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**BIOMASS AS A FEEDSTOCK FOR HIGHWAY VEHICLE FUELS:
A RESOURCE AND AVAILABILITY SURVEY**

December 1979

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Mueller Associates, Inc.
Baltimore, Maryland

U.S. Department of Energy

Solar Energy

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AND AVAILABILITY SURVEY

DECEMBER, 1979

UNDER CONTRACT

NO. DE-AC05-79CS56051

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PREPARED FOR:

U.S. DEPARTMENT OF ENERGY

ASSISTANT SECRETARY FOR

CONSERVATION AND SOLAR ENERGY

OFFICE OF TRANSPORTATION PROGRAMS

WASHINGTON, D.C. 20585

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FOREWORD

This report represents the culmination of an overview study performed by Mueller Associates, Inc., Baltimore, Maryland for the U. S. Department of Energy's Alternative Fuels Utilization Branch, Office of Transportation Programs.

The study was initiated because of the recognized need to compile a concise description of biomass as an energy base for liquid transportation fuels (namely alcohols) for highway vehicles. The aim is to provide a brief familiarization of biomass-related terminology to those with limited technical background and to present a summary assessment of the potential that biomass can provide as a resource base for liquid transportation fuels.

Biomass may play a significant role in supplying liquid fuels for transportation (indeed, for other sectors, as well), however, there are fundamental limitations imposed by the size of the biomass resource, production and distribution economics, and the difficulty of ensuring sustained availability for an extended period of time. Bioconversion is one of a number of developing energy options that individually, may make relatively small contributions but in the aggregate, are likely to be significant. Thus, research and development related to fuels from biomass and their utilization continue to be major areas of activity sponsored by the Department of Energy.

In support of the report's intent to be readable and readily understood by people with a limited technical background, the authors have chosen to depart somewhat from traditional technical reporting by not specifying reference material in the text. The Bibliography contains a listing of all references used in the preparation of this report. We apologize for any inconvenience that this format may pose for more learned and informed readers.

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I. SUMMARY AND CONCLUSIONS

This report addresses the use of biomass as a feedstock for highway vehicle transportation fuels (alcohols). The scope is limited to aggregate, nationwide supply aspects without consideration for overall system economics or the availability of alcohol processing facilities (which, of course, would be major factors that would affect the implementation of biomass-based transportation fuels). In this regard, the report presents a first-ordered estimate of the range of alcohol fuels that could be produced (again, from strictly a supply viewpoint) based on known biomass availability and with consideration for land-use limitations, time factors and technology improvements.

One of the difficulties in assessing biomass availability is that estimates of sources and quantities vary widely. This is because of differences in:

- Terminology.
- Data gathering methods.
- Definition of available versus potential production.
- Site-specific factors related to economics and collection practicality.
- Estimates of technology readiness.

While no attempt has been made to resolve these differences, data obtained from various sources are presented on a common basis and in terms of range of biomass availability for collection.

Biomass can be trees, crops, aquatic plants, and even natural ecosystem plant communities not subject to human management. For purposes of this report, biomass has been categorized as either wastes, residues or fuel crops, as described in Section II. The biomass resources most amenable to conversion to highway vehicle fuels (alcohols) are municipal solid wastes (MSW), crop residues, forestry wastes and residues, trees (as standing forest vegetation and/or cultivated terrestrial energy farms), and surplus grain crops.

Land availability is a key factor in determining overall biomass supplies. Of the 2.3 billion acres of land in the U.S. about 1.4 billion acres are devoted to cropland, forestland or grassland, and according to the U.S. Soil Conservation Service, an additional 120 million acres could be made available for crop production with little or no problems. Crops produced on this additional land can offer a sizeable contribution to biomass-based alcohol fuels for highway transportation.

With respect to conversion processes, fermentation (followed by distillation) of sugar- and starch-bearing materials to ethanol, and gasification (followed by synthesis) of MSW, forestry (wood) materials and agricultural residues to methanol seem the most likely, given current economics and the state of technology readiness. Either of these two alcohol fuels can be used straight (neat) in spark ignition internal combustion engines or, if completely water free (anhydrous), can be blended with gasoline to extend current petroleum-based transportation fuel supplies.

Based on resource supply aspects only (regardless of price), the potential availability of biomass suitable for conversion to alcohol fuels and the corresponding volumes of methanol and ethanol that could be produced from these materials are presented in Tables I-1, I-2, and I-3. Sections IV, V and VI contain the data used to develop these tables.

Significant conclusions that can be drawn from the availability data developed herein are as follows:

- As a group, crop residues, forestry wastes and residues, standing forest vegetation and municipal solid wastes offer high potential for supplying methanol (about 2.4 quads annually or 16% of the 1978 motor gasoline energy usage) both immediately and in the near-term (to about 1985). In the mid-term future (to about the year 2000), the addition of methanol from silviculture energy farms could provide an additional 1.5 quads of annual energy value.

TABLE I-1, METHANOL POTENTIALLY SUPPLIED
FROM AVAILABLE BIOMASS MATERIALS

RESOURCE	ANNUAL RESOURCE AVAILABILITY (Millions of Dry Tons)	ANNUAL METHANOL AVAILABILITY					
		IMMEDIATE		NEAR-TERM		MID-TERM	
		Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)	Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)	Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)
Municipal Solid Wastes	92	0.47	3.2	—	—	—	—
Crop Residues	100-146	0.52- 0.75	3.5-5.1	—	—	—	—
Forestry Wastes	23	0.12	0.8	—	—	—	—
Forestry Residues	187-200	0.98- 1.04	6.6-7.0	—	—	—	—
Standing Forest Vegetation	20	0.10	0.7	—	—	—	—
Silviculture Energy Farms	270-300	--	--	--	--	1.41- 1.55	9.5-10.5
MAXIMUM AVAILABILITY	692-781	2.19- 2.48	14.8-16.8	2.19- 2.48	14.8-16.8	3.60- 4.03	24.3-27.3

**TABLE I-2, ETHANOL POTENTIALLY SUPPLIED
FROM CROP SURPLUSES**

RESOURCE	ANNUAL RESOURCE AVAILABILITY (Millions of Bushels)	ANNUAL ETHANOL AVAILABILITY					
		IMMEDIATE		NEAR-TERM		MID-TERM	
		Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)	Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)	Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)
Corn	532	0.10	0.70				→
Sorghum	60	0.01	0.08				→
Oats	225	0.02	0.12				→
Barley	123	0.02	0.13				→
Wheat	638	0.12	0.83				→
MAXIMUM AVAILABILITY	1,578	0.27	1.86	0.27	1.86	0.27	1.86

