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I. POTENTIAL FOR BIOMASS UTILIZATION

Biomass residues, vegetative growth and wastes offer significant potential for reducing any country's dependence on fossil fuels. Biomass and wastes can be used to produce electricity, steam, liquid transportation fuels (alcohol, synthetic gasoline and oils), low and intermediate caloric gas, also known as intermediate Btu gas (IBG), synthetic natural gas (SNG) and other energy intensive materials such as petrochemical substitutes and fertilizers. Biomass residues include agricultural manures and crop residues (wheat and rice straw, corn stover, bagasse, prunings, etc.) and forest residues, (slash, bark, sawdust, etc.). All residues will be delivered to the energy conversion facility or the consumer at a cost. As an example, even animal manure which many consider a waste can cost from $2 to $40 per tonne delivered to the consumer. In studies done in the United States residues have been identified to be capable of satisfying up to 15 per cent of the current energy demand.

The vegetative growth can be classified as either terrestrial or aquatic. The terrestrial energy crops are composed of woody biomass (silvicultural) crops typically short-rotation tree crops, herbaceous crops, including some convertional crops produced by traditional farming methods, and standing forest biomass (e.g., cull trees and nonmerchantable stands). Aquatic energy crops include freshwater, brackish-water, and marine algae and aquatic plants.

Wastes are defined as those materials which must be disposed of at a cost to the user. Thus, garbage, sewage and the products of manufacturing are wastes which have credits associated with them. The characteristics of the wastes and residues are very different and often necessitate entirely different conversion systems.

Wastes usually are heterogenous mixtures of a number of items. As an example, municipal solid wastes contains food, glass, plastics, metals, cloth, ashes, lawn trimmings, leaves and a variable amount of water. Most energy conversion processes require the removal of the inorganic materials which do not contain recoverable energy. The preprocessed wastes are non-homogenous feed-stock for conversion processes. Most of the separation processes used cannot distinguish between plan materials and plastics. The plastics, if put into a thermochemical system, decompose and release materials which can foul catalysts and corrode the system.

Residues are more homogenous and may or may not require size reduction. Residues can be used without extensive pretreatment and in the case of thermochemical systems, catalysts can be used to increase the reaction rates of the materials.

II. BIOMASS RESOURCE BASE

The components of the biomass resource base include agricultural and forest residues, standing vegetation, energy crops, municipal and industrial solid wastes and sewage sludge. This section will discuss the various components and methods of determining the availability.

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A. Agricultural and forest residues

In most countries a data base exists on the historical and projected crop yields and agricultural exports. These data, unfortunately, are only for the marketable portions of the crop and not for the residues. SRI International in 1978 (1, 2, 25) developed a method to estimate the quantities of residues produced in the United States based upon the marketable portions of the crops.

For various livestock classes similar numbers were developed for those animals in confinement where the manure could be collected and used in conversion processes.

For lodging and primary wood products industry MITRE and Georgia Pacific (9) developed residue factors and projected the residue production through the year 2020 for the United States. It should be pointed out that the residue production per lumber unit product is expected to decrease as technologies for more complete utilization of the entire trees are incorporated into the sawmills.

Issue:

1. Are the residue factors available from current reports adequate to estimate the quantities of residues that might be available?

B. Standing vegetation

Standing vegetation is defined as the current inventory of dead and diseased trees and noncommercial cuttings or thinnings. The availability varies widely by location. Because the standing vegetation inventory is normally scattered, it is less dense than other woody biomass residues and the collection and harvesting costs are often greater.

C. Energy crops

Many countries have unused or underutilized lands which are available for energy farming. This land can vary from unused crop lands to deserts. Among the energy crops proposed are sugarcane, sweet sorghum, corn sillage, woody plants and aquatic crops. In the United States, a number of system studies have been performed which provide an approach for determining the availability and cost of biomass from energy crops grown in various areas (4, 6, 7, 9, 18).

One concept of silvicultural energy farm is a short-rotation tree farm where production objective is maximum energy harvest at minimum cost. Trees are grown closer together and on shorter harvest rotations, hence the description "short-rotation". Production of silvicultural energy crops requires fewer inputs of resources and energy than conventional farm crops for comparable yields. The woody biomass harvested is the raw material for conversion to clean fuels.

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A variety of crops can be grown on herbaceous energy farms. The basic difference between woody and herbaceous crops is that herbaceous crops have soft stems that do not live from year to year and they do not form woody tissue. Some herbaceous crops offer an advantage over woody crops in either production or conversion, i.e. sugar crops for fermentation to ethanol.

Issues:

1. Can an assessment of the global potential of biomass availability be made at this time?

2. If so, how should this be done, and how much would it cost?

3. How much biomass can be removed without adverse environmental effects?

4. How much land is available to grow biomass energy crops on?

5. Is adequate water available for the marginal lands for use in producing biomass?

6. What can be done to reduce the uncertainties in continuity of supply of biomass?

7. Do economies of scale exist in the production, harvesting and transportation of biomass to a conversion facility or point of use?

