condense out the bio-oil product.

Bio-oil is obtained in yields of up to 80% by weight on dry feed, together with by-products char and gas, which may be used within the process, eliminating waste streams. While a wide range of reactor configurations have been operated, fluid beds are the most popular configurations due to their ease of operation and ready scale-up. Canadian company Dynamotive has a 50 kg/h demonstration unit (see also section 1.3.3). Circulating fluid beds and transported bed reactors

have been developed to commercial status by Ensyn and are used in the USA for food flavourings and related products in several plants of 1 to 2 t/h. [PYNE 1999]

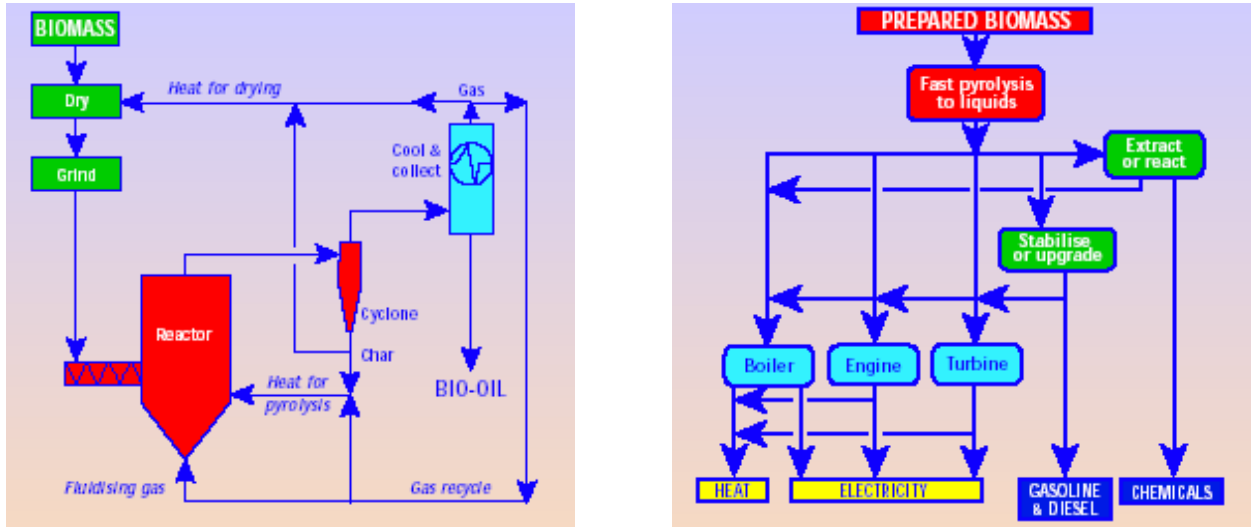


Figure 4.6 Generic Pyrolysis Process Flow Chart and Possible Uses of Oil [PYNE 1999]

Bio-oil has the potential to substitute for fuel oil or diesel in many static applications including boilers, furnaces, engines and turbines for electricity generation, although the lower pH of the bio-oil and its high water content must be taken into account. The possibilities are summarized in Figure 4.6. There is also a range of chemicals that can be extracted or derived including food flavourings, specialities, resins, agri-chemicals, fertilizers, and emissions control agents. Upgrading bio-oil to transportation fuel quality is feasible but currently not economic [PYNE 1999].

Due to its high moisture content, waste biomass usually needs to be dried before it can be converted to bio-oil. As discussed in chapter 1.3.4, this reduces the amount of useful energy that can be extracted, and negatively affects process economics.

More information: Biomass Pyrolysis Network - <http://www.pyne.co.uk/pyne/>

4.2.10 Waste to Ethanol

Feedstocks that can be used to produce ethanol include waste sludge from pulp and paper mills, waste paper, grass, straw, leaves and other solid landfill wastes that contain cellulose, or plant fibres.

The process of making ethanol from pulp and paper sludge is similar to the process used in making ethanol from wheat (see Figure 4.7). The sludge is pre-treated to further break down the cellulose. Enzymes are added to convert the cellulose to glucose. Then yeast or, in some cases, genetically altered bacteria, are added to create the fermentation process. The mixture is then distilled to produce ethanol.

