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DIRECT COMBUSTION OF WINTER RAPE PRODUCTS

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SUMMARY:

The potential of winter rape as a direct combustion fuel was evaluated in a residential pellet stove. The emissions and general combustion characteristics of the plant residue and of the seed meal were determined. Pelleted combinations of meal and wood showed potential as direct combustion fuels.

KEYWORDS:

Biomass, Direct Combustion, Pelletizing

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ABSTRACT

The characteristics of winter rapeseed have been investigated to determine its potential as a fuel in residential stoves. The study included the plant residue and the seed meal which remains after removal of the oil through expression. Dwarf Essex, a variety grown for industrial applications, was pelleted for use in combustion tests. A commercially produced residential pellet stove was used to determine the emissions characteristics and the long term effects of the direct combustion of winter rape products.

INTRODUCTION

Rape plant residue and rapeseed meal are currently unusable by-products of the rape oil extracted by the Agricultural Engineering Department at the University of Idaho. Residue includes all portions of the plant except the seed. Residue is usually left in the field when the seed is combined. The oil pressed from the seeds is an industrial variety which is being tested as an alternative fuel in diesel engines. The meal left by the pressing process of this seed variety has a high glucosinolate content which makes it unsuitable as animal feed. The search for a use for these by-products led to the consideration of rape products as fuels in direct combustion processes. Use of the by-products of the rape oil process for energy sources also provides opportunity for rape to be considered a total energy crop: The oil as a diesel fuel substitute; The meal and residue in direct combustion. Thus, no part of the crop would compete in the food or the feed markets.

Recent developments in the home heating industry enhance the prospect for the use of non-conventional fuels such as rape products. The introduction of pellet burning stoves gives additional control over combustion processes and therefore allows the burning of materials with characteristics considerably different than those of wood or coal. A variety of configurations increases the likelihood of finding a combustion device with characteristics compatible with the unique properties of rape products.

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LITERATURE REVIEW

Many residue materials have been evaluated as potential fuels. A few examples include: the investigation of corn-cob combustion by Payne et al (1984) and Morey (1984) and others; evaluation of fruit pomace by Mason et al (1985); and studies of fuel characteristics of evergreen shrubs by Erdman et al (1984). Information specific to the combustion of rape residue and meal could not be found.

The properties of rape residue have seldom been investigated because it is usually not collected when the rapeseed is harvested. Information generally applicable to vegetable crop residues (Envirosphere, 1980) indicates that a gross heat of combustion of 17.5 KJ/g can be expected.

A number of the properties of rape meal have been determined. Katz (1982) reported a heat content of 22.5 KJ/g. This is very comparable to the commonly reported value of 20 KJ/g for wood, but similarities end there. Wood is often treated as a three component mixture of cellulose, hemicellulose, and lignin in a 50:25:25 ratio. All three of these components are included in the fraction termed crude fiber in food technology. Sosulski et al (1969) reported a value of 14.0% (oil-free, dry basis) for the crude fiber content of the meal of the Argentine variety of rape. The same source reports an ash content of 8.0%. This is more than three times as great as the 2.5% ash content of hardwoods reported by Junge (1975). The bulk of rape meal is comprised of protein (45.5%) and nitrogen free extract (32.5%) as reported by Sosulski. These components are virtually absent from most woods.

These differences between rape meal and wood emphasizes the importance of selecting a combustion device compatible with the properties of the meal. Edwards (1974) discusses the possible configurations of fuel and air supplies in combustion chambers. Air supply is usually separated into primary, for oxidizing solid fuel; and secondary, for completing oxidation of gaseous products. Continuous fuel feed mechanisms are either overfeed or underfeed devices. The "over" and "under" describe the location of the fuel inlet with respect to the burning pile. These two configurations provide completely different environments for fuel oxidation.

The overfeed arrangement (Fig.1) places fresh fuel on top of the burning pile. Evaporation of fuel moisture and release of volatiles absorb heat from the radiation of gases combusting over the pile. As the nonvolatile portion of the fuel settles into the pile, it is oxidized by the primary air which is introduced below the pile.