8. If fertilizers are used in the production of biomass how can they be produced and at what energy and economic cost?

9. What is the cost of the biomass delivered to the conversion site? Is this competition with other alternative sources?

10. Can new and improved species of plants be developed which will produce larger quantities of biomass and low per unit costs?

D. Feedstock preparation

Agricultural residues have very low bulk density and a relative high moisture content. To increase the bulk density, reduce the moisture, aid in the transportation and storage, pelletization has been proposed. The pelletized materials are easier to handle and do burn better. The pelletization process, however, uses energy for drying and compressing the biomass and binders must be added as well. Pellets tend to absorb moisture and desintegrate, so they must be stored in dry areas, thereby increasing the cost of handling. The cost of pelletization has been estimated to be up to $18 per tonne oven dried weight (ODT).

For non-commercial use, forest residues and standing vegetation may be used in large pieces, but commercial facilities frequently prefer wood chip because of their uniform size and greater ease of handling.

Issues:

1. Can simple pelletization systems be developed for use in rural areas?

2. What is the energy balance of pelletization?

3. What is the cost of pelletization?

4. Are the advantages of the pelletization process worth the cost of preparing the product?

E. Municipal solid wastes

Most municipalities have data on the as-received quantities of municipal solid wastes which have been collected and disposed of. However, for most conversions systems the data may not be adequate. Energy and energy products can only be obtained from the organic fractions, and in many of the processes the organic fractions must go through size reduction. The composition and quantities of municipal solid wastes vary over the year so that either the facility must be designed for the minimum quantities or use a supplemental fuel to maintain the capacity of the facility. If over-designed and supplemental fuel is not used in the facility, the efficiency and cost of the energy product increases.

Issues:

1. Is the organic fraction of municipal solid wastes sufficient to provide a useful resource base?

2. What are inexpensive alternatives to recover the organic fraction of urban solid wastes for use in biomass conversion facilities?

3. What supplemental fuels can be used with municipal solid wastes to provide a uniform supply?

F. Sewage sludge and human wastes

Human beings produce small quantities of feces (0.17 pound per day) which can be treated to prevent the transmission of disease and can be used to produce additional energy. In rural areas pit latrines or septic tanks are used to treat the wastes, while in cities water carriage systems take the wastes to treatment facilities where the solids are removed from the water as sludge. This sludge fraction has traditionally been treated in anaerobic digesters which produce methane gas and a relatively stable sludge. The methane gas is used for heating

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the digesters or for generating electricity. The stabilized dewatered sludge may be used as a soil conditioner or burned to recover additional energy.

Issues:

1. Can enough human wastes be collected to have an impact on the energy needs of the rural population?

2. Can cities make better use of the sewage sludge and human wastes to produce energy?

III. CONVERSION TECHNOLOGY AND PRODUCT ROUTES

A. Definition of technologies

The two general classification of the conversion technologies are: Biochemical and Thermochemical. Figure 1 illustrates the possible conversion routes and products from biomass and wastes.

B. Biochemical conversion

Biochemical conversion entails energy yielding enzymatic breakdown of biomass by micro-organisms under anaerobic conditions. There are two routes (1) anaerobic digestion which produces a fuel gas, methane, and (2) fermentation to produce liquid fuels, mainly ethanol.

1. Anaerobic digestion

Anaerobic digestion is a familiar process because of its wide application in sewage treatment plants to stabilize the settleable solids. The process works best on organic substances with high moisture contents, and converts them in the absence of oxygen to methane and carbon dioxide. The quantity of methane is slightly larger than that of the carbon dioxide. The process is very slow at ambient temperatures in septic tanks and land fills but for each $10^{\circ}C$ increase up to $60^{\circ}C$ the rate of the reaction doubles. Recent research and full scale facilities have used thermophilic temperatures of 55° to $65^{\circ}C$ which accelerate the process, and reduce the capital and operating costs. The gas can be burned directly or it can be upgraded to synthetic natural gas (SNG) by the removal of the carbon dioxide.

Current research efforts are being concentrated on the conversion of other biomass feedstocks such as corn, stover, wheat straw and new plants especially grown for the conversion into IBG and SNG. The results of this research have indicated the need to optimize the yields of energy products and the necessity to speed the reaction to achieve shorter detention times.