**TABLE I-3, ETHANOL POTENTIALLY SUPPLIED FROM PLANTING ANY
SINGLE CROP ON AN ADDITIONAL 120 MILLION ACRES¹**

RESOURCE	ANNUAL RESOURCE AVAILABILITY (Millions of Bushels)	ANNUAL ETHANOL AVAILABILITY					
		IMMEDIATE		NEAR-TERM		MID-TERM	
		Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)	Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)	Energy Value (Quads)	% of 1978 Motor Gasoline (14.8 Quads)
Corn	10,488	--	--	2.09	14.1	→	→
Sorghum	5,832	--	--	1.12	7.6	→	→
Oats	5,448	--	--	0.44	3.0	→	→
Barley	5,376	--	--	0.84	5.7	→	→
Wheat	3,636	--	--	0.70	4.7	→	→
Sugarcane	129/1,148 ^{2,3}	--	--	0.22	1.5	2.01	13.6
Sugar Beets	2,338/1,785 ^{2,4}	--	--	3.51	23.7	2.62	17.7
MAXIMUM AVAILABILITY		--	--	3.51	23.7	4.63 ⁴	31.4 ⁴

NOTES

- ¹ The volume of ethanol available is not additive for all crops, however, any combination of crops is possible as long as 120 acres is not exceeded.
- ² Values quoted are in millions of tons. First value indicated is for near-term availability, second value is for mid-term availability.
- ³ Only 30.3 million acres maximum (mid-term) and 3.4 million acres minimum (near-term) are available for additional sugarcane production.
- ⁴ Largest volume would be produced by utilizing all 30.3 million acres for sugarcane and 89.7 million acres (120 minus 30.3) for sugar beets.

- Municipal solid wastes can provide less than 0.5 quads of methanol energy value annually (less than 13% of the total annual methanol energy value available from all biomass resources suitable for methanol production).
- Use of available crop surpluses (assuming they continue to be available at the same rate) to produce ethanol would provide the highway transportation sector with an energy contribution of less than 0.3 quads annually or 2% of motor gasoline energy used in 1978. However, this resource is the only one immediately available (for ethanol production) at reasonable cost and without affecting crops grown for direct food consumption.
- The addition of 120 million acres for producing crop-derived ethanol can substantially contribute to the near- and mid-term ethanol supply for highway transportation (about 3.5 quads annually or 24% of 1978 motor gasoline energy usage).
- With maximum utilization of all biomass resources listed, about 9 quads, or 60% of 1978 motor gasoline energy usage could be provided annually in the mid-term time frame. In this respect, the potential energy contribution offered by aggregate nationwide supplies of biomass as a feedstock for highway vehicle fuels is significant.
- Tables I-1, I-2, and I-3 indicate only the amounts of fuel that could be obtained from biomass resources, and do not reflect how much energy might be used in production and/or conversion. Thus, they represent an upper limit on potential contribution.

II. PURPOSE AND INTRODUCTION TO TERMINOLOGY

Biomass is a renewable energy source that can be used directly (as a fuel) or converted into various fuel products including: char (carbon), methane or similar gaseous fuels, ethyl alcohol (ethanol), or methyl alcohol (methanol). Recent interest in biomass as an energy source and its conversion to biofuels has led to a great amount of activity (in the form of programs, studies and reports) on the subject. These activities have centered on a wide variety of study areas including resource availability, end-use applications, conversion to finished fuel products, process economics, transportation of resource materials, societal impacts, market feasibility, energy considerations and environmental implications. The scope of this report, however, is limited to a rather cursory identification of U.S. biomass resources (in terms of existing and potential availability) and their appropriate conversion to liquid fuels (namely alcohols) for highway vehicle transportation.

This report addresses aggregate, nationwide supply aspects of biomass as a feedstock for highway vehicle transportation fuels, but does not consider site-specific factors that may favor one resource-to-fuel system over another. The report does not address the detailed economic factors that comprise the ultimate cost of producing transportation fuels from biomass, nor does it consider the energy required to produce biomass or the technical factors related to fuel distribution and end-use within vehicles.

The intent is to present this information in summary form which can be readily used and understood by reading audiences having broad interests and backgrounds. Information contained in this report is based on a survey of existing literature as set forth in the Bibliography.

In reviewing the various information sources, it became evident that estimates of biomass availability vary widely. This is because of differences in data gathering methods, differences between available and potential crop production, and also due to some confusion about what is considered as available biomass

wastes. Thus, different sources often quote far different values of biomass availability. Also, variations in the factors that comprise the economics and system energy requirements of biofuels production lead to differences in the costs of supplied fuels. For purposes of this report, no attempt was made to resolve any of the aforementioned differences or undertake any sort of detailed economic assessments. Instead, the authors have presented what they feel are representative values (or ranges) for resource availability and costs. It should be recognized that as with other developing energy-related technologies, the conversion of biomass to usable fuel products will be subject to technological and data gathering refinements, and will be affected by a host of institutional, environmental and socio-economic considerations. Accordingly, the information contained in this report can be considered as reasonably factual for the particular "slice in time" for which these data are available.

Biomass can be trees, crops, aquatic plants, and even natural ecosystems (i.e., plant communities not subject to human management), and can be classified in a variety of ways. For purposes of this report, however, biomass will be divided into three (3) categories: wastes, residues and fuel crops. Wastes are defined as biomass having a significant "negative cost" component (i.e., a credit is obtained at some stage of their use). Some people have chosen to include municipal solid wastes (MSW) within the definition of biomass, but as will be shown later in this report, the energy contribution from MSW (on a national aggregated basis) is minimal. For this reason, MSW is not treated extensively in this report. Residues are the plant remains left in the field of forestry or agricultural operations. Residue costs are positive not only for collection and transportation but also for alternative uses (such as livestock feed, soil conditioners, fertilizers, etc.). The third category, fuel crops, is biomass that is specifically cultivated for its fuel content. Fuel crops could be conventional annual crops, various tree species, aquatic plants or

even multiplant communities. Silviculture (forestry cultivation) and aquatic energy farms are the subject of particular interest and study because of their potential for the development of large-scale biomass systems. Since energy farms are still a subject of developmental interest, their relationship to the scope of this report is limited to quantifying the potential contribution to the U. S. transportation fuels supply.

