Alcohols from Cellulose - Agricultural Resources

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Abstract

Canadian agriculture has developed into a highly efficient producer of biomass for food and feed. The energy content of the plant biomass produced is about 1755×10^{12} BTU annually. Direct food use of plant material in Canada accounts for 50.5×10^{12} BTU, 262×10^{12} BTU are exported as grain and oilseeds and an estimated 801×10^{12} BTU are used as animal feed (grain and forages). Animals graze an additional 595×10^{12} BTU from pasture land. Seed, industrial use and losses account for the remaining 46.5×10^{12} BTU.

Of particular interest from an energy resource viewpoint is the co-production of large quantities of plant residues and animal waste. Estimated tonnage of plant residue produced is almost 1/3 that of feed and food crop production. A large portion of the plant residue is required to maintain soil tilth and fertility and so is not available for use. As well straw is used for bedding and in some animal maintainance diets. Available plant residue is estimated at 18.6×10^{6} tons annually with a crude energy content of 23.4×10^{13} BTU. Animal manures are produced in large quantities but are largely returned to the soil. Manure theoretically available from confinement operations (feed lots, dairies, broiler houses, etc.) amounts to 14×10^{6} tons containing 33.8×10^{13} BTU. In relation to the 7×10^{15} BTU annual total energy use in Canada these quantities of energy could have significant impact if efficient conversion processes were developed.

The chief drawbacks to the use of agricultural "waste" are in the seasonal and annual variation in supply and the wide dispersion of these products.

Introduction

Quite apart from its primary role in food production (Table 1) Canadian agriculture produces large quantities of plant residues and animal wastes. While extensive use is made of these "wastes" within the agricultural system a portion can be considered available for alternative uses. With todays interest in greater energy efficiency in all industrial sectors and the search for alternate sources many people are looking at these residues. In this symposium the concern is as an energy source, however, the competitive uses as soil amendments and in animal feeding programs will place constraints on material availability. In periods of surplus grain production Canada has considered the production of ethanol from grain crops. This would hardly seem logical today in the face of the parallel food and energy crises, and the emphasis should be kept on waste utilization. In the long term, one can foresee the production of biomass for energy purposes on land not suitable for agriculture or land which is under utilized. The types and classes of land which will become available for energy production will of course depend on economics, but also on the development of a Canadian food policy which will influence future production requirements.

Agricultural Production

Canadian agriculture produces large quantities of plant biomass largely in terms of cereal grains, forages and pasture plants (Table 1). It is, at the farmgate, one of the very few industries that can point to a net energy yield. Plant biomass production in terms of food and feed totals about 130 x 10^6 tons with an energy equivalent of 1755 x 10^{12} BTU. Direct food use in Canada accounts for 50.5 x 10^{12} BTU, 262 x 10^{12} BTU are exported as cereals and oilseeds, and an estimated 801×10^{12} BTU from grain and forages are used as animal feeds. Animals graze an estimated additional 595×10^{12} BTU from pasture land. Seeds, industrial uses and losses account for the remaining 46.5×10^{12} BTU. Meat, poultry and dairy production is about 12×10^{6} tons with an energy equivalent of 41×10^{12} BTU. These animal products provide about 1/2 of the Canadian dietary calories and 63% of the dietary protein.

This agricultural production is supported by large inputs of mechanical and chemical energy, which has radically reduced the human labour required. The greatest energy inputs are in petroleum fuels (12% of the diesel and 9% of Canadian gas useage) and fertilizers (Table 2). Total energy inputs to agriculture are estimated at 257.5×10^{12} BTU, or 3.6% of the total Canadian energy use of 7000×10^{12} BTU.

Plant Residues

Agricultural production of this magnitude results in the production of large quantitites of residues and "wastes". This aspect has been seized by many authors as a large potential energy source. While there is certainly a real potential, careful examination of the availability is required, so that estimates are realistic.