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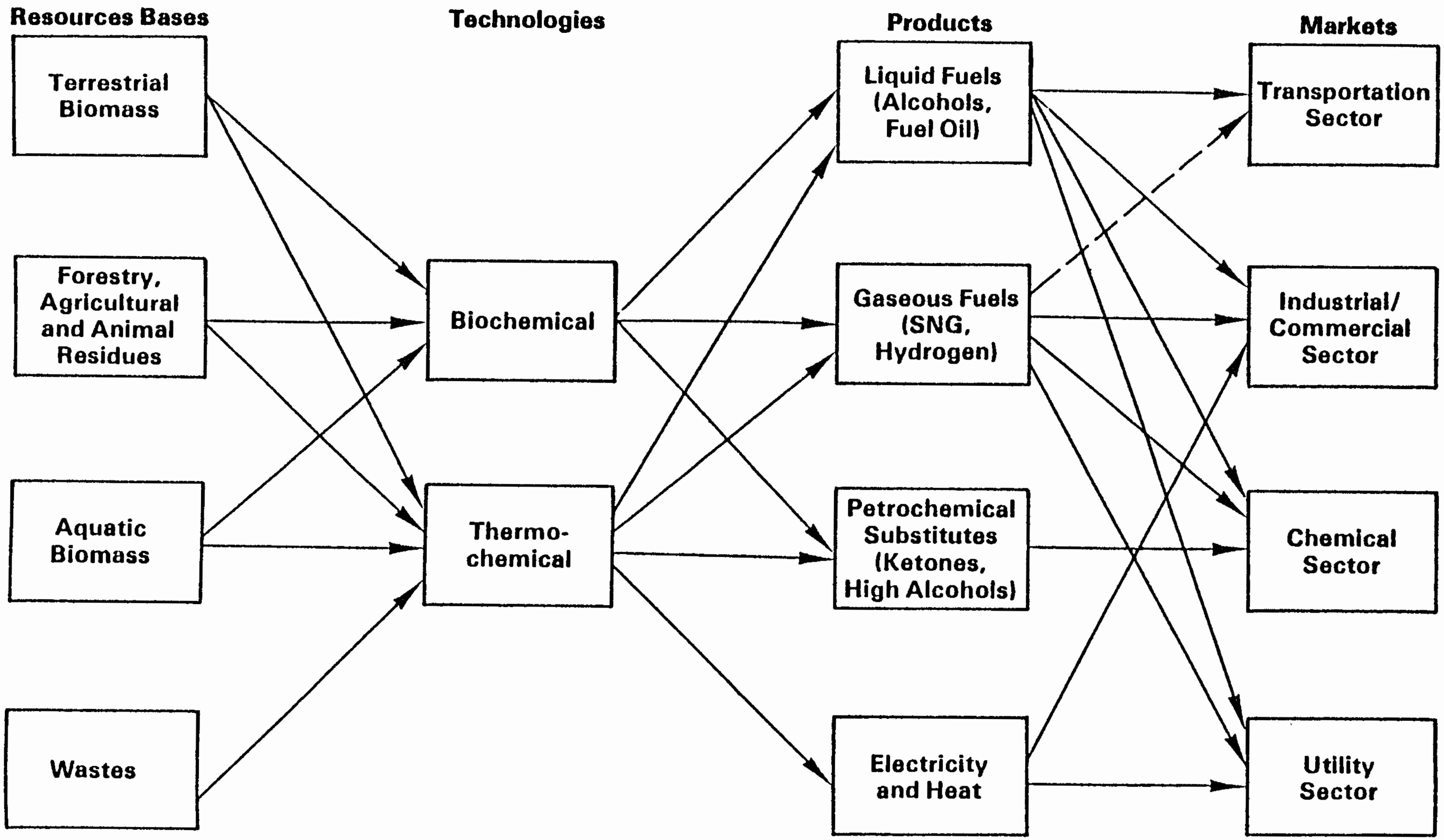
Figure 1

Biomass Energy Systems



The Dynatech study (3) and the SRI Mission Analysis (12) have both reviewed the economics of using the anaerobic digestion process for manure. SRI also projected the costs of methane from agricultural residues and aquatic biomass. Based upon estimated market penetration, SRI concluded that anaerobic digestion of manure and high moisture terrestrial biomass appears to have a near term commercialization potential.

SRI has indicated methane gas prices from $9.00 to $27.71 per MJ using straw (12). Recent research by McCarty (19) and Pfeffer (22) have indicated that sizeable increases in degradability of wheat straw can be obtained, and that significantly lower chemical requirements would be needed. The two factors should decrease the cost of methane from residues.

The aquatic biomass case using kelp was even more speculative, with the base case of $37 per MJ and the most optimistic case of $12 MJ for a facility using 1000 dry ash free tonne per day. The major cost is that of the raw material.

Issues:

1. Can lower cost anaerobic digestion systems be developed as to be economically viable?

2. What pretreatment is required of agricultural residues is required to increase the digestability?

3. Can process improvements be made to suit the use of agricultural residues and new plant growth as feedstock to digester systems?

4. Is it necessary to scrub the gas (remove the carbon dioxide and other trace gases) in order to transmit the gas from the conversion facility to the point of use?