Any fuel derived from biomass is a biofuel. Biomass can be used as a biofuel directly, as when firewood is burned; or a series of processes and transformations may be necessary before it becomes a fuel. Biofuels can be produced by either thermochemical, biological or photochemical conversion processes. There are three (3) basic types of thermochemical conversion processes: direct combustion, pyrolysis and gasification. Direct combustion involves the feeding of a burnable biomass into a combustor with sufficient air to result in complete conversion to carbon dioxide, water, and inorganic ash. Combustion processes and combustors can vary greatly, from simple wood burning stoves or fireplaces to modern fluidized-bed boilers. The processes of pyrolysis and gasification involve the heating of biomass in the absence of air (or with only sufficient air to provide necessary heat) to yield dilute mixtures of gaseous fuels (carbon monoxide and hydrogen), liquid fuels (condensed volatiles and highly oxygenated pyrolytic oils), and solid fuels (char and charcoal). In general, pyrolysis refers to lower-temperature processes that favor liquid and solid fuel formation, while gasification is a higher-temperature process that results almost exclusively in gaseous fuels (chiefly methane). Through further processing, methane can be used as a feedstock for producing methanol. Biological conversion processes are all fermentations, or bacteriological processes carried out in the absence of oxygen. They result in the production of a large variety of chemicals and fuels including hydrogen, methane, acids, ethanol, and other higher alcohols. Methane fermentations

take place in anaerobic digestors. Ethanol fermentations are well developed technically and can be used with sugar- or starch-containing feedstock materials. Biophotolysis involves the production of hydrogen from water and sunlight by photosynthetic microorganisms. Currently, there is one photochemical conversion processes of prominent interest; photoelectrolysis entails the generation of hydrogen via a controlled synthetic reaction. Both biophotolysis and photoelectrolysis are still experimental at this time, and as such, are treated only in passing for purposes of this report.

Before biomass can be used in these various conversion processes it must often be subjected to various pretreatments. Feeding wood into boilers requires that it be reduced to chunks or small chips, for example. High moisture content and the need for storage frequently make it necessary to dry densify the biomass. Alcohol fermentation of cellulosic biomass requires prior hydrolysis, via enzymes or with acids. Pretreatments, of course, increase the cost of the ultimate biofuels and thus are a major factor in the economics of producing biofuels. Pretreatments are also the subject of considerable research and development.

Figure II-1 is a general overview of biomass resource bases, process conversion technologies, fuel products, and appropriate end-use sectors.

FIGURE II-1, GENERAL OVERVIEW OF THE
BIOMASS/BIOFUEL SYSTEM

III. BIOCONVERSION PROCESSES PERTINENT TO THE PRODUCTION OF TRANSPORTATION FUELS

Since the scope of this report is limited to transportation fuels (for highway vehicles, more specifically), the emphasis of this section will be on those biomass conversion processes that are most appropriate for producing such fuels. In addition, several assessments performed by or for the U.S. Department of Energy have identified alcohols (methanol and ethanol) either neat (straight) or in blends with gasoline as viable near-and mid-term (to the year 2000) alternatives to current petroleum-based highway transportation fuels. Before detailed discussion is developed, several points should be emphasized. First, there are a number of conversion processes at various states of in-use practice and/or technology development. Second, several processes are capable of producing a multiplicity of intermediate fuel products which may or may not be suitable for transportation purposes. Third, just about any biomass resource can be converted to almost any fuel product with appropriate pretreatment, intermediate processing and final "refining," yet due to economic and/or site-specific practicalities, some processes are better suited to converting one class of biomass to one class of fuel.

Of all the processes described briefly in Section II, gasification with subsequent conversion of the methane-containing gaseous fuel product to methanol, and fermentation of sugar- or starch-containing biomass to ethanol are felt to be the most appropriate to supplying liquid fuels for highway transportation. Since it is beyond the scope of this report to present all of the reasons for process appropriateness (without a detailed discussion of all conversion processes and their associated fuel products), suffice it to say that these reasons relate to a variety of factors including:

- Process, biomass feedstock, and fuel product economics.
- The state of conversion process technology readiness.
- Usefulness of specific fuel products to more appropriate end uses (such as the direct combustion of MSW in boilers).
- Overall process conversion energy efficiency.

With this perspective on biomass conversion processes (relative to the production of liquid fuels for highway transportation), Figure III-1 shows the most likely production routes for methanol and ethanol as transportation fuels for highway vehicles. Either of these two alcohol fuels can be used straight (neat) in spark ignition internal combustion engines or, if completely waterfree (anhydrous), can be blended with gasoline to extend current petroleum-based transportation fuel supplies. Engine modifications are required for use of neat alcohols but these modifications are considered to be straightforward. Relatively minor engine modifications are required for use of alcohol/gasoline blends with up to about 15% (by volume) alcohol concentrations.

Production of methanol is likely to be based on MSW, forest crops (wood) and agricultural residues. Conversion includes a two-step process of gasification followed by methanol synthesis and is schematically depicted in Figure III-2. Ethanol is most likely to be produced from fermentable biomass feedstocks: sugarcane, corn, wheat, sugar beets, etc. Conversion to ethanol is through the well-known fermentation/distillation process used for beverage alcohol. Ethanol can also be produced from cellulosic biomass, however, this production route requires an additional enzyme or acid hydrolysis step (which breaks down the complex cellulose molecules into simple sugars) prior to fermentation and distillation. Significant development efforts are being applied to hydrolysis processing of cellulose, however the costs and complexities associated with these processes are such that significant production via these processes is not anticipated before 1990. Figure III-3 is a simplified flow diagram of the ethanol fermentation/distillation process. Although corn is shown as the feedstock, numerous other starch- or sugar-containing materials can be used.

It is pertinent to note that several U.S. plants currently produce fermentation ethanol (from biomass) for highway transportation fuel use, and that the quantity produced amounts to about 15 to 20 million gallons per year (for 1979) as estimated by the U.S. Department of Energy.

FIGURE III-1, BIOMASS-DERIVED ALCOHOLS FOR MOTOR VEHICLE USE

FIGURE III-2, SIMPLIFIED METHANOL PRODUCTION PROCESS

FIGURE III-3, SIMPLIFIED ETHANOL PRODUCTION PROCESS

IV. LAND USE AND AVAILABILITY

Before discussing the availability of biomass resources for transportation fuels (Section V of this report), it is useful to present an overview of land availability since this is a key factor in determining overall biomass supplies.

Of the 2.3 billion acres of land in the United States, 1.4 billion acres (about 60%) are devoted to cropland, forestland or grassland, according to the U.S. Department of Agriculture. In terms of agriculture, during 1976, there were 2.8 million farms in the United States with an average size of 389 acres. This represents a total farmed acreage of 1.08 billion acres, which has declined from 1.14 billion acres since 1965. Tables A-1 and A-2 in the Appendix present data on the number of farms and land in farms, by state, for 1974-76, as well as U.S. totals for the period 1965 through 1976. These totals include pasture, range and forage grass lands which account for about 700 million acres. Actual cropland constitutes about 400 million acres or roughly 40% of the total farmed acreage.