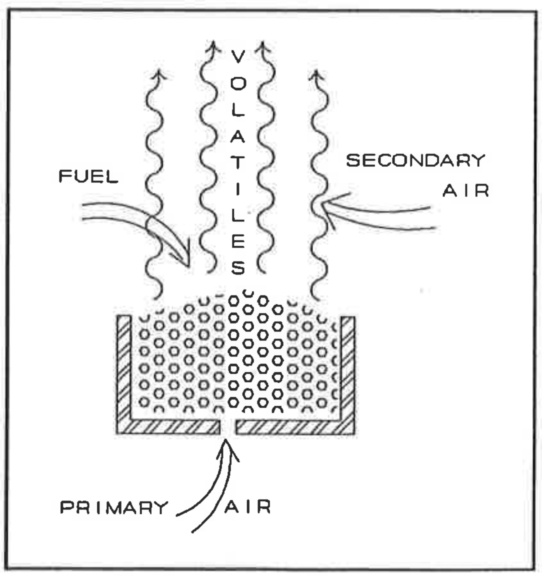

Figure 1 Overfire Feed Configuration

In the underfeed arrangement (Fig.2), fresh fuel is introduced below the fuel pile. Heat for pre-combustion processes such as volatilization must be conducted downward from the burning pile. When fresh fuel is augured into the chamber, it pushes the nonvolatile portion of the fuel upward into the primary air supply and oxidation begins.

The difference in the environments provided by the two fuel feed configurations has several implications. Most important is the temperature at which initial fuel heating occurs. Shafizdah and Chin (1977) list 500 to 773 K as the range of temperatures at which the components of wood undergo pyrolysis. Pyrolysis contributes to burning by breaking down the fuel, but the conditions under which it occurs have significant consequences. A study by Batelle-Columbus Laboratories (Cooke et al.,1981) listed premature pyrolysis and excessive pyrolysis rate as the first factors affecting emissions. Thus, control of pyrolysis conditions is necessary for control of pollutants. Some increase in efficiency can also be expected with the decrease in emissions.

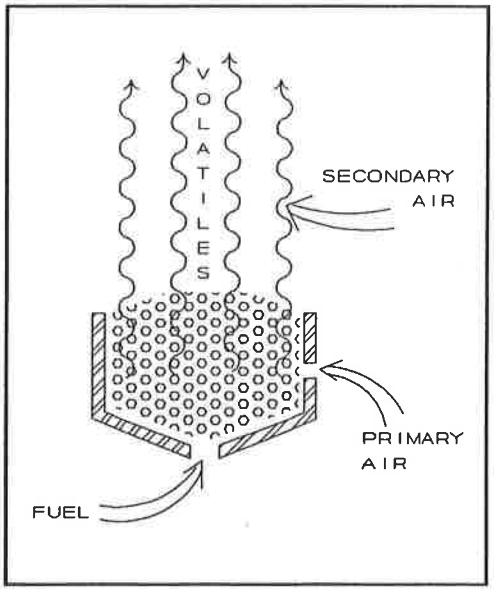

Figure 2 Underfire Feed Configuration

It is obvious that the introduction of fuel between a burning pile and radiating gases favors higher temperatures than those existing under the pile. Edwards concludes that "...underfeed is conducive to promoting the oxidation of the volatile organics rather than pyrolysis as occurs when fresh fuel is introduced on top of the bed." The composition of rape meal suggests that the underfeed configuration will be essential to proper combustion.

Another major factor in the relationship between pyrolysis and oxidation is the amount of available oxygen. The concentration of oxygen is quantified by the excess air (EA). Excess air is the portion of air introduced into the combustion chamber that is not necessary for stoichiometric oxidation of the fuel. It is obvious that large EA enhances the combustion efficiency (portion of fuel completely oxidized), but it also decreases the heat output of the appliance because heated EA is exhausted. Breene (1976) studied coal-fired burners and concluded "Impressive fuel savings can be achieved by minimizing excess air usage...". In some circumstances, lower EA can have lower emissions because of decreased particulate entrainment.

Emissions from residential woodstoves now exceeds the particulate emissions from industry in some areas. This information was revealed by a study done for the formulation of the Oregon State Implementation Plan (1980), and resulted in the inception of a woodstove certification program which requires determination of particulate emissions of all models of stoves sold in that state. State Implementation Plans (SIP) are required by the 1977 amendments to the Clean Air Act of 1970 (40 CFR Part 51). Mors et al (1981) says "...states with woodburning air pollution problems may attempt to control stoves through their SIP" as Oregon has. The process of national regulation has begun (Vranzian et al., 1986) and is expected to include emission standards applicable to most newly manufactured stoves. Whatever the means of implementation, evaluation of a fuel must include consideration of environmental impact and potential regulation.