2. Fermentation

Ethyl alcohol (ethanol) from sugar, molasses or grain can be used to supplement hydrocarbon fuels. Brazil has established a national programme to build alcohol facilities and to produce cars that will burn only alcohol. Other countries have used mixtures of gasoline and ethanol in various proportions up to 20 per cent with some difficulties. Alcohol from grains and sugar crop have a measurable though limited potential impact on the fuels needs of most countries. Raw material cost is an important factor. Over the past year the price of sugar which is one raw material used to produce alcohol has varied from $0.13 to $0.34 per kg. Molasses is now selling at the near-record price of $110 per tonne. Corn has varied from $2.25 to $3.40 per bushel. When corn was $3.00 a bushel, anhydrous alcohol sold at prices up to $0.50 per liter. At the same time, gasoline without taxes was selling at the refinery for $0.15 per liter.

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The near term fermentation efforts have concentrated on the use of sugar crops, i.e., sugar cane, sugar beets, sweet sorghum instead of grain. Sweet sorghum appears to be the most viable crop in that it can be grown over large areas of the world and it is not widely used as a food crop for either humans or animals. The sugar yields and gross alcohol yields from sweet sorghum per hectare are about double that of corn.

The energy inputs into the systems need to be carefully reviewed to be certain that the energy balance is positive. Many different approaches have been used to convince the public that alcohol production and use is an advantage.

The energy inputs into the system include:

1. The petroleum and the petroleum products used in the production of the corn, sugar cane, sweet sorghum, or other sugar crops. From 0.2 to 0.3 liters of petroleum per liter of ethanol produced (17, 18).

2. Energy used in the fermentation and distillation of ethanol. If fossil or nonrenewable energy is used from 0.2 to 0.64 liter of petroleum per liter of ethanol produced (17).

3. Drying of the distiller's dried grains and/or the evaporation of the stillage, 0.34 liter of petroleum per liter of ethanol produced (17).

The energy saved or used in the making a one part alcohol to nine parts of gasoline mixture is as follows:

1. The one liter of ethanol added to the mixture.

2. Crude oil saved if the refinery is modified to produce a lower octane gasoline to take advantage of the octane boosting ability of ethanol. From 0.0 to 0.54 liter of petroleum per liter of ethanol used in the mixture is saved.

3. The change in mileage obtained using ethanol/gasoline mixtures has been reported to be from no change to a minus 4 per cent. Some have assumed, without adequate documentation that the performance will improve up to 4 per cent.

Using the above data a "Best Case" and a "Worst Case" can be estimated.

BEST CASE

Assumptions: 1 liter of ethanol is added to 9 liters of gasoline, which has been produced in a refinery with an octane rating. The gasoline is 3 to 4 octane numbers lower than the regular gasoline:

	Liters - gasoline saved or used
Ethanol used.	1.0
Petroleum saved in the refinery	0.54
Gasoline due to improved millage	0.4
Agricultural energy used.	(-0.2)
Distillery uses no petroleum or petroleum products producing the alcohol or drying the distillers dried grains	0.0
Net gain.	1.74 liter

WORST CASE

Assumptions: 1 liter of ethanol is added to 9 liters of gasoline, which has been produced in an existing refinery:

	Liters - gasoline saved or used
Ethanol used.	1.0
No petroleum saved at refinery.	0.0
Milage decrease because of the lower energy content of the mixture.	(-0.4)
Fossil energy used in the production of biomass .	(-0.29)
Distiller uses fossil energy	(-0.64)
Grain is dried or stillage is evaporated using fossil energy.	(-0.34)
Net petroleum used in the manufacturing and use of the ethanol/gasoline mixture . . .	(-0.67) liters

An additional factor is the cost of ethanol versus the cost of gasoline. Gasoline sold at the refinery in mid-1979 (no taxes and distribution charges added) at $0.15 per liter and ethanol sold at the distillery at $0.50 per liter. Thus, one liter of ethanol with nine liters of gasoline mixture would cost:

Gasoline	9 x $0.15	=	$1.35
Ethanol		=	$0.50
			$1.85 or $0.185 per liter

The consumer would pay $0.035 per liter more than for gasoline alone.

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Mid-term and long-term research and development efforts have been directed toward the hydrolysis of agricultural and forest residues and new crops especially grown for conversion into fuels. These biomass feedstocks can be converted into the C6 sugars which can then be fermented into ethanol. Both acid and enzymatic hydrolysis can be used to obtain the sugars from the lignocellulosic materials.

In all the fermentation processes the lignocellulosic materials are broken down to obtain the C6 sugars. Research and development are directed toward production and separation of C6 sugars at low cost leaving the C5 sugars and lignin as by-products. The lignin and C5 sugars represent approximately two-thirds of the materials fed into the processes and can be used as a fuel for the process or converted into other as yet unidentified materials (10, 11, 12, 13, 14, 21).