A Japanese team has also developed a process to make ethanol from waste construction wood. A factory producing 3.7 million litres of ethanol from 30,000 tonnes of waste wood is to be operational in Osaka by 2007. The process consists of acid pre-treatment and subsequent

fermentation, and is being developed by a group of five organisations, including Marubeni and Tokyo Board Industries.

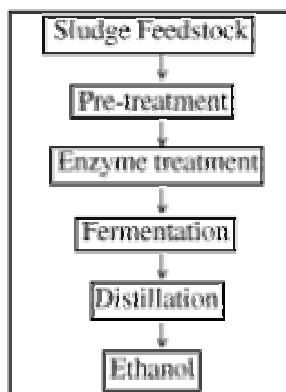


Figure 4.7 Fuel Ethanol Production from Pulp and Paper Waste

4.2.11 Gasification

Gasification can also be applied to biomass waste. It is a process that chemically and physically changes biomass through the addition of heat in an oxygen-starved environment. The end products of gasification include solid ash, slag, and synthesis gas, or syngas, which can be used for electricity production or be turned into other, higher-value chemical products (see Figure 1.2). The gas has a calorific value, or heat content, equivalent to less than 25% that of natural gas if ambient air is used or 40% if oxygen enriched air is used. Gasification can be applied to various biomass waste feedstocks, including Municipal Solid Waste, sludges, bagasse, sugarcane, corn fibre, rice straw and hulls, nutshells, tree clippings, animal wastes, process sludges, industrial biomass residues, etc.

Although several gasification systems have been designed and constructed in the past two decades, most have been demonstration and laboratory-scale systems. Large-scale demonstration plants in the U.S. experienced technological problems and are no longer operating. There are currently no commercial-scale solid waste gasification systems operating in the United States [BREDL 2002]. Canadian company Enerkem does promote a biomass gasification concept (see section 1.1.1).

4.2.12 Fractionation into Fibre and Lignin

The PureVision process allows several biomass waste streams to be split up into lignin and fibre. Possible feedstocks include pulp from paper mills, municipal biosolids, and the organic and paper fraction of municipal solid waste (see section 2.2.2).

4.2.13 Composting of Separated Fractions

Methane is formed in landfills due to the decomposition of organic materials in landfills. Diverting the organic fraction of waste to composting will reduce the organic residue in landfills, and therefore methane emissions as well. In addition to that, large-scale composting has other climate change benefits, including:

- reduced N₂O emissions, since compost use reduces the need for fertilizers; and

- reduced CO₂ emissions, since compost use increases soil moisture retention and thus reduces the amount of energy needed for irrigation. [Woodrising 1999]

The challenges in waste composting is its separation from other waste items, especially those containing contaminants, such as heavy metals, and the control of salt content from food waste.

Chapter 5 Energy Crops and Biochemicals

5.1 Canada's Potential

5.1.1 Overview

There is no official estimate with respect to how large Canada's potential for energy crops would be. Issues to be addressed would include competing land uses, e.g. growing energy crops vs. afforestation to obtain carbon credits for Canada's offset system, or utilization of existing crops for energy purposes instead of current uses.

However, there is a strong policy drive towards energy crops in the U.S. and the EU, and also the Canadian government has made \$100 million available for the furtherance of the ethanol industry within its 2003 budget for climate change-related measures.

A variety of biomass crops can be used for energy purposes. Table 5.1 shows a few examples of the most typical ones. Some provinces have started analyzing their potential to use biomass crops for the production of biodiesel and ethanol. In Manitoba, as well as in many other jurisdictions, the addition of 10% ethanol to gasoline is encouraged with tax breaks. Expanding this to all gasoline sold in the province would create a market for 140 million litres of ethanol that would require approximately 420,000 tonnes of wheat, the crop seen with the most near-term potential for conversion to ethanol [AGRI 2003].