According to the U. S. Soil Conservation Service's analysis of land use capabilities for privately held lands, there are about 35 million additional acres which could be used for cropland with no development problems. Suitable pasture, range, forest and other lands which have high and medium potential (see Table A-3 in the Appendix for definition of terms) for use as cropland total an additional 85 million acres. These two groups combined would add 120 million acres (or an increase of about 30%) of total cropland for a total availability of 520 million acres. An analysis of how this additional land (120 million acres) could be used to produce liquid transportation fuels in highway vehicles is presented in Section VI. Since it would require some period of time to clear and prepare such a sizeable piece of land for crop cultivation, crop availability (and resultant alcohol fuels) is considered a near-term prospect as opposed to being available "immediately" (as in the case of crop surpluses, for example).

Forest lands cover approximately 750 million acres of the conterminous U.S. land area. Land that produces or is physically

capable of producing wood products on a commercial basis includes about 500 million acres. Of this 500 million acres, the Federal Government owns 107 million acres; 364 million acres are privately owned forest lands and state and local governments own 29 million acres.

Tables A-4, A-5 and A-6 in the Appendix detail the land use and capability classes for privately held lands in the United States.

V. AVAILABILITY OF BIOMASS RESOURCES PERTINENT TO THE PRODUCTION OF TRANSPORTATION FUELS

This section addresses the present and potential availability of various biomass resources that are appropriate for the production of alcohol fuels. Crops, crop surpluses, wastes, residues, forestry products and land-based energy farms are considered. In presenting this section, it should be emphasized that while virtually any organic matter can be converted to a biofuel (solid, liquid or gaseous), no attempt has been made to list or consider the availability of all these materials, only the ones most suitable for conversion to highway transportation fuels (alcohols) according to the conversion processes listed in Section III.

Considerable controversy exists regarding the economically recoverable U.S. biomass resource. Reasons for this controversy include:

- Differences in data collection methods.
- Differences in the definition of "boundaries" that separate available vs. potential resources.
- Lack of uniformity in reporting resource quantities e.g., as-collected wet vs. dry (moisture removed). The moisture content of most biomass materials ranges from less than 10% to over 80% by weight, with a more typical range of from 20% to 50%.
- Differences in assumptions for the energy content of biomass materials (which range from less than 5,000 Btu per pound to 10,000-12,000 Btu per pound).
- Differences in assumptions for estimating biomass resources that are available for energy use vs. total availability (which would include other uses such as for food, fertilizer, etc.).

Because of the potential that biomass holds as an energy feedstock, the U.S. Department of Energy has applied substantial effort toward characterizing the availability of U.S. biomass resources. In large part, the information contained in this section is derived from biomass systems studies performed for the Department of Energy by the Mitre Corporation, SRI International, and Battelle Columbus

Laboratories. The information on crop surplus availability is from the U.S. Department of Agriculture.

For purposes of this report, estimates of biomass resources were developed in terms of availability (for conversion to alcohols) on a dry weight equivalent basis (except for farm crops). Factors that will influence the expansion of biomass utilization for transportation fuel purposes are related to economics, yield, the availability of process conversion facilities and the matching of various fuel types to specific processing applications.

A. Wastes and Residues

The discussion of biomass wastes and residues will be preceded by introducing some useful definitions:

- Available: That portion (in dry tons) of the generated residues (crop, forest and animal) that is collected during normal harvest or is realistically collectible. This varies by residue type.
- Fed: That portion of available residues that is fed to animals without collection or with collection but without sale.
- Fuel: That portion of available residues that is used as fuel without sale. This category includes all forestry residues used as fuel.
- Returned: That portion of the available crop and manure residues that is returned to the soil without sale.
- Sold: That portion of available residues that is collected and sold for any purpose other than fuel as in the case of forestry residues. All forestry residues used as fuel are included as "Fuel" regardless of source or previous sale.
- Wasted: That portion of the available residues that must be disposed of at an economic cost, i.e., hauled away, burned, etc. This category includes all logging residues as well as collected residues that are not sold, fed, or used as fuel, i.e., they are returned to the soil at an economic cost.

The most readily available resources for bioconversion are wastes and residues: municipal, agricultural and forestry. Because these materials are usually available in relatively large amounts at specific sites, their use is simplified. However, several varieties such as manures have characteristics that are sometimes considered to be undesirable for conversion to highway transportation fuels, requiring additional processing or resulting in significant energy conversion losses. Another factor affecting the utilization of biomass wastes and residues is that fuel markets can be far from the resource collection facility, thus feedstock transportation costs are critical to competitively-priced waste-derived highway transportation fuels. For general information, Figure V-1 illustrates the total annual crop, forestry and manure residues generated in the United States (by state).

Municipal wastes are currently one of several environmental problems in the United States. Municipal solid wastes are produced at a rate of about 3.5 to 4.0 pounds per person per day or, currently, 140 million tons per year of total gross discards (about 115 million dry tons). Unfortunately, this large resource base contains a variety of organic and inorganic materials (thus a variable energy content) which do not lend themselves to uniform processing to liquid fuels. Pre-process materials separation is costly and consumes both time and energy, but if utilized, could allow about 80% of this waste material (92 million dry tons) to be used as a transportation fuel feedstock.

Agricultural residues consist of crop materials left in the fields during and after harvesting. The predominance of these residues are found in the corn, wheat and other grain-producing regions of the nation. The amount of residues that could be collected and converted to fuels is limited by several factors. Soil condition and fertility greatly depend on the residues returned to the soil; therefore, the amount of residues that may be removed without affecting future crop production is very site-specific and somewhat controversial. In general, about one-third of the crop residues presently returned to the soil will provide sufficient nutrients; this leaves two-thirds of the returned

FIGURE V-1, ANNUAL U.S. CROP, FORESTRY AND MANURE RESIDUE GENERATION

portion for other uses (including conversion to biofuels). Other factors such as moisture content, seasonal availability and transportation limitations have an inhibiting effect on large-scale use. Estimates of current crop residue available for collection range from about 100 to 146 million dry tons per year.

Forestry wastes and residues combine to make up a substantial biomass resource. Forestry wastes are the bark, sawdust, and other wastes that accumulate at lumber and pulp mills. They are also generated, along with some foliage residues, in the growing and harvesting of timber. Lumber mill wastes are generated in very large amounts, since only about half of the timber processed into lumber and plywood becomes part of the finished product. Unlike forestry residues, about 70 percent of all wood wastes collected by the lumber, plywood and miscellaneous wood products industries (about 76 million dry tons per year) are used for some purpose. This leaves about 23 million dry tons per year available for other purposes.