Issues:

1. Should food (i.e. grains, sugar and molasses) be used for conversion into alcohol?

2. Is the process energy efficient, or is more fossil energy used in the production of alcohol that is produced?

3. What types of new separation units can be developed to reduce the energy requirement of distillation?

4. What types of new separation units can be developed to reduce the energy requirements of drying of the grain or disposing of the stillage?

5. Can alcohol be made at a cost competitive with other fuels alternatives?

6. Can fuel products be made out of the hemicellose portions of lignocellulose?

7. Is the best use of the legnin for fuel?

C. Thermochemical conversion

Thermochemical conversion denotes technologies that use elevated temperatures to convert the fixed carbon of the biomass materials by (1) direct combustion to produce heat; (2) pyroloysis to produce gas, pyroloytic liquids, chemicals and char; (3) gasification to produce low or intermediate Btu gas. The gas produced can be subjected to indirect liquefaction processes to produce ammonia, methanol, Fischer-Tropsch liquids; and (4) liquefaction to produce heavy fuel oil or with upgrading, lighter boiling liquid products used as distillates, light fuel oil or gasoline.

1. Direct combustion

Today direct combustion of biomass provides energy for cooking and heating to the majority of the rural population of the world. Biomass provides process heat and/or electricity throughout the pulp, paper and forest products industry (23). In addition, utilities throughout the world are producing small quantities of electricity from wood fired power plants. In the case of the rural populations, the biomass source may be wood, crop residues and/or manure. The fuels used in the pulp, paper and forest products industries often include the bark and other residues from sawmills and pulpmilk.

The combustion systems used for woody biomass include open fires, simple cook stoves, Dutch ovens, packaged boilers, or fluid bed units. In most cases the larger units use two to three-inch wood chips.

Cyclone collectors are used to remove the entrained solids from the flue gas when chips are used. Pulverized fuels require wet or dry scrubbers, precipators or bag houses to keep particulate emissions at acceptable levels. Although wood feedstocks with up to 65 per cent moisture have been used, lower moisture contents improve the efficiency of the system.

Costs of wood fired systems are discussed by MITRE (5) and SRI (16) for 1000 ODT facilities. The capital cost of large facilities have been estimated at about $300 per MJ hour installed.

The net output of the 1000 ODT after deducting for the power requirements for the combustion air, blower, cooling tower fans, pulp wood receiving and handling and other uses is about 178.6 G. J.

Other possible combinations of products are steam and electric and steam, as has been described in detail in SRI Federal Fuels from Biomass Mission Analysis (16).

The two types of facilities which recover energy from municipal solid wastes (MSW) are:

1. Bulk or mass (conventional incineration) where the MSW are received and burned on inclined moving grate system.

2. Suspension firing of prepared wastes use shredded, air classified, magnetically separated waste materials so as to provide a more homogenous feedstock. The fine particles of the waste are rapidly burned in suspension while coarser, heavier particles descend to the bottom of the furnace on a moving grate.

Waterwall furnaces are the most frequently used system. The waterwall furnace uses closely placed steel tubes welded together to form continuous wall with water or steam continuously circulating through the tubes.

The waterwall furnace has excess air introduced beneath the grates which helps keep the grates cool and aids in the combustion. The excess air supplied above the bed provides oxygen and turbulence for adequate combustion.

The flue gases should go through air pollution devices for cleaning. Frequently water scrubbers or electrostatic precipators are used to remove the fly ash. Fly ash and slag builds up on the boiler tubes and hydrochloric acid from the combustion of vinyl chloride plastics can corrode tube surfaces.

The residues consisting of ash, glass, ferrous and non-ferrous metals, and unburned organic materials, representing 20 to 25 per cent of the incoming materials must be disposed of. Unburned organics are a particular problem which requires careful attention so as not to cause a nuisance (15, 24, 26).

Issues:

1. What type of direct combustion system should be recommended for use with biomass and wastes?

2. Can these direction combustion systems be improved?

3. What is the cost of the direct combustion units and can the costs be lowered?

4. Should the inorganic materials contained in the wastes be removed before or after shreading?

5. How can air pollution be avoided?

6. What use can be made of the inorganic fractions of the urban solid wastes being discharged from direct combustion units?

7. Do sufficient economies of scale exist to warrant larger scale conversion facilities producing heat and/or electricity by direct combustion?

2. Pyrolysis

"Pyrolysis" is the thermal decomposition of carbonaceous materials in the absence of oxygen. A broader definition of pyrolysis is a system which thermally decomposes carbonaceous materials, having at least one zone in which the thermal decomposition proceeds in the absence of oxygen. Some examples of pyrolysis are the destructive distillation of wood to produce methanol, charcoal and low caloric gas, batch coking of coal in iron- and steel-making, and coking in the petroleum industry. Approximately equal quantities of oil, char and gas are produced, but one or more of the three products must be used to supply the energy for the facility. The oils produced by pyrolysis are low in sulfur, ash, and nitrogen, and should create few problems in combustion. However, they are acidic and heat-sensitive and require certain precautions for storage and handling.