Table 5.1 Energy Crops and Their Uses [OEKO 2000]

Energy Crop	Products
Sugar beets, potatoes, corn, grain	Bioethanol
Rape seed	Biodiesel or heating oil
Wood, grass, straw, grain, miscanthus	Heat, steam, power

5.1.2 Switchgrass

Switchgrass is a high-yielding species that can be planted on marginal agricultural lands. Ontario alone has 1.5 million hectares of such areas, which could yield biomass equivalent to 17 million litres of ethanol [Levelton 2000, p.14]. However, switchgrass only grows well in Ontario and Manitoba, with yields in Manitoba somewhat reduced from 8-10 t/ha to only 5-6 t/ha, but with a larger surface available for its production. So, about the same annual yield as for Ontario can be assumed. Further West and East of Ontario, either willow or other kinds of grass could be grown instead of switchgrass [AAFC 2002]. The potential yield can be assumed to be as high as Ontario's for Alberta, Saskatchewan, Quebec and the Atlantic Provinces together, leaving out BC because of its small arable land surfaces [REAP 2002(2)]. The overall potential yield of grass crops on marginal land in Canada has been estimated to about 6.8 million tons per year [PP 2002, p.193].

5.1.3 Oil Seeds

In Canada, the 2003 production of canola was 6.3 million tonnes. Soybean seeds were projected at 2.5 million tonnes [Agnews 2003]. Due to exports, Canada only processed about 1.3 million tonnes of these seeds (1996 figure). Assuming 10% of Canada's canola and soy oil

potential was used for biodiesel production, 277 million litres of biodiesel could be produced per year [GCSI 1998, p.15]. This amounts to only about 1.5% of the Canadian diesel consumption of approximately 19 billion litres per year. However, as mentioned in chapter 4.1.3, the use of oil seeds for biodiesel production is not likely as long as other uses promise much higher returns.

5.1.4 Wheat, Corn and Sugar Beets

Ethanol is already being made from bioenergy crops: as Table 5.2 shows, several plants with a combined output of 212 million litres per year are in operation in Canada. Both wheat and corn are currently being used as feedstocks, although the use of sugar beet is also employed, especially in Europe. Additional ethanol plants are proposed for Ontario and Québec [CRFA 2003(2)]. As part of the Climate Change Plan for Canada, the government created an Ethanol Expansion Program funded with \$100 million over three years in 2003, to support the construction of ethanol plants. From this program, Suncor has been awarded \$22 million to build a 200 million tonne ethanol plant in Sarnia, ON, in February 2004.

Table 5.2 Ethanol Production in Canada [CRFA 2003, corrected acc. To CARC 2003]

Producer	Location	Capacity	Other Information
Mohawk Oil, Canada, Ltd.	Minnedosa, Man.	10 million litres	Wheat-based
Pound-Maker Agventures, Ltd.	Lanigan, Sask.	12 million litres	Wheat-based Partnered with a cattle feedlot
Commercial Alcohols, Inc.	Tiverton, Ont.	23 million litres	Corn-based
Commercial Alcohols, Inc.	Chatham, Ont.	150 million litres	Corn-based
Tembec	Temiscaming, Qué.	17 million litres	Forestry product-based

The Government of Canada’s Future Fuel Initiative has the objective to increase bioethanol fuel use in vehicles from the current 212 million litres per year to over 1.3 billion litres per year by 2010. This volume is based on bioethanol achieving 35% market penetration of gasoline blends formulated with 10% bioethanol (E10) [ARC 2003(1), p.31]. This is equivalent to 3.5 million tonnes of wheat, at an average yield of 370 litres of ethanol per tonne processed. E10 is more realistic as a near-term target, as blends with 85% bioethanol (E85) cannot be used in most vehicles [CCC 2003, p.6].