In plants produced for specific food parts, such as seeds, fruit or roots, the other components including leaves, stems and roots are not used. For many crops these unused portions are a significant part of the total biomass production. Of greatest importance in Canada are the cereal and oilseed crops, primarily in the prairie regions (Table 3). Production of forage and pasture crops does not offer any direct residue source as cattle use essentially all the above-ground material. In Ontario large acreages are used in horticultural crop production (Table 4).

The great majority of horticulture residues produced are returned to the soil as green manure to maintain soil organic matter. Corn is produced for grain on about 1 million acres in Ontario and produces some 2+ million tons of stover as well as the grain. A million acres of corn is also grown as fodder, but there are essentially no residues available from this crop.

Straw and Stover

It is evident that the most promising source of agricultural plant residue is cereal straw, produced mainly in the west. The majority of cereal straw presently produced in Ontario is used within the farm sector primarily as animal bedding. Bedding material mixed with manure after use is usually returned to the soil, but could be considered available in a manure processing system.

Cellulose is a major component of cereal straws and corn stover, (Table 5) and as well there is a large percentage of hemi-cellulose. Lignin is lower in stover than in the straw. These products are lower in cellulose and lignin than woods which range from 45 - 57% cellulose and 16 - 30% lignin.

Availability of Material

While some 50+ million tons of straw and stover are produced annually containing perhaps 20 million tons of cellulose, not all this material can be considered available. As noted earlier, most Ontario production is used in bedding, but on the prairies the major requirement is as a soil amendment. Concern is being expressed agin that adequate straw be left in the fields to prevent wind erosion. Considerable regional differences exist on the prairies with virtually no straw available in the south-west but with increasing amounts available further north and east. The quality depends on straw production, climatic and soil conditions. In the areas of greater straw production, straw must be removed to avoid nutrient imbalance in the soil. An average availability of 1/2 ton per acre in the prairies seems reasonable, yielding 22×10^6 tons annually. With the 2×10^6 tons of corn stover, total available cellulose and hemi-cellulose is in the order of 13×10^6 tons annually.

Animal Manures

Animal manures constitute a major source of agricultural cellulose available from a "waste" product. Feces of farm animals contain from 16 - 20% hemi-cellulose and 11 - 28% cellulose (Table 6). Poultry manures are low in fiber and high in nitrogen when compared with ruminant manures.

Total production of manure in Canada is large but it must be assumed that manure is only available from confinement operations such as dairy barns, feed lots, poultry and swine houses. Manures from animals on pasture and range are not amenable to collection, even if that was desirable. Environmental constraints on large confinement operations near the population centers will add impetus to finding means of utilizing these products.

With the manure available estimated at 14.7×10^6 tons/annum, this is equivalent to the production of about 7 million tons of cellulose, and hemi-cellulose.

Food Plant Wastes

Another source of cellulose which could be considered of agricultural origin is the residue from fruit and vegetable processing operations. These are of interest particularly in Ontario, however the volumes available are small relative to the agricultural wastes. With less than 1 million tons of canned and frozen fruit and vegetables produced the quantity of cellulosic wastes at the various food plants in the form of peel, seeds, etc. is probably less than 30,000 tons annually.

Problems with Agricultural Wastes

Seasonality

Agricultural crop residues are highly seasonal, with the bulk of the residues produced in the 3rd and 4th quarters. This necessitates provision for on farm and/or on site storage for long periods of time. With straw in dry western areas this is not a severe problem, but for stover precautions must be taken to avoid spoilage. Animal wastes from confinement operations will not have the seasonal production problems associated with crop residues. Annual, as well as seasonal variations in production affect security of supply.

Dispersion and Density

One of the chief problems with agricultural residues is the dispersion of the material in a low density form. The collection and transport of material spread at less than one ton per acre over several million acres poses quite a difficult situation. This will demand an analysis of the energetics of the complete material supply chain, and the selection of local or regional processing. The density of straw can be increased for transport through baling, wafering or pelleting. Each step to increase density is of course accompanied by an energy penalty. Quite sophisticated hay and forage handling systems have been developed in recent years, such as the 'big bale', stack maker wagons and bale handling wagons, all of which would have to be considered in a straw handling system. Stover is frequently collected using stack makers, and the stacks are then handled with stack movers.