OBJECTIVES

It is the intent of this study to evaluate the suitability of rape residue and rape meal as fuels in residential stoves. Specific objectives are:

1. Establish suitable test procedures and select equipment for the evaluation of alternative fuels for residential heating. A complete study would include determination of the following characteristics;
   a. Physical parameters of fuel; density, moisture content, heat content.
   b. Composition of fuel including ash content and elemental analysis.
   c. Combustion characteristics including efficiency and deposit formation.
   d. Emissions, especially particulates.

2. Optimize combustion with respect to efficiency and emissions by;
   a. Controlling excess air and temperatures
   b. Modifying fuel form or composition

3. Investigate the economic considerations of using rape products as fuels.

PELLETING

The original forms of the plant residue and of the meal are not suitable for combustion in conventional stoves. The plant material is objectionably bulky and densification is desirable. Rape meal cannot be handled in its original form without breakage and trials showed that complete combustion of the resulting material was unlikely. These results led to the investigation of pelleting.

The rape plant residue pelleted well in a commercial mill but rape meal created several problems. Originally, rape meal pellets were produced by an agricultural pelleting facility. These rape pellets were noticeably softer than the wood-based pellets and produced higher and less controllable burn rates at the same volume feed rate. Therefore, mixed fuel pellets were also tested. A blend of 60% rape meal and 40% red fir shavings produced excellent pellets in a commercial mill.

FUEL PROPERTIES

Investigation of the fuel properties of the pellets began with the determinations presented in Table I. The column labelled **BLEND** refers to pellets composed of a 60% rape meal and 40% red fir. The **MIX** properties are for a mixture of 60% rape pellets and 40% wood pellets. The heats of combustion and the S, C, and H percentages of these two fuels were calculated from their components.

Table I Fuel Properties

	WOOD	RESIDUE	MEAL	BLEND	MIX
DENSITY, Kg/m^3	639	584	664	637	664
MOISTURE CONTENT[a], %	5.5	4.3	7.6	6.0	6.8
HEAT OF COMBUSTION[b], KJ/g	19.2	16.5	20.8	20.2	20.2
ASH CONTENT[c], %	0.20	8.17	7.52	3.77	4.59
SULPHUR[b], %	0.02	0.36	1.18	0.72	0.72
CARBON[b], %	47.55	41.37	46.54	46.94	46.94
HYDROGEN[b], %	6.75	6.03	7.48	7.19	7.19

a Determined at University of Idaho, ASAE S352.1.
b Data by Phoenix Chemical Lab, Chicago, Ill. Gross heat of combustion.
c Determined at University of Idaho, ASTM D1102.

The densities of Table I are bulk densities of the pellets and show the effect of both the pelleting process and the packing of the pellets. As shown by Table I, the rape pellets have an 8% edge in energy content based on mass and a 12% advantage based on volume. The residue pellets have a 9% less energy per unit mass and 17% less energy per unit volume than the wood based pellets.

The ash contents of the rape products demonstrate the need for long term tests for deposit formation. The relatively high sulphur content of the residue and meal introduces the possibility that sulphur emissions should be determined even though there are no regulations concerning sulphur based emissions.

EQUIPMENT

A schematic of the test equipment is given in Figure 3. A commercially produced residential stove was used for the fuel tests. It has an underfire feed configuration with induced draft (an exhaust fan) and controllable feedrate. Air is introduced at the fire pile and in the flame zone. Both inlets are controllable.

Type K thermocouples were used to monitor temperatures in the fire pile, and the flame zone. Type J thermocouples were used in the exhaust stack and at various points in the particulate sampling equipment. Exhaust flow was measured by a sharp edge orifice. The pressure differential was monitored with a diaphragm type transducer with electrical output. All transducer outputs were converted to digital form by an A/D converter unit with an RS-232 output. A portable PC provided floppy disk storage of the parameters at intervals selected by the user. Mass burn rate was determined with a scale which was capable of continuously weighing the stove and fuel.