From 1992-1996, about 2.9 million tonnes per year of all wheat classes were designated as (inferior) feed quality. Together with 1.8 million tonnes of “Canadian Prairie Spring Red” and 0.4 million tonnes of “Canadian Prairie Spring White” – both low-protein varieties that have less value for human consumption - the total available feedstock for ethanol production would amount to 4.6 million tonnes per year, surpassing the 3.5 million tonnes required to meet the national 35% E10 fuel target. This does not include the use of Eastern Canadian corn, the largest feedstock for current ethanol production. [CCC 2003, p.7]

It is also likely that wheat production would be increased if a large ethanol market existed. The number of acres of land used in wheat production has declined steadily for the past decade or more. If more land were to be used for wheat production, reaching the volume required for a 10% ethanol blend in 35% of all gasoline would be even more easily attained. It is estimated that Saskatchewan alone could increase production of ethanol grade wheat by some 1.3 million tonnes per year by using half of the current summer fallow land. This could represent an additional 480 million litres of ethanol per year [CCC 2003, p.7]. Of course, increased wheat production could reduce opportunities to grow other energy crops, such as switchgrass, for energy purposes.

Canada only has one sugar beet plant, located in Taber, Alberta. Sugar beets have been successfully grown in Québec and Ontario, but the Prairie provinces have proven to be the most ideally situated for economic production. Sugar beet harvests have declined in recent years and the area planted has decreased from 18,000 hectares in 1998 to 11,700 hectares in 2001. With a 2001 yield of 46.5 tonnes per hectare, the total harvest was 544,000 tonnes, virtually all in Alberta [AAFC 2003]. Based on an estimate for Australian sugar beet (ethanol yield of 4,500 litres/hectare), the 2001 harvest represents a potential 53 million litres of ethanol [Weeden 2000]. If the decline in areas used for sugar beets in Alberta were reversed, then the 6,300 extra hectares would yield another 28 million litres of ethanol, or about 22,000 tonnes per year (specific weight of ethanol: 0.79 kg/l). Acreages for growing sugar beets could be significantly increased across Canada, and would be able to yield ethanol in the same order of magnitude as grains or corn.

5.2 Utilization Options for Energy Crops and Biochemicals

5.2.1 Use as Heating Fuel

A furnace is the simplest combustion technology. Biomass is burned in a combustion chamber, converting it to heat energy. The released hot gases contain about 85 percent of the energy contained in biomass. Commercial and industrial facilities use furnaces to directly or indirectly heat facilities or processes through a heat exchanger in the form of hot air or water.

Densified (pelletised) biomass fuels can be transported and used in wood pellet stoves. This technology is apparently being explored by tobacco farmers in southwestern Ontario looking to use switchgrass pellets instead of natural gas for heating their tobacco dryers. Currently, Canada produces about 350,000 tonnes of pellet fuels per year. Approximately 100,000 tonnes of pelletised wood residues are being exported annually to Scandinavia from Canada, but the market within Canada remains underdeveloped [ECS 2001, p.8]. Gasifier pellet stoves are being produced and sold in Canada that are burning moderately high ash pellets and grains at 80-85% efficiency [REAP 2004]. Numerous attempts have been made in both Canada and USA to develop a wood pellet market but have met with limited success.

Heating with biomass is also being proposed for homes. A biomass-fed furnace offered by a U.S. company can heat houses using fuels such as corn, rye, pellet fuel or even cherry pits.

More information: <http://www.ja-ran.com/superior.html>

5.2.2 Lactic Acid from Starch

Biodegradable plastics are gaining market momentum in Europe as a result of government regulations promoting the composting of biodegradable materials. The EU market for bioplastics in 2000 was 10,000 tonnes (40% of world market) and it is expected to grow to 60,000 tonnes by 2005. The main product markets are food packaging, compost bags, paper coatings, dishes and cutlery. Other commercial applications for starch biopolymers include loosefill packaging; sheets, shaped and blocked packaging for electronics; injection moulding; films and fillers; and children's toys. Long term market opportunities for bioplastics in the EU are estimated to be about 300,000 tonnes by 2010 [CARC 2003, p.84].

Cargill Dow LLC's facility for the production of polylactic acid (PLA) in Blair, Nebraska, has a capacity of 140,000 metric tons/year. The plant began operations in the fall of 2001. At present,

the products include polymers for packaging, polymers for fibres and lactide as a source of chemical intermediates. These materials replace conventional plastics made from fossil fuels.