Handling of animal manure from the multitude of point sources will also require an extensive storage and transport system. The choice of handling system will have to be based on both the farm requirements and on the processing system. Most hog operations use liquid manure systems as do many dairies. Mixtures of manure and straw or in some cases, wood chips, will be obtained from dairy, poultry and feedlot operations which use bedding. It is possible that on farm separation, operations could be included to separate the fiber fractions from the manure if only these fractions are to be used for processing to alcohol.

Competitive Uses

With the rapidly accelerating fuel and feed prices, many agriculturalists are looking at uses for the agricultural waste materials. The use of manure for on farm methane production is being extensively studied in Canada as well as many other countries. More effective recycling of the available nutrients in manure to the soil is being stressed to relieve the demand for energy intensive chemical fertilizers.

Traditionally when overwintering feed supplies were limited farmers have used straw and stover for animal feed. This causes problems in supply, and was one of the reasons straw was discontinued for use in paper making in Britain. Extensive research has been conducted and is continuing on the upgrading of straw as a forage material. Both mechanical and chemical treatment can be used to increase digestibility. Four plants have been installed in the U.K. to upgrade straw using NaOH, using a technique based on Canadian research. Perhaps the most promising technique is based on treating the straw with anhydrous ammonia. These procedures can improve straw so that it is nutritionally equivalent to a medium quality forage.

Dedicated Biomass Production

An alternative or supplement to reliance on crop residues is the production of biomass crops specifically for energy production. This concept of "energy plantations" whether based on short rotation forestry, annual crop production or even aquatic systems has received considerable attention. Given the present world food situation, the better grades of land will have to be kept in food production, however, it may be possible to develop energy producing crops for the marginal lands. Considerable genetic work is being done to improve forest biomass yields and many prospects exist for high biomass production from agricultural type crops. Breeding of crops for total biomass production, rather than for specific components, such as grain, could result in increased biomass yield without sacrificing food production. Crops which are receiving attention include the Jerusalem artichoke and the artichoke, sunflower hybrids. These crops are noted for their high biomass yield. The Jerusalem artichoke also has the interesting feature that the tubers are high in levulose which can be harvested for food while the above groundbiomass can be harvested for other uses. Experiments on the Canadian prairies have shown yields in excess of 15 tons per acre when harvested for silage.

A breeding program aimed at development of biomass crops for Canada's marginal lands could have considerable impact. Most of the reserve land is of relatively poor quality with only 4 million hectares of reserve in class 1-3 while the remaining 10 million hectares are class 4 or poorer.

Summary

Cellulose is produced in large quantities in the agricultural system. Most is produced in the form of forages and pasture for livestock feed, however, there are large tonnages of plant residues produced as by-products of food production. The chief cellulose resource from agriculture for alcohol production is in the cereal straw produced on the prairies. Animal manures constitute a second source. The major problems in use are in dispersion and seasonality. Long term prospects exist for genetic improvement to increase total biomass yield as well as the development of plants specifically for energy production. In the area of "energy plantations" on agricultural land, Canada will have to make the moral choice between producing crops for domestic energy supply and food crops for export to other parts of the world.