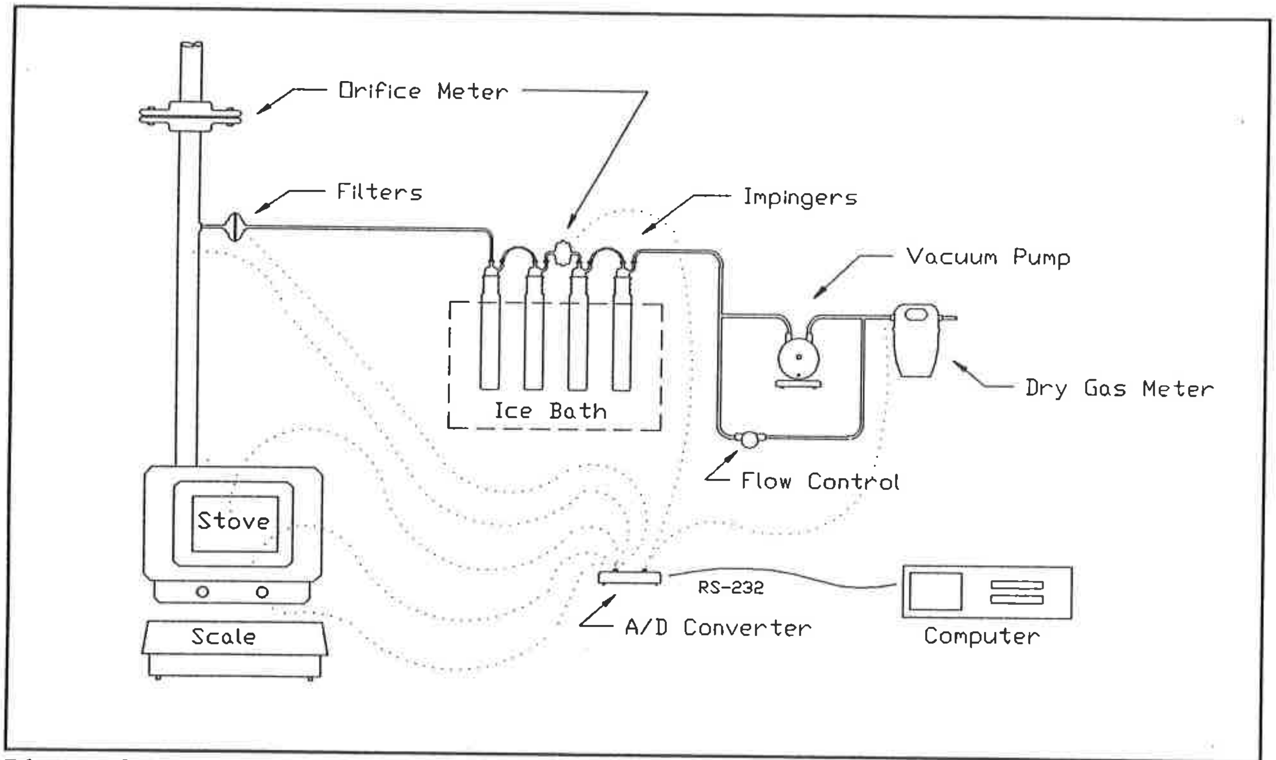

Figure 3 Test Equipment

As previously mentioned, some particulate emission regulations already apply to residential woodstoves. The Oregon Department of Environmental Quality Method 7 was selected as the particulate monitoring method most suitable for pellet stoves. This test is essentially the EPA Method 5 (FR 36,24877). Stack gas is sampled at a rate between 0.015 and 0.045 m /min. The sample is kept heated until it passes through a filter. It is then drawn through a series of cooled impingers where condensable material and water is collected. An Orsat analyzer (Hays Improved) provides O_2, CO_2, and CO concentrations for the calculation of mass flow rate, excess air, and some combustion efficiencies. Particulate matter is determined gravimetrically.

PROCEDURES

The characterization of the direct combustion of rape products was accomplished with three sets of tests:

i) **Two Fuel Comparison.**
Wood and rape meal were tested for emissions and general performance at three fuel feed rates.

ii) **Five Fuel Comparison.**
Wood, meal, residue, blend, and mix were tested for general performance and emissions at a medium fuel feed rate.

iii) **Durability Test.**
Meal and mix were tested for general performance and deposit formation until definitive information was obtained.

The **Two Fuel Comparison** was designed to test the procedures and as an extensive test of the rape meal performance throughout the operating range of the stove. The test was done in one hour "runs" which were repeated until reproducible results were obtained. The same volume feed rate was used for the two fuels, but some variation in mass burn rate resulted from differences in the physical properties of the materials. Inlet air was adjusted for each fuel to obtain the greatest amount of flame above the fire pile. Temperatures and flows were recorded at 1 minute intervals. Two Orsat analysis' were done for each test.

The **Five Fuel Comparison** provided qualitative information about the various forms of rape products. This test also consisted of one hour runs, with three replicates for each fuel. Again, air flows were adjusted for each run. Monitoring procedures were the same as the previous test.