The corn wet milling process converts corn into several fractions, the largest of which is starch. The starch is then converted in an enzymatic process into dextrose. Dextrose is combined with appropriate nutrient sources and minerals and is converted via fermentation and purification to lactic acid. An anaerobic fermentation using either *Bacillus* or *Lactobacillus* species is used to prepare the crude broth, maintaining a neutral pH with the addition of lime. The lactic acid can be either of two isomers, or a mixture, depending on the organism used for the fermentation. The crude broth is then purified by acidulation, precipitation, or ion exchange and then evaporated to the final concentration. Conversion of lactic acid to lactide follows, which is blended to the desired isomer content, polymerized and finished to form the various grades for a variety of products.

The life cycle assessment of the overall process and the component pieces, including farm inputs, transportation, power generation demonstrates that use of PLA can result in a 25-55% reduction in fossil fuel and significantly reduced greenhouse gas emissions, compared to the incumbent petroleum-based polymers. [IC 2003]

Cargill Dow is further developing the fermentation process to operate on sugars from biomass feedstock and agricultural wastes rather than more expensive food-grade corn sugars. As the cost of fermentable sugars is reduced and production volumes increase, PLA will become more price competitive with commodity plastics such as polystyrene and should experience expanding markets [ARC 2003(1), p.58].

More information: <http://www.cargilldow.com/corporate/index.asp>

5.2.3 Switchgrass to Polyhydroxyalkanoates

Polyhydroxyalkanoates (PHA) are a family of polyester polymers that can be biosynthesized in bacteria and plants. U.S. company Metabolix Inc. is using nuclear transformation to introduce PHA-encoding genes into switchgrass and tobacco. To recover PHA from biomass, solvent extraction techniques using green solvents such as ethanol and ethyl acetate are used, as well as hydrolytic enzymes to facilitate aqueous extraction of PHA from biomass. In 2002, Metabolix announced it had demonstrated the feasibility of high yield commercial scale manufacturing of PHA with costs projected at under \$US 1 per pound. [ARC 2003(1), p.58]

5.2.4 Corn to Bulk Chemicals and Chemical Intermediates

1,3-Propanediol

Genencor International, with Dupont, genetically engineered a micro-organism which combines the needed metabolic pathways from bacteria and yeast to make 1,3 propanediol (bio-PDO) by fermentation of corn-based sugars. PDO is used to produce polytrimethylene glycol terephthalate (3GT), which Dupont is marketing as a new fabric polymer called Sorona™, displacing polyester in applications such as clothing, carpets, packaging and automobile interiors. 3GT has enhanced fabric properties compared to traditional polyester, including improvements in fit and comfort, softness of touch, dyeability, resilience, and stretch recovery. Other high performance bioplastics and fabrics could also be made using bio-PDO and 3GT as technology platforms.

The production of PDO involves a costly petroleum-based synthetic process, which makes the process too expensive so far. DuPont and Tate & Lyle are jointly developing the bio-PDO manufacturing process. Once bio-PDO can be produced more cheaply than petroleum-based PDO, 3GT could penetrate more of the polyester market. [ibid., p.50]

α,ω -Dicarboxylic Acids

These dicarboxylic acids are chemical intermediates used in the production of nylon polymers, lubricants and plasticizers. The production of succinic acid derivatives from corn sugars has been explored in the U.S. – where the market for these chemicals is 450,000 tonnes per year. [ibid., p.51]

Biobased Solvents

Cargill-Dow Polymers can produce ethyl lactate, through the fermentation of corn sugars. Other esters can be made from soy or citrus peels. [ibid., p.52]

Alcohols

Fusel oil, a by-product of ethanol production, is a mixture of various higher alcohols which have a potentially high market value. [ibid., p.53]

Biolubricants

Vegetable oils can be used to make a broad range of lubricant products, including: machinery oils, chain bar lubricants, gear and transmission fluids, hydraulic fluids, farm tractor oils, drilling oils, outboard marine two-stroke engine oils, metal cutting oils, etc. Although the performance of biolubricants is sometimes lower than that of petroleum-based oils, their lesser ecotoxicity and better biodegradability opens up great market opportunities. In Europe, biolubricants already gained a market share of 20%, whereas in Canada they only hold a very small margin of the market [CARC 2003, p.120].