Issues:

1. Which of the three products (oil, char or low caloric gas) should be produced for use outside the conversion facility?

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2. Can pyrolytic oils be used to produce other products?

3. Is the process economically viable?

3. <u>Gasification and indirect liquefaction</u>

Low Btu gasification has been used for gas engines, power generation, or for industrial uses. For years, the size of the units has been limited to about 50 ODT/per day. The technology is well developed and a number of manufacturers produce commercial units.

The principal focus of R and D in the areas of gasification and indirect liquefaction has been the production of medium caloric gas (MBG), substitute natural gas (SNG), and the conversion of the SNG to a liquid fuel by indirect liquefaction to produce methanol or gasoline.

A number of medium caloric gas (MBG) gasifiers are under development for use with woody biomass since it represents the largest of supply. The candidate types are grouped into fixed bed, fluid bed, entrained, and molten bath types with variations of staged gasification, catalytic gasification and other classifications.

(a) <u>Molten bath gasifiers</u>: Molten carbonate, lead and iron beds have been studied for urban solid wastes and coal gasification. These baths result in a high degree of carbon conversion and rapid gasification. The residues remaining in the bath must be removed. Available information indicates that the process will be expensive. This type of unit is in the early stages of development for use with biomass.

(b) <u>Fluid beds</u>: There are a number of commercially available fluid bed gasifiers. These gasifiers operate by cracking the organics into gases at high temperature. It appears that biomass feedstocks, with lower bulk density and ash content than coal, will require different design and operating criteria. SRI has analysed for DOE a conceptual pressurized fluidized bed wood gasifier using lock hopper feed systems to produce a syngas (14).

(c) <u>Catalytic gasification</u>: A number of companies are experimenting with the effects of alkali metal catalysis biomass gasification. These experiments are in early stages and the results are promising. It appears that complete gasification might take place in the reactor, thus reducing physical and cost requirements for additional cleanup processes used for gasification.

(d) <u>Methanol for biomass by direct gasification and indirect liquefaction</u>: Methanol can be used as a gasoline extender for industrial and utility gas turbines. Today, most methanol is produced from natural gas and production from municipal wastes, agricultural residues and other materials is being evaluated. There are a number of licensors of commercial systems for the methanol synthesis, including Lurgi, Imperial Chemical Industries, Vulcan Cincinnati, Japan Gas Chemical Company, Missouri-Tropsoi, J. F. Pritchard and Company and Chemi-Systems.

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Gasifier systems used (or proposed) for biomass are often oxygen-steam fluidized bed units which produce the synthesis gas and superheated steam. The synthesis gas is taken to a shift reactor where the carbon dioxide is converted to carbon monoxide and the gases are scrubbed to remove the carbon dioxide, hydrogen sulfide (if any) and water prior to application to a catalyst bed where the methanol is formed.

The economics of biomass systems indicates that methanol from wood would be more expensive than that from coal due in part to the smaller scale of biomass units. None the less, there are opportunities to decrease the costs. Proposed modifications include the elimination of the oxygen system, the use of catalysts, and the elimination of hydrogen sulfide and carbon dioxide cleanup units. In addition, the clustering of gasification units near biomass sources and transmitting gas to a central methanol unit can greatly reduce costs.

Issues:

1. What type of gas should be produced? Low, intermediate caloric or synthetic natural gas?

2. What type of gasification system has the most desirable characteristics for use with biomass?

3. Is it better to try to retrofit existing gas and oil burning units to utilize low caloric gas or is it better to install complete new direct combustion units which have better efficiencies and lower operating costs?

4. What size units will produce methanol on a competitive basis with other fuels?

5. Can gasification and liquefaction take place in a single unit?

6. Does the low sulphur content of the gas warrant the elimination of cleanup system?

7. Should methanol be converted directly into synthetic gasoline using the Mobil process?

4. Liquefaction

A number of alkaline metal catalysts appear to be effective for gasification and liquefaction of organic materials. One catalytic liquefaction process uses wood as a feedstock to produce oil. The wood is dried, ground and slurried with recycled oil, unconverted wood and the catalyst. The slurry is then pumped into a high temperature reactor. After leaving the reactor the dissolved and unreacted gases and carbon dioxide are cooled and removed leaving only the liquids and unreacted solids from which the oil is segregated. The gases are then transferred to a catalytic unit where hydrogen and carbon monoxide are combined

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and used as a fuel while the oil stream is split into a recycle and product stream. The oil produced is similar to No. 6 bunker oil.