An assessment performed by the Mitre Corporation for the U.S. Department of Energy describes current annual above-ground forest residue generation at 83 million dry tons, while the stump-root systems left as logging residues are estimated at 104 million dry tons. Other estimates place the total logging residue generation at about 200 million dry tons per year. Forest residues generally include the "slash" left on the ground after logging operations, intermediate cuttings, understory (stump and root system) removal, diseased and otherwise unsuitable woods, and so on. Although an accurate estimate of the recoverable biomass (for conversion to liquid fuels) from this source is difficult, in many areas the amount could be substantial since essentially all forest residues are unused (i.e., wasted). The reason for this is that at present, the economics of collection and the quality of residues are not favorable for conversion into conventional wood products. Forest residues could conceivably be collected and reduced to a convenient size by on-site chipping machines or by processing through a hammer-mill similar to that used for reducing mill residues to fuel. Such collection methods may make the use of forestry residues more economically attractive.

Kraft black liquors, which contain the residual liquor and cellulose from the pulping process, are one of the major sources of fuel in the pulp and paper industry. Although their liquid nature makes their use as fuels somewhat inefficient, the need to recover the pulping chemicals makes their incineration a necessary component of the kraft pulp production process. Currently, kraft black liquors provide about 0.4 quads (one quad is 10^{15} Btu) or about half of the biofuel-derived energy used by the lumber and paper industries. One promising approach to the recovery of biofuels from liquid pulping wastes is the hydrolysis of the cellulose contained in them, followed by fermentation to ethanol (as described in Section III). The Georgia-Pacific Corporation's integrated pulp, paper and processing facility located in Bellingham, Washington, incorporates this process to produce anhydrous (water-free) ethanol and, in fact, supplied the State of Nebraska with anhydrous ethanol for its state Gasohol* program.

With respect to the economics of producing alcohols from biomass wastes and residues, Table V-1 illustrates the costs associated with obtaining such materials. The cost of these materials obviously has a direct impact on the overall cost of alcohol production.

B. Standing Forest Vegetation

As described in Section IV, forest lands cover approximately 750 million acres of the conterminous U.S. land area. The amount of accumulated standing forest vegetation not currently harvested (including dead and diseased trees) is theoretically a billion dry tons. However, since it takes an average of 50 years for a forest to regenerate itself, the practical availability is more like 20 million dry tons annually. The significance of standing forest vegetation is its ready near-term availability as a feedstock for biofuels.

*Gasohol is a registered trademark of the Nebraska Agricultural Products Industrial Utilization Committee, and consists of 10% (by volume) anhydrous ethanol blended with 90% commercially available unleaded gasoline.

TABLE V-1, SELECTED FORESTRY AND AGRICULTURAL RESIDUE
PURCHASE PRICES AND COMPONENT COSTS (1976 DOLLARS)

RESIDUE/LOCATION	RESIDUE PRICE \$/TON	COLLECTION COST* \$/TON	TOTAL DELIVERED COST \$/TON	PERCENT DRY WEIGHT	DELIVERED DRY COST	
					\$/TON	\$/MM Btu
Wheat Straw/Colorado	4.50-11.50	4.50-10.00	11.50-24.50	91	12.50-26.50	0.80-1.80
Mill Bark/California	3.00	--	4.00-5.50	50	8.00-11.00	0.40-0.60
Mill Bark/Maine	--	--	2.00-4.00	50	4.00-8.00	0.20-0.40
Logging Residue/ California	--	11.00-12.00	12.00-22.50	50	24.00-44.50	1.30-2.50
Field Corn Residues/ Illinois	12.00-15.00	4.50-10.00	19.00-28.00	53	35.50-52.50	2.40-3.50
Field Corn Residues/ Delaware	7.00-9.00	4.50-10.00	14.00-22.00	53	20.50-39.50	1.30-2.70
Beef Manure/Colorado	0.50-1.00	0.25-0.50	3.00-4.50	60	5.00-7.50	0.40-0.60
Poultry Manure/Delaware	14.00-17.00	3.00-6.00	19.50-26.00	75	26.00-34.50	1.60-2.30

*Estimated cost for 15-mile transportation, loading and unloading charges, except for Maine which required a 25-mile transport.

C. Crops and Crop Surpluses

Cultivation of conventional crops such as corn, sugar-cane, sugar beets, wheat, grasses, etc., for conversion to fuels has been the subject of recent systems analysis studies sponsored by the U.S. Department of Energy. Crop biomass can be classified as fermentable (sugars and starches) or cellulosic (suitable for thermochemical conversions or requiring hydrolysis before fermentation).

The availability of crops and crop surpluses (not crop wastes or residues) for biofuels is dependent upon several important variables, including annual crop production, crop yields, suitability (for bioconversion), and U. S. Department of Agriculture (USDA) policies. This section will briefly discuss these variables. For purposes of this discussion, "surplus" is equated to yearly "ending stock," i.e., that amount which is not used for food, feed or export. Table V-2 summarizes the supply, disappearance, ending stock, and typical yields for selected crops that would be most amenable for conversion to alcohols. These data are the most recently available from the USDA.

Current USDA policy, implemented in accordance with the provisions of Public Law 95-113, the Food and Agricultural Act of 1977, is intended to assure a fair return for farmer's products through loan, acreage set-aside and grain reserve programs. These programs will effectively work against additional crop production. Farmers who elect to participate in the USDA program are entitled to loans which will enable them to wait for a better selling price. Farmers may also place their crops into a reserve program to receive annual storage payments. This three-year program established by the Act will provide for about a 15.5 million ton feed grain reserve and about a 8.2 million ton wheat reserve. Farmers who participate must agree to set aside 10% of their corn, sorghum and barley acreage and 20% of their wheat acreage. This will most likely bolster grain prices by reducing production, and have a controlling effect on any crop surpluses that might otherwise be available for conversion to biofuels.

TABLE V-2, AVERAGE YEARLY SUPPLY, DISAPPEARANCE AND
ENDING STOCKS OF SELECTED CROPS
(FOR THE YEARS 1974 - 1977)

CROP	SUPPLY	DISAPPEARANCE	ENDING STOCK
<u>GRAINS</u> (millions of bushels)			
Corn	6107	5575	532
Sorghum (sweet and grain varieties)	810	750	60
Oats	912	687	225
Barley	519	396	123
Wheat	2451	1813	638
<u>SUGARS</u> (1000's of tons)			
Sugarcane	2684	2684	---
Sugar Beets	3705	3705	---

Of the crops listed in Table V-2, sugarcane and corn exhibit the highest productivity of the major crop plants. At present, sugarcane yields range from an average of 16 tons per acre (dry matter) to a high of 35 tons per acre. Sugarcane typically contains about 16% fermentable solids; about half of the total organic material is a cellulosic residue called bagasse. Unfortunately, the frost sensitivity and water needs of sugarcane restrict the area in which it can be cultivated to about 30.3 million acres currently. Sweet sorghum, although not commercially cultivated on a significant scale at the present time, would have potential for extending the growing area of sugar crops but at somewhat lower yields.