5.2.5 Fractionation into Fibre and Lignin

The PureVision process can split up various biomass crops, such as switchgrass, hybrid poplar and willow, into lignin and fibre (see section 2.2.2).

Flax and hemp fibres are replacing glass fibres in applications, such as cement and composites. The use of fibres is becoming more and more important in composites for the automotive industry, increasing recyclability, reducing vehicle weight – and therewith fuel consumption – and reducing the energy required for the production of composites by 80%. In Europe, the glass fibre market has a size of 600,000 tonnes, whereas 100,000 tonnes of plant fibres were used already in 1999. In North America, their application is less advanced. [CARC 2003, p.108ff.]

5.2.6 Other Options

In essence, the technologies and options to use biomass crops are the same as for the previous sections. They can be summarized as follows:

- Switchgrass and other lignocellulosics (poplar and willow trees, switchgrass, elephant grass, prairie bluestem, etc.) to ethanol and CO₂ (fermentation)
- Canola and soy beans to biodiesel (transesterification)
- Biomass to syngas and then electricity or biobased products (gasification)
- Switchgrass or forest biomass to electrical power
- Forest biomass to charcoal for co-firing or other applications
- etc.

Chapter 6 Results from Stage I and Recommendations

6.1 Biomass Availability in Canada

Table 6.1 summarizes the findings of the previous chapters. It becomes evident that the largest sources of biomass are the ones current forest practices leave behind unused, agricultural residues, and municipal waste. Black liquor was included as a major resource, although it is already being used for energy purposes. However, applying alternative technologies may increase the emission reduction benefits from black liquor use in the pulp and paper industry.

It is also striking that there is a very large potential for both switchgrass and also wheat and corn. Most of the other waste-related resources, such as yellow grease, do occur in important amounts, but still an order of magnitude less than the aforementioned resources. Without taking energy crops into account, BIOCAP has calculated that biomass residues alone have an energy content equivalent to between 18 and 27% of Canada’s annual energy consumption [BIOCAP 2003, p.2].

Table 6.1 Summary of Canada’s Biomass Resources

Biomass from ...	Specific Type	Availability [Mt/year]	Appr. Energy Content in Dry Biomass [PJ]
Forestry Residues	Non-stem wood	92	1440
	Mill residues	<5.7	<117
	Tall oil	0.18	7
	Black Liquor	24	282
Agricultural Residues	Straw & Stover	18-25	277-385
	Livestock manure	58-79	65-88
Landfill Gas	(in tonnes of CO ₂ e)	21.9	
Municipal and Industrial Residues	MSW (50% of total)	8	132
	Municipal water purification sludge	0.4	7
	Yellow grease*	0.16	6
	Beef tallow*	0.20	8
	Pork Lard*	0.07	3
	Canola oil* (from low-quality canola only)	0.01	0.4
Energy Crops (Potential)	Switchgrass and other grass	6.8 ¹	107
	Canola and soy beans (10% of harvest)	0.23	9
	Grains (wheat and corn; enough for a national E10 standard)	>4.6	89

* assumed density: 0.91 kg/l

¹ REAP Canada assessed Canada’s potential eight times higher, to 55 million tonnes for perennial grass yields. This is based on an available surface of 23.4 million acres, which would not affect food production in Canada (about 13%) [REAP 2004]. The lower estimate above is based on the assumption that Ontario would have 282,000 acres available for growing perennial grasses, and that Canada’s overall yield could be three times that of Ontario.