TABLE 1 - AGRICULTURAL PRODUCTION OF BIOMASS AS FOOD AND FEED

PRODUCT	QUANTITY	ENERGY	
	$\times 10^6$ Tonnes	$\times 10^{12}$ BTU	$\times 10^6$ G.Joules
Cereal Grains	33.3	549.	579.
Oilseeds	2.2	42.4	44.8
Forages	35.2	559.	590.
Pasture	43.1	595.	627.7
Fruit, Vegetables and Potatoes	4.15	9.6	10.1
Dairy Products	9.2	19.9	21.
Meat and Poultry	2.0	21.	21.6
Total of Plant Origin	117.95	1755.	1851.6

1 GJ = 10^9 Joules = 9.47×10^5 BTU = 2.39×10^5 Kcal

TABLE 2 - ENERGY USE IN CANADIAN AGRICULTURE

DIRECT USE	BTU x 10^{12}	GJ x 10^{6}
Fuel	170.1	179.3
INDIRECT USE		
Fertilizer	39.6	41.7
Chemicals	3.15	3.32
Machinery	13.3	14.
Miscellaneous	28.5	30.
TOTAL	254.5	268.3

TABLE 3 - PRODUCTION OF CEREAL CROP AND STRAW (10 YEAR AVERAGE)

Cereal	Acres $\times 10^6$	Grain Production lb $\times 10^9$	Straw:Grain Ratio	Straw Production lb $\times 10^9$
Wheat	24.2	35.7	1.5:1	53.5
Barley	10	18.4	1:1	18.4
Oats	7.1	11.5	2:1	23
Rye	.8	.9	2:1	1.8
Flax	1.8	1.3	1.5:1 (Est.)	1.9
Rapeseed	2.7	2.25	1.5:1 (Est.)	3.4
Total	46.6	70.1		102
				$= 51 \times 10^6$ tons

TABLE 4 - HORTICULTURAL CROP PRODUCTION IN ONTARIO

Crop	Acreage $\times 10^3$	Production $\times 10^6$
	Acres	lbs.
Tomatoes	23.37	827.8
Carrots	3.75	152
Peas	23.6	68.2
Potatoes	41.8	647
Grapes	22.1	133.4
Corn	42.3	333.9
Fruits	76.4	458.1
TOTAL	233.32	2620.4
		$= 1.31 \times 10^6$ tons

TABLE 5 - COMPOSITION OF CEREAL STRAWS AND STOVER

Type	Crude Fiber	Cellulose	Hemi-Cellulose	Lignin
	% of dry matter			
Wheat	41.5			13.7
Oats	41	40		14.6
Barley	42	40	30	10
Rye	47			
Corn Stover	42	30-35	30	5

TABLE 6 - SOME TYPICAL CHEMICAL COMPOSITIONS OF FECES FOR THE MAJOR SPECIES OF FARM ANIMALS

Feces Source	Neutral Detergent Solubles	Nitrogen	Hemicellulose	Cellulose	Lignin	Ash
	% Dry Matter					
Broiler (caged)	69	6.5	16	11	4	22
Laying hen (caged)	65	6.2	17	15	3	28
Swine (growing & fattening)	60	3.0	20	15	5	17
Beef cattle (fattening)	53	3.0	22	17	8	7
Dairy cattle (lactating)	41	2.6	21	25	13	9
Dairy heifers (all forage-fed)	32	2.0	20	28	20	12
Sheep (all forage-fed)	45	2.5	15	28	15	13

From: L. W. Smith, 1973, Nutritive Evaluation of Animal Manures

Symposium: Processing Agricultural and Municipal Wastes (Proceedings) AVI Publication, 1973.

TABLE 7 - ANIMAL NUMBERS AND MANURE PRODUCTION

Livestock	Numbers	Waste Produced		% Dry matter	Estimate of available[2] dry matter in tons
		cu. ft/year	lb/year[1]		
	$x\ 10^6$	$x\ 10^6$	$x\ 10^9$		$x\ 10^6$
Cattle	14.9	4802	298	15	9.64
Hogs	6.6	431	27	20	3.4
Sheep	.78	34	2	25	.15
Poultry	87.5	160	10	25	1.25
Turkeys	9.5	23	1.4	25	.18
Totals	119.3	5450	338.4		14.62

(1) Estimated at 62 #/cu. ft.

(2) Estimated for cattle that 66% of the manure is available in the east and 25% in the west.
Estimated for sheep that 50% of the manure is available.