Corn is the largest single crop produced in the United States. It is cultivated on about 60 million acres of land and produces about 90 bushels or two tons of dry matter per acre. Other conventional crops, particularly grain sorghum (milo), have been considered for energy production. Yet even if the economics were favorable, crop production (for fuel purposes) may face competition (restrictions, more probably) with the need for food and feed.

Several unconventional fuel crops have been suggested as a source of biofuels: cattails, rubber trees, weeds, desert plants, etc. At this time, identification and selection of appropriate contenders are still in progress, thus further discussion beyond this point would be very speculative.

D. Energy Farms

The cultivation of biomass on large-scale energy farms is a major program element of the DOE's Fuels From Biomass Program.

There are several advantages associated with the energy farm concept (both terrestrial and aquatic). Energy farms offer potential for reclaiming marginal lands and would minimize the problems and costs associated with biomass collection and transportation. Also, process conversion facilities could be built "on-site" and optimized for handling specific crop types.

Conflicting opinions surround the economic, environmental, and social feasibility of such energy farm operations.

The most important issue facing the production of terrestrial energy crops is the availability of land and water resources to be allocated to such an enterprise. If water could be made available at reasonable cost, marginal lands, including desert lands, could be utilized for energy farms. Unfortunately, water is a relatively scarce resource in many parts of the United States, and its scarcity may restrict the use of marginal lands. Research and study are still in progress, thus the material presented in this section is somewhat speculative (although based on the judgement of those who are most knowledgeable in this area).

The concept of silviculture energy farms involves the cultivation and processing of selected, rapidly growing tree species planted in closely spaced rows and harvested on a short rotation (on the order of every 4 to 7 years). Cultivation would have to be relatively intensive, compared to normal forestry practice, and would involve the use of fertilizers, weed controls and possibly irrigation.

Silviculture energy farm studies conducted thus far have postulated a large farming area (on the order of about 25,000 acres) with a centrally located fuel processing facility. The Mitre Corporation has investigated the feasibility of silviculture biomass plantations and has offered the following conclusions:

- If 27 to 30 million acres of the Nation's forest, pasture range and other grasslands were to be used for woody biomass production, about 270 to 300 million dry tons per year would be available.
- Biomass productivity under close-spaced, short-rotation conditions is estimated to range from 5 to 13 dry tons per acre each year with current production technology, depending upon species and site selection.
- In terms of potential availability of suitable land, the Southeast, Mississippi Delta region and Great Lakes region are the most likely locations for biomass farms in the United States.

The basic assumption in most silviculture energy farming studies is that fertilization and irrigation (where rainfall is inadequate) of closely spaced selected tree species will allow yields of three to four times greater than those presently obtained, and that future research will allow those yields to nearly double to 15-20 dry tons per acre-year. If these assumptions are accepted, silviculture energy farming appears to be an attractive energy option, but not until well into the 1990's (according to the Department of Energy's Fuels From Biomass Program).

E. Summary of Biomass Availability

In summary, a tabulation of biomass availability (including contributions offered by silviculture energy farms) is presented in Table V-3. The information from this table will be utilized in developing the estimates of potential highway transportation fuel supplies described in Section VI of this report.

It should be noted that estimates of future biomass availability, especially for agricultural (including forestry) wastes and residues, are continuing to be developed as a result of systems studies work performed under the DOE Fuels From Biomass Program. These studies typically base future forecast scenarios of biomass availability on a variety of economic, agro-science, institutional, and site-specific factors, all of which are beyond the scope of discussion within this report. Thus, as progress is achieved, the data reported in Table V-3 are subject to revision in terms of both quantity and availability time frame.

TABLE V-3, SUMMARY OF BIOMASS AVAILABILITY FOR
CONVERSION TO ALCOHOL FUELS FOR
HIGHWAY TRANSPORTATION

RESOURCE	CURRENT AVAILABILITY (COLLECTIBLE)
<u>WASTES AND RESIDUES</u>	
Municipal Solid Wastes	92 million dry tons per year
Crop Residues	100-146 million dry tons per year
Forestry Wastes	23 million dry tons per year
Forestry Residues	187-200 million dry tons per year ¹
<u>STANDING FOREST VEGETATION</u>	20 million dry tons per year
<u>CROP SURPLUSES</u>	
Corn	532 million bushels per year ²
Sorghum	60 million bushels per year ²
Oats	225 million bushels per year ²
Barley	123 million bushels per year ²
Wheat	638 million bushels per year ²
Sugarcane	None ³
Sugar Beets	None ³
<u>SILVACULTURE ENERGY FARMS</u>	270-300 million dry tons per year ⁴

NOTES

- 1 Value quoted is for that which is generated. Since virtually all of these residues are wasted, it is assumed that all may be collected for conversion to alcohol fuels.
- 2 Presumes the same recent historical ending stocks will be available in the future.
- 3 The U.S. is a net importer of sugar products.
- 4 Would not be available immediately due to length of time required to reach the first harvest. This resource is included because of its mid-term (by the year 2000) energy supply potential.

VI. TRANSPORTATION FUELS POTENTIALLY SUPPLIED FROM BIOMASS

Utilizing the biomass resource availability data developed in Section V, and the information from Section IV on additional land availability, this section presents the potential supply of alcohols that could be produced from these resources. The alcohol supply data are expressed in terms of actual volume, the percent of 1978 motor vehicle gasoline energy usage (14.8 quads), and percent of 1978 total transportation energy usage (20.6 quads).

Table VI-1 illustrates the quantity of methanol that potentially could be produced if all wastes, residues, standing forest vegetation, and woody biomass from silviculture energy farms were converted via the gasification/synthesis route. All wastes and residues are considered immediately available, and if all were converted to methanol, could supply an annual energy equivalent of about 16% of the 1978 motor gasoline usage. Silviculture energy farms are considered a mid-term source of biomass materials (for alcohol fuels), and if all of the yearly expected availability were converted to methanol, could supply an annual energy equivalent of about 10% of the 1978 motor gasoline usage. When grouped together as a single biomass resource class, agricultural wastes/residues and woody biomass from standing forests can provide over four times the methanol energy equivalent than that provided by MSW.

Table VI-2 illustrates the quantity of ethanol that potentially could be produced if all crop surpluses were converted via fermentation and distillation. All of these crop surpluses are considered immediately available (presuming the same surplus levels continue to prevail), and if all were converted to ethanol, could supply an annual energy equivalent of less than 2% of the 1978 motor gasoline usage.