The above Table does not contain data on wood from Reduction of Fuel Loading in the forest. This initiative is underway in the U.S. in order to prevent forest fires, and may also yield

additional wood in Canada if implemented here. However, it is a forest treatment that is only appropriate for ecosystems which naturally have fire as a regular part of the cycle but from which fire has been excluded for the past 100 years or more. This includes the ponderosa pine ecosystems of the western US, extending into the Southern Interior of BC. Most of the forests of Canada are in the boreal forest zone, however, where wildfire is also part of the regeneration cycle (though on a much longer cycle than in ponderosa pine) but which have continued to experience periodic fires in historic times. However, thinning, particularly pre-commercial thinning (at an early age before any regularly merchantable wood can be extracted) is good silvicultural practice throughout the boreal forest, improving the growth of the rest of the stands, and an energy market for the thinnings would make the practice more viable economically [CanBIO 2003]. The quantities available from fuel loading reduction and thinning may be significant, but at the moment, no such program has been decided on in Canada. It can be treated the same way as non-stem wood, as it mainly concerns thinning out smaller trees. More forest biomass may be derived from fire management, bugwood and other sources (see section 1.1).

6.2 Selection of Threads to be Analysed in Phase 2

The following matrix summarizes the findings from the first few weeks of research into biomass in Canada and its possible uses. 19 of the threads identified in this table are further analysed in the Phase II Report, selected based on the preferences of the funding partners. Envirochem has highlighted further threads that seem to be relevant and that it recommends for being examined further on a life-cycle basis (marked “nf” for “not funded”).

The following feedstock-to-product threads were selected for a full life-cycle study during Phase 2:

- a comparison of the use of non-stem wood residues for power production as opposed to gasification, and with fast pyrolysis of sawmill residues, and proposed technologies for CHP;
- a comparison of landfill gas use for electricity production as opposed to simply flaring it, as well as municipal waste incineration and increased recycling of biomass;
- an examination of the use of yellow grease for biodiesel production as opposed to making it from energy crops, such as canola (Ontario)
- production of ethanol from straw and stover residue as opposed to from field crops (Prairies)
- the use of switchgrass for power production as opposed to hydrogen generation (Prairies)
- a comparison of local small power systems versus larger centralized systems for forest residues (not marked in Table 6.2);
- comparison of land-use options (afforestation and energy crops) against “business as usual” or the “do nothing” alternative.

The Phase 2 research was carried out in “modules”, which means that feedstock-to-product threads were examined in several steps: harvesting/transportation – first processing step – second processing step – distribution - consumption. Some of these steps may be identical for several biomass feedstocks: for example, any feedstock that can be gasified can also be used for hydrogen production. This modular approach allows the application of information about certain common end products like hydrogen to several feedstocks. For example, once the “hydrogen module” has been put together, it can then be applied to several feedstocks, enriching the results flowing from this study and making more comparisons possible without multiplying the work.

Table 6.2 Biomass Resources and Possible Uses

	Feedstock	Product																
		Fertiliser (aerobic)	Burning/Flaring	Heat (direct comb.)	Electricity (direct comb.)	Syngas/Electricity (Biogas)	Methanol	Hydrogen	Bio-Oil and Charcoal	Biodiesel	AGTANE	Diesel Addit.	Heating Oil	Ethanol	Poly-lactic Acid	Bulk Chemicals	Fibre and Lignin	Composite Board
Forest Biomass	Non-stem wood, bugwood, etc.	x			f		x	x	x	x				x*			x	
	Sawmill residues	x		nf	f	nf	x	nf	f	f				x*			x	
	Tall oil										x	x						
	Pulp liquor			x	x		x							x				
Agricultural Biomass	Straw & stover residue	x	x	x	x		x	x	x	x				f	(x)		x	x
	Manure	nf		x	x	nf								x				
Waste	Landfill gas		f		f			x	x					x				
	Municipal solid waste	f		x	f	f	nf	x						x			x	
	Waste wood			x	x		x	x	x	x				x			x	x
	Yellow grease						x				f	nf						
	Beef tallow										f	x						
	Pork lard										f	x						
	Canola oil waste										f	x						
	Biosolids/municip. and ind. sludges	nf	x	x	x	nf	nf											x
Energy Crops	Corn													f	x	x		
	Grain													f	(x)			
	Sugar beets													x				
	Canola & soy										f	x	x					
	Switchgrass			nf	nf		x	nf	f					f				x
	Willow			x	nf		x	x	f									x

* hardwood only; f: funded within existing budget; nf: suggested, but additional funding needed

Chapter 7 What Is “Sustainable Biomass”?