Issues:

1. Are the properties of the oils produced by liquefaction of better quality than those oils produced by pyrolysis?

2. Can the oils be refined to produce gasoline and other petrochemical substitutes?

3. Is the process economically competitive with other alternate sources of liquid fuels?

IV. ECONOMICS AND ENERGY COSTS

The cost of producing energy from biomass is determined principally by the cost of the biomass, the conversion system used and the size of the facility. The costs of biomass energy products for the United States have been studied by SRI, under conditions of both regulated and unregulated financing. The regulated utility financing was with a 65 to 35 per cent debt to equity financing. It should be pointed out that tax laws, interest rates, labour and materials costs will vary from country to country and thus the figures given are for illustration only.

Table 1 represents the SRI results for the thermochemical conversions systems. The units all process 3,000 dry tonnes of feedstock per day. To determine the sensitivity of product price to feedstock cost, a second case is shown without feedstock cost. The optimistic thermochemical process case assumes a 20 per cent reduction in base case capital costs. All other costs were held constant.

The biochemical calculations used varying sizes for conversion facilities, feedstock materials and costs. Three cases are shown in tables 1 and 2: base case, a base case with zero feedstock cost, and an optimistic case, which reflects high-by-product values and favourable product yields for biochemical processes. A set of suggested cost goals are shown in table 3.

Issues:

1. Can systems be developed to aid countries in comparing the cost of various options available to them for biomass conversion using local labour and material costs?

2. For individual or community conversion systems what type of economic analysis should be used? Should the analysis represent only purchased materials, all materials, or all materials and labour?

Table 1

DETAILED ANALYSIS RESULTS OF THERMOCHEMICAL FACILITIES

(Feedstock = 3,000 dry tons per day)
(2,727 dry tonnes per day)

Route	Conversion* process	Revenue required ($/MJ)+ Base case	No feedstock cost case	Optimistic++
Wood to:				
Steam	DC	$2.84	$1.61	$2.56
Steam and electricity (total product basis)	DC	3.22**	2.00	2.94
Oil and char by-product	P	4.27+++	1.32+++	3.79+++
Oil and char (total product basis)	P	2.54**	1.23**	2.37**
Intermediate-Btu gas High pressure (280 psia)	P	3.79	2.46	3.41
Low pressure (25 psia)	P	3.22	1.99	2.84
Heavy fuel oil	CL	5.11	3.31	4.55
SNG	GOB	6.16	4.55	5.31
Methanol	GOB	7.39	5.69	6.35
Ammonia ($/short ton)	GOB	164.00	126.00	141.00
Electricity	DC	15.54 (1.6/MJ)	11.00 (1.1/MJ)	13.64 (1.4/MJ)

* Key: CL = catalytic liquefaction; GOB = gasification - oxygen blown; DC = direct combustion; P = pyrolysis.

\+ 1977 dollars in year 1985. Data source, SRI Detailed Analysis - Regulated Utility Financing. Plant size = 3,000 dry tons/day of feedstock.

++ Capital cost = 80 per cent of base case. Feedstock cost = $1.00/MMBtu.

** Revenue required is on a total product basis.

+++ Char valued at $1.18 per MJ (higher than current but less than projected future coal price).

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Table 2

DETAILED ANALYSIS RESULTS: BIOCHEMICAL FACILITIES

Route	Conversion* process	Feedstock dry tons/day	Revenue required ($/MJ) + Base case	No feedstocks case	Optimistic++
Cattle manure to SNG - 100,000 head environmental feedlot	AD	450	$6.64	5.59	2.80
10,000 head environmental feedlot	AD	45	13.27	12.70	7.11
Cattle manure to IBG	AD	450	4.64	3.70	4.17
Wheat straw to IBG (40% conversions)	AD	3 000	20.95	10.52	8.53
Corn stover to ethanol (Purdue process)	F(A)	1 562	21.33	17.39	15.36
Sugar cane to ethanol	F	2 756	25.59	10.71	18.96
Tilby process sugar cane to ethanol	F	2 756	21.80		14.22
Wheat straw to ethanol	F(E)	3 270	49.86	41.23	27.68***
Kelp to SNG** (speculative design case)	AD	3 000	20.09	2.84	11.33
Algae to ethanol**	F	1 126	24.55	10.43	16.49

* Key: AD = anaerobic digestion; F = fermentation (E = enzymatic hydrolysis A = acid hydrolysis).

\+ 1977 dollars in year 1985. Data source: SRI Detailed Analysis - Regulated Utility Financing.

++ Assumes refeed by-product values and high product yields.

*** Does not assume continuous fermentation processes which could reduce the optimistic estimates.

** These missions entailed the use of conceptual process designs based on minimal experimental data and numerous process design assumptions in the technoeconomic analysis.