Table VI-3 illustrates the quantity of ethanol that potentially could be produced if 120 million more acres of land were placed into alternative crop production. This presumes that the additional acreage would not go into food production or other uses and that the land is in areas suitable for biomass energy

TABLE VI-1, METHANOL POTENTIALLY SUPPLIED FROM AVAILABLE BIOMASS MATERIALS

RESOURCE	AVAILABILITY (MILLIONS OF DRY TONS PER YEAR)	METHANOL VOLUME ¹ (MILLIONS OF GALLONS PER YEAR)	% OF 1978 MOTOR GASOLINE ENERGY (14.8 QUADS) ⁴	% OF 1978 TOTAL TRANSPORTATION ENERGY (20.6 QUADS) ⁴
Municipal Solid Wastes	92	8,464	3.2	2.3
Crop Residues	100-146	9,200-13,432	3.5-5.1	2.5-3.7
Forestry Wastes	23	2,116	0.8	0.6
Forestry Residues ²	187-200	17,204-18,400	6.6-7.0	4.7-5.0
Standing Forest Vegetation	20	1,840	0.7	0.5
TOTALS	422-481	38,824-44,252	14.8-16.8	10.7-12.2
Silvaculture ³ Energy Farms	270-300	24,840-27,600	9.5-10.5	6.8-7.6

NOTES

- 1 Conversion factor of approximately 92 gallons of methanol per dry ton of biomass.
- 2 Assumes all are collected and converted to methanol.
- 3 Not available (practically) for several years. Availability could increase with technology advancements.
- 4 Calculated based on methanol's lower heating value of 56,560 Btu per gallon, and one quad equal to 10^{15} Btu.

TABLE VI-2, ETHANOL POTENTIALLY SUPPLIED FROM CROP SURPLUSES

RESOURCE (CROP)	AVAILABILITY (MILLIONS OF BUSHELS PER YEAR)	ETHANOL VOLUME ¹ (MILLIONS OF GALLONS PER YEAR)	% OF 1978 MOTOR GASOLINE ENERGY (14.8 QUADS) ²	% OF 1978 TOTAL TRANSPORTATION ENERGY (20.6 QUADS) ²
Corn	532	1,383	0.70	0.51
Sorghum	60	150	0.08	0.06
Oats	225	236	0.12	0.09
Barley	123	252	0.13	0.09
Wheat	638	1,595	0.83	0.59
TOTALS	1,578	3,616	1.86	1.34

NOTES

- 1 Conversion factors as follows: corn @ 2.6 gallons per bushel, sorghum @ 2.5 gallons per bushel, oats @ 1.05 gallons per bushel, barley @ 2.05 gallons per bushel, and wheat @ 2.5 gallons per bushel.
- 2 Calculated based on ethanol's lower heating value of 76,670 Btu per gallon, and one quad equal to 10¹⁵ Btu.

**TABLE VI-3, ETHANOL POTENTIALLY SUPPLIED FROM PLANTING
ANY SINGLE CROP ON AN ADDITIONAL 120 MILLION ACRES**

RESOURCE (CROP)	AVERAGE YIELD (BUSHELS PER ACRE)	AVAILABILITY (MILLIONS OF BUSHELS PER YEAR)	ETHANOL VOLUME ¹ (MILLIONS OF GALLONS PER YEAR)	% OF 1978 MOTOR GASOLINE ENERGY (14.8 QUADS) ²	% OF 1978 TOTAL TRANSPORTATION ENERGY (20.6 QUADS) ²
Corn	87.4	10,488	27,269	14.1	10.2
Sorghum	48.6	5,832	14,580	7.6	5.4
Oats	45.4	5,448	5,720	3.0	2.1
Barley	44.8	5,376	11,020	5.7	4.1
Wheat	30.3	3,636	9,090	4.7	3.4
Sugarcane	37.9 ³	(max.) 1,148 ^{4,5} (min.) 129 ^{4,5}	(max.) 26,232 (min.) 2,945	(max.) 13.6 (min.) 1.5	(max.) 9.8 (min.) 1.1
Sugar Beets	19.9 ³	2,388 ⁵	45,713	23.7	17.0

NOTES

- 1 Conversion factors as follows: corn @ 2.6 gallons per bushel, sorghum @ 2.5 gallons per bushel, oats @ 1.05 gallons per bushel, barley @ 2.05 gallons per bushel, wheat @ 2.5 gallons per bushel, sugarcane (containing 16% fermentable solids) @ 14 pounds of fermentable solids per gallon, and sugar beets (containing 13.4% fermentable solids) @ 14 pounds of fermentable solids per gallon.
- 2 Calculated based on ethanol's lower heating value of 76,670 Btu per gallon, and one quad equal to 10¹⁵ Btu.
- 3 Values quoted are in tons per acre.
- 4 A maximum of about 30.3 million acres in the U.S. are capable of producing sugarcane. Exclusion of land area for competing crops, urban area, topography, etc. reduce this area to less than 3.4 million acres.
- 5 Values quoted are in millions of tons per year.

crops. Note that the volume of ethanol so produced is not additive for all crops. Any combination of crops is also possible (although not illustrated in the table), but limited to a total of 120 million acres (except for sugarcane) planted and harvested. Recall from Section V that because of frost and water availability conditions in the mainland U.S., only about 30 million acres could be considered candidate land area for sugarcane agriculture. Considering the exclusion of competing crop land, urban area, topography, environmental impacts and crop risks would reduce this sizeable candidate area to less than 3.4 million acres. Cultivation of the entire candidate land area (30.3 million acres) is felt to be the upper limit that can be achieved during the mid-term, while 3.4 million acres of additional sugar crop planting/harvesting is considered achievable in the near-term, as are all other crops and the subsequent ethanol from them. The maximum amount of ethanol that could result from this additional acreage is an annual energy equivalent of nearly 24% of the 1978 motor gasoline usage. Additional residues and/or wastes that could result from crops produced on this additional 120 million acres (and subsequent conversion to methanol) have not been considered in this analysis.

Table VI-4 is a summary of Tables VI-1, VI-2, and VI-3, and includes estimates of reported overall process conversion efficiency and the range of reported alcohol fuel costs. The typical range of plant gate gasoline prices is also shown on Table VI-4 for comparison purposes. Note from this table that the costs for producing methanol (on both a volume and energy basis) are typically lower than those for ethanol.