Finally, the **Durability Test** produced information concerning the practical problems of utilizing the rape products. The all meal pellets were burned for 16 hours, and the 60:40 mixed pellets were burned 84 hours. These tests were done at a low to medium feedrate. Temperature and flow parameters were recorded every 30 minutes and Orsat readings were taken every hour.

RESULTS

The **Two Fuel Comparison** indicated that rape meal pellets cannot be burned as cleanly as wood based pellets, but that their particulate emissions are well within typical regulations (Fig.4). The values given are for comparable mass feed rates of the two fuels, but the higher EA requirements of the meal (Table II) implies that the particulate load for heat outputs equivalent to those of wood

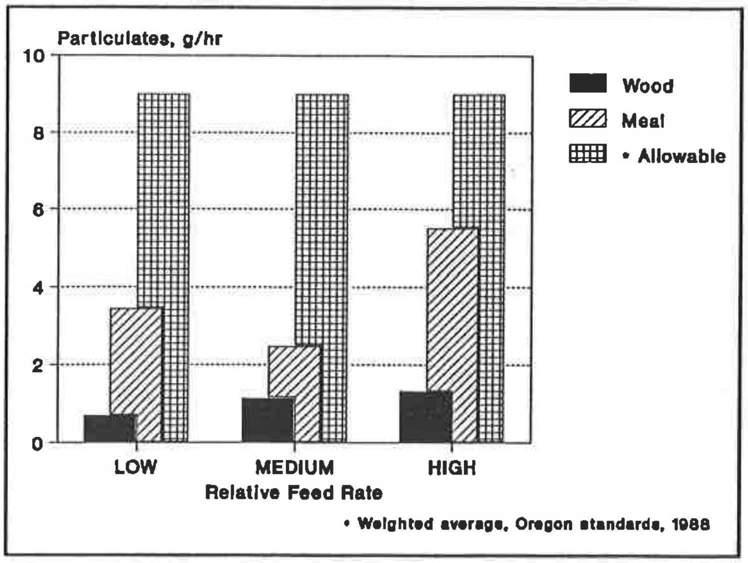

Figure 4 Particulate Emissions for the **Two Fuel Comparison**.

Table II Excess Air and Efficiency for **Two Fuel Comparison**.

	Wood	Meal
Excess Air, %		
Low Rate	417	342
Medium Rate	48	258
High Rate	50	106
Efficiency, %	95	88
(overall)	97	94
	94	95

may be 10% higher than the values shown. Table II also contains an estimate of the efficiencies of the two fuels, based on the combustion efficiency (conversion of CO to CO_2) and a calculation using the heat loss implied by the EA.

General observations made during the **Two Fuel Comparison** were;

1. The emission testing compared favorably with results of certified testing labs.
2. Combustion of the meal pellets was more difficult to control due to the relatively high mass feed rates and a tendency to form deposits.
3. The meal requires more excess air than wood for comparable combustion.

The **Five Fuel Comparison** produced particulate loads shown in Fig.5. The values given are normalized to the energy output of the wood pellets by adjusting each fuel by its feed rate, heat of combustion, and excess air according to the relationship;

$$P = \frac{m_{wood}}{m_{fuel}} \frac{\Delta H_{wood}}{\Delta H_{fuel}} \left\{1.04 - 0.04\frac{EA_{fuel}}{EA_{wood}}\right\}^{-1} \{ P_{measured} \} ,$$

P = Particulate load,
m = mass burn rate,
ΔH = heat of combustion,
EA = excess air.

The factor applied to the *EA* ratio is the ratio of heat lost through excess air to heat released for average conditions. The application of this equation allows the comparison of the emissions of the fuels for the same useful heat release.

The average conditions during the **Five Fuel Comparison** are shown in Table III. Combustion efficiencies for this test were greater than 97% for all fuels. Again, the higher EA requirements of the rape based products imply that they would have slightly lower overall efficiencies.