Table 3

COST GOALS

(1978 dollars)

System	End product	Operational data available	Goal: Time	Goal: Cost/MJ (dollars)
Forest agricultural Residue gasification	MBG	1983	1988	2.40 to 3.00
Mixed agricultural Residues/A.D.	MBG/SNG	1986	1991	2.50 to 4.00
Energy farms Residue/gasification	SNG	1988	1993	3.50 to 5.00
	Methanol	1988	1993	5.50 to 7.00
	Gasoline	1988	1993	6.50 to 8.00
	Hydrogen	1988	1993	3.00 to 5.00
Energy farms Residue/fermentation	Ethanol	1990	1995	8.00 to 10.00
Energy farms Residue/liquefaction	Fuel oils	1990+	1995+	2.50 to 3.50

V. LONG TERM OPTIONS

A number of long term options, which might have impacts on countries' energy needs after the year 2020, have been proposed. These include the use of aquatic biomass, exotic plants and biophotolysis to produce hydrogen.

A. Aquatic biomass

Because of the competition for land in many countries, there will be less and less surplus space available to produce biomass. It is, therefore, only natural that aquatic plants are being considered as an energy source, despite the fact that in many areas, bodies of water are deficient in the trace nutrient required to sustain plant growth. Nevertheless, water plants are now used for food, and some species of seaweed are used commercially to produce chemicals. For energy purposes, aquatic biomass would have to be produced at cost in the range of $20 an oven-dried tonne to be cost competitive with other alternative feedstocks (2, 4, 20).

Issues:

1. Can aquatic biomass be grown at cost competitive prices?

2. How can trace nutrients required for plant growth be supplied?

3. Can aquatic biomass be converted using anaerobic digestion or fermentation processes into clean fuels?

4. Will these fuels be cost competitive?

B. Exotic plants

Considerable interest has been aroused by the possibility of substituting hydrocarbons from plants for those obtained from petroleum. The current economics of such systems have indicated that oil would have to reach over $90 bbl (1977 dollars) for this source of hydrocarbons to be viable (14).

Issues:

1. What species of plants would be the best to consider using for a source of hydrocarbons?

2. Where can these plants be grown?

3. What are the land, water and nutrient requirements of the plants?

4. What processing techniques can be used to obtain the oils from the plants?

5. Can hydrocarbon bearing plants be produced at a low enough cost to make oil from this source cost competitive?

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C. Biophotolysis

Biophotolysis involves the production of hydrogen by algae. The hydrogen can be used as a fuel. This type of system is only in the research stages and is at best a long term option.

Issue:

1. Can hydrogen by produced by biological means at a competitive price with other fuels?

VI. SPECIAL PROBLEMS OF DEVELOPING COUNTRIES

At present, biomass is used as an energy source in developing countries where it is burned or converted into methane gas through anaerobic digestion.

A. Direct combustion

Direct combustion systems vary from open fires to simple cook stoves, wood fired engines or small electric power plants. Many of these systems are very inefficient and result in the usage of much larger quantities of biomass than would be required to meet the energy needs of the persons using the biomass.

Issues:

1. What type of low cost, highly efficient direct combustion systems can be developed for use in the area with limited biomass resources?

2. How can these systems be introduced into the areas where the need is greatest for conservation of the biomass sources?

B. Anaerobic digestion (biogas)

Anaerobic digestion systems have been used for almost 100 years in the stabilization of human wastes, sewage sludge and industrial wastes (3). Because of rising energy costs, there has been a resurgence of interest in using these systems in developing countries to stabilize waste, prevent the transmission of disease, produce soil conditioners and methane gas. Unfortunately, many digestion systems are costly, even if adequate feedstocks are available.

Issues:

1. Can less expensive, more efficient anaerobic digestion systems be designed?

2. How can the operational problems of digestion be overcome?

3. What pretreatment can be used to increase the availability of agricultural residues for digestion?

4. How can the gas from the digesters be stored inexpensively for use at peak times?

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VII. SUMMARY AND CONCLUSIONS

Large quantities of agricultural and forest residues and standing biomass are currently available for conversion into heat, steam for process energy and/or electricity, and the technology is available to produce clean gaseous and liquid transportation fuels at competitive prices. Based on conceptual designs, technoeconomic analysis and projected energy prices of biomass from energy farms and waste system are approaching economic viability.

The analysis done in the United States would indicate that the greatest near term commercialization potential exists for:

- Combustion of wood and low moisture plants to produce steam and cogenerated steam and electricity.

- Gasification of wood and low moisture plants to produce IBG, SNG, LNG and ammonia.

- Pyrolysis of wood and low moisture plants to produce IBG, fuel oil, and char.

- Anaerobic digestion of manure and high moisture terrestrial crops to produce IBG and SNG.

Missions that appear to offer minor future contribution are marine crop production, catalytic liquefaction, and fermentation to produce ethanol (25).

The decision to use biomass and biomass fuels is a site specific decision and can be made only by the individuals and Governments involved after a systematic review of the options and their economic and social costs.

Appendix 1

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