The use of biomass for energy production has been common practice for thousands of years. Yet, its large-scale use is controversial for a number of reasons, and the inclusion of biomass-based power generation in “green labelling” and renewable energy policies is highly contentious. Some of the main arguments brought forth against large-scale use of biomass are:

- **Energy crops:** the displacement of other activities, such as agriculture for food-related crops
- **Energy crops:** the need for fertilizer and transport, which can undo much of the emission benefits hoped for
- **Forest residues:** unsustainable harvest of additional biomass could harm ecosystem balances
- **Agricultural residues:** centralised treatment can prevent valuable nutrients from being returned to the field
- **Municipal waste:** using waste for energy is unsustainable; organic residues should be separately collected and composted
- **Landfill gas:** waste-related energy sources are not “green” (per definition)
- **Co-firing:** the combustion of biomass in coal-powered stations supports the use of coal, a fossil fuel with the highest greenhouse gas and other emissions
- **Biomass (general):** the combustion of biomass creates air particulate emissions

To make a judgement about the sustainability of biomass use, several questions need to be answered. For example, energy crop production depletes soils of minerals and, in an intensive farming scenario, requires replenishment of essential minerals through artificial fertilizers. The collection and transport of biomass must be done in a manner that does not cause excessive emissions so that possible benefits from biomass use are undone. The combustion of biomass is often seen as polluting, for example due to increased particulate emissions as compared to fossil fuels. However, abatement technology can be used to prevent such emissions, and biomass-derived power will reduce net carbon dioxide emissions, as biomass is considered “carbon cycle neutral”. The direct combustion of biomass, emitting carbon dioxide, has less GHG impacts than its natural decomposition, which produces methane gas; a 21 times more potent greenhouse gas. It is clear that electricity production from biomass causes air pollution and that the only emission that is clearly reduced by regrowing the feedstock is carbon dioxide. This must be weight against the notion that biomass is the only renewable energy that if not used productively can be detrimental to the environment. Natural occurring decomposition systems to convert accumulation of biomass residue from agricultural and industrial activity can be shown to produce more environmental damage than many conversion technologies used to harness product and power.

Internationally, there is no consistent approach to defining “sustainable biomass”, and a variety of definitions exist under various labelling and legislative support schemes (see Table 7.1). To address sustainability issues, the North American forest industry has created “sustainable management” protocols, which can be used to sell wood products as certified under Canadian Standards Association or Sustainable Forestry Initiative® Standards.

An exhaustive examination of sustainability must incorporate more than just carbon dioxide emissions. This study can help determine which uses of biomass should be preferred as it describes energy payback, life-cycle carbon emissions and also includes information on other air pollutants, as well as financial aspects. However, the final decision whether a biomass technology or project is sustainable or not will also depend on issues not related to air

emissions, including community involvement and acceptance, the possible competition between resource uses (e.g., agriculture for food as opposed to agriculture for energy crops), and other changes induced by the increased use of biomass for energy purposes.

Table 7.1 Types of Biomass Included in Various Renewable Energy Schemes

	Wood waste	Agricultural and forest residues	Energy crops	MSW	Landfill Gas	Sewage gas	Co-firing	Other
Canadian Low Impact Electricity Guideline (draft)	Un-treated	x	x	An-aerobic	x	x		Management, social and environmental pre-assessm't requirements; air emission limits
Green-e	x	x	x	(x)	x			MSW not allowed in some regions; air emission limits
North American RPS definitions	15	13	7	10, some "no"	19	4		out of 27 RPS examined [CEC 2003]
Australian Renewable Energy Act	x	x	x	x	x	x		bagasse co-generation, black liquor, food waste
EU Renewable Energy Directive	Un-treated	x		x				Cork waste
Netherlands (groencertificaten)	x	x		50%	x	x	No	
German OK Power label	Un-treated	Wood from certified forestry operations	Organic only				x	
EUGENE	Un-treated	x Certified wood only	x	No		x	x	Specifications concerning consumer information and additionality
EKOENERGIA (Finland)	Un-treated	x	x		x	x		

x = included

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