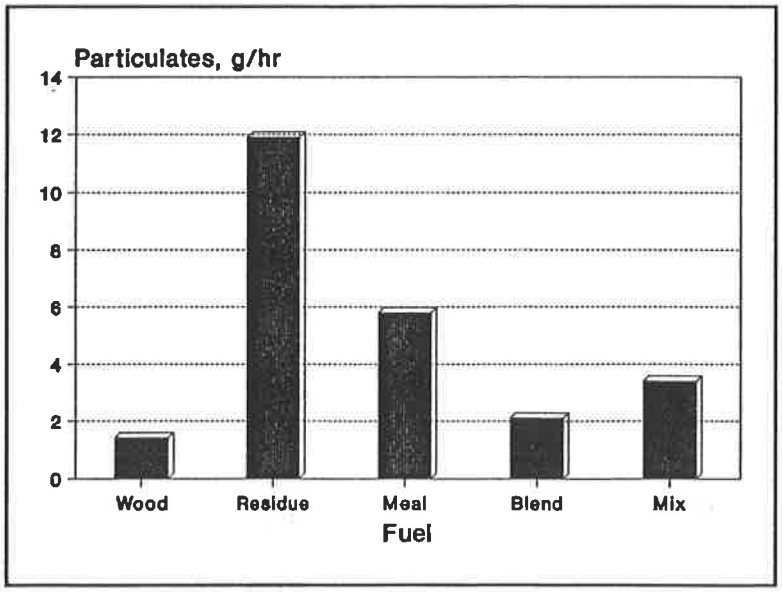

Figure 5 Particulate Emissions for the **Five Fuel Comparison**.

The **Five Fuel Comparison** revealed the serious emission problems of the residue but the acceptability of the meal, especially in blends and mixes with wood.

Table III Averages, **Five Fuel Comparison**

Fuel	Feed Rate Kg/hr	EA %	CO_2 %	O_2 %	CO %
Wood	1.99	48	9.9	6.0	0.2
Residue	1.61	177	5.9	12.6	0.3
Meal	1.54	154	6.8	11.5	0.1
Blend	1.87	100	8.5	8.8	0.1
Mix	1.89	67	10.5	7.3	0.0

The **Durability Test** revealed practical problems for the rape meal. Deposits (commonly called "clinkers") formed at the edges of the fire pile and interfered with the flow of combustion air. Cleaning was required four times during the 16 hour test and 7.84% of the fuel remained as deposits. Due to the underfire feed configuration, the deposits tended to obstruct air inlets and resulted in poor combustion. The 60:40 meal and wood blend also formed deposits (5.4%), but they were porous and did not interfere with combustion to the same extent as the meal deposits. Maintenance was required 3 times during the 84 hour test.

The **Durability Test** revealed the practical problems of the utilization of rape meal in conventional stoves but also the potential of the fuel as a component of blended and mixed fuels.

ECONOMICS

Currently, the market for pellet raw material is met with by-products of the lumber industry. These include mill by-products and a portion of logging residues. The mill by-products are those which are unacceptable as pulp material. The logging residues are expensive to collect but their removal is a requirement of many public land timber contracts. The cost at the pelleting site for these materials is generally limited to transportation and chipping costs. A study done for BPA (Vranian et al., 1987) found prices paid for wood fuels in the Pacific Northwest vary from 0 to $22 per ton (dry weight basis). Thus, the current value of rape products for direct combustion is negligible except in isolated cases where a pellet market exists far from lumber industry locations.

The increasing use of pellets implies that sources of no-cost raw materials will not meet future demand. In this case, prices may rise to the cost of gathering logging residues whose collection is not currently required in timber contracts. This would create an in woods price of between $23 and $41 per ton for residues (Envirosphere, 1986) and with average processing and transportation costs of $11, a total price of $52 per ton of pellettable material is possible.

Although the economic picture for rape product utilization is not promising, the characteristics of the rape seed plant offers the potential for a unique utilization -- that of a "total energy crop." The primary product, the oil, can be used as a diesel fuel extender (Peterson, 1988). If the meal is utilized as pellet material, the entire harvested portion of a rapeseed crop would be used for energy production. Such a crop could be grown on the currently subsidized "set-aside" land without impacting any existing agricultural markets. Thus, an unproductive subsidy could be used to finance a new and unique source of energy.

CONCLUSIONS

Testing of rape products in a conventional residential stove has produced the following conclusions;

1. Rape residue can be pelleted and it burns well, but emissions and deposit formation in a conventional stove are unacceptable.
2. Rape meal can be pelleted. The procedure does not substantially change the properties of the meal. The physical characteristics of meal pellets are inferior to those of wood based pellets but they can be burned in a conventional stove. Emissions are acceptable but deposit formation limits the utility of pure meal pellets when used with underfire feed configurations.
3. The blending of meal and wood produces excellent pellets which burn with low emissions and little deposit formation.
4. The burning of meal pellets mixed with wood pellets is feasible -- emissions and deposit formation are acceptable.
5. If the current trends in biomass utilization continue, the use of rape products as direct combustion fuels may become economically viable. A public policy allowing the use of set-aside land for 'total energy crops' such as rapeseed would be advantageous.

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