**TABLE VI-4, SUMMARY OF ALCOHOLS POTENTIALLY SUPPLIED FROM
AVAILABLE BIOMASS MATERIALS AND ADDITIONAL CROP ACREAGE**¹

RESOURCE	CONVERSION PROCESS	ALCOHOL FUEL PRODUCT	OVERALL PROCESS CONVERSION EFFICIENCY	REPORTED COST ESTIMATES (PLANT GATE) ²		% OF 1978 MOTOR GASOLINE ENERGY (14.8 QUADS)	% OF 1978 TOTAL TRANSPORTATION ENERGY (20.6 QUADS)
				DOLLARS/ GALLON	DOLLARS/ MILLION Btu		
1. Municipal Solid Wastes	Gasification/ Synthesis	Methanol	0.25-0.40	0.60-2.18	10.6-38.6	3.2	2.3
2. Crop Residues	"	"	0.48-0.68	0.35-1.14	6.2-20.2	3.5-5.1	2.5-3.7
3. Forestry Wastes	"	"	"	"	"	0.8	0.6
4. Forestry Residues	"	"	"	"	"	6.6-7.0	4.7-5.0
5. Standing Forest Vegetation	"	"	"	0.35-1.00	6.2-17.7	0.7	0.5
MAXIMUM IMMEDIATE METHANOL SUPPLY POTENTIAL (1 through 5)						14.8-16.8	10.7-12.2
6. Silviculture Energy Farms	Gasification/ Synthesis	Methanol	0.48-0.68	0.40-1.42	7.0-25.2	9.5-10.5	6.8-7.6
MAXIMUM METHANOL SUPPLY POTENTIAL (1 through 6)						27.3	19.7
7. Surplus Crops							
o Corn	Fermentation/ Distillation	Ethanol	0.15-0.50	1.00-1.55	13.2-20.5	0.70	0.51
o Sorghum	"	"	"	"	"	0.08	0.06
o Oats	"	"	"	"	"	0.12	0.09
o Barley	"	"	"	"	"	0.13	0.09
o Wheat	"	"	"	"	"	0.83	0.59
MAXIMUM IMMEDIATE ETHANOL SUPPLY POTENTIAL (7)						1.96	1.34
Additional 120 Million Acres							
8. Corn	Fermentation/ Distillation	Ethanol	0.15-0.50	1.00-1.55	13.2-20.5	14.1	10.2
9. Sorghum	"	"	"	"	"	7.6	5.4
10. Oats	"	"	"	"	"	3.0	2.1
11. Barley	"	"	"	"	"	5.7	4.1
12. Wheat	"	"	"	"	"	4.7	3.4
13. Sugarcane ³	"	"	"	"	"	13.6 (max) 1.5 (min)	9.8 (max) 1.1 (min)
14. Sugar Beets	"	"	"	"	"	23.7	17.0
MAXIMUM NEAR-TERM ETHANOL SUPPLY POTENTIAL (14)						23.7	17.0
MAXIMUM ETHANOL SUPPLY POTENTIAL (7 plus 13 plus 75% of 14) ⁴						33.24	23.99
MAXIMUM TOTAL ALCOHOL SUPPLY POTENTIAL (METHANOL AND ETHANOL)						60.54	43.59

NOTES

1 See explanatory notes from Tables VI-1, VI-2 and VI-3.

2 Cost data from several sources that, for uniformity, have been adjusted to 1978 dollars. For comparison purposes, plant gate gasoline prices ranged from \$0.41 per gallon to \$0.50 per gallon (3.5-4.3 dollars per million Btu) during the same time frame.

3 Only 30.3 million acres maximum (mid-term) and 3.4 million acres minimum (near-term) are available for additional sugarcane production.

4 Represents the summation of immediate, near-term and mid-term supply potential; therefore, the largest volume of ethanol would be produced by utilizing all 30.3 million acres for sugarcane (mid-term) and 89.7 million acres (120 minus 30.3) for sugar beets.

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TABLE A-1

NUMBER OF FARMS AND LAND IN FARMS

United States, 1965-76
By States, 1974-76

Released:
December 30, 1975
3:00 P.M. ET

FARM NUMBERS DECLINED ONE PERCENT

Farm numbers totaled 2,808,480 in the United States during 1975, one percent fewer than in 1974. The 1976 preliminary estimate of 2,785,780 is also one percent less than the previous year.

The estimated total land in farms of 1,086 million acres in 1975 is slightly less than 1974. The preliminary estimate for 1976 at 1,085 million is down slightly from 1975.

The average size of farm has increased 47 acres during the past decade. The 1975 average of 387 acres is 3 acres larger than 1974 and the 1976 average of 389 acres continues the upward trend.

NUMBER OF FARMS AND LAND IN FARMS, U.S. 1965-76

YEAR	FARMS	LAND IN FARMS	AVERAGE SIZE OF FARMS
	THOUSANDS	THOUSAND ACRES	ACRES
1965	3,356	1,139,597	340
1966	3,257	1,131,844	348
1967	3,162	1,123,456	355
1968	3,071	1,115,231	363
1969	2,999	1,107,711	369
1970	2,954	1,102,769	373
1971	2,909	1,097,300	377
1972	2,870	1,093,017	381
1973	2,844	1,089,530	383
1974	2,830	1,087,788	384
1975	2,808	1,086,025	387
1976 ^{1/}	2,786	1,084,671	389

^{1/} PRELIMINARY.

UNITED STATES DEPARTMENT OF AGRICULTURE
STATISTICAL REPORTING SERVICE CROP REPORTING BOARD
SpSy 3 (12-75) WASHINGTON, D.C. 20250

TABLE A-2, NUMBER OF FARMS AND LAND IN FARMS,
BY STATES, 1974-76

STATE	FARMS			LAND IN FARMS		
	1974	1975	1976 1/	1974	1975	1976 1/
	NUMBER			1,000 ACRES		
ALA	78,000	77,000	77,000	14,600	14,700	14,700
ALAS 2/	310	300	300	1,710	1,710	1,710
ARIZ	5,900	5,800	5,700	38,400	38,000	37,500
ARK	69,000	69,000	69,000	17,300	17,300	17,400
CALIF	63,000	63,000	63,000	36,100	36,000	36,000
COLO	29,500	29,500	29,500	39,900	39,900	39,900
CONN	4,400	4,400	4,400	540	540	540
DEL	3,600	3,500	3,500	698	697	696
FLA	34,000	33,000	32,000	14,500	14,200	14,000
GA	75,000	74,000	73,000	17,000	17,000	17,000
HAW	4,300	4,300	4,300	2,300	2,300	2,300
IDAHO	27,200	26,900	26,500	15,500	15,600	15,600
ILL	126,000	124,000	122,000	29,200	29,100	29,100
IND	106,000	106,000	105,000	17,500	17,500	17,500
IOWA	138,000	136,000	135,000	34,300	34,200	34,200
KANS	83,000	81,000	79,000	49,900	49,900	49,900
KY	126,000	125,000	124,000	16,200	16,100	16,000
LA	48,000	47,000	47,000	11,800	11,800	11,900
MAINE	7,600	7,600	7,600	1,710	1,710	1,710
MD	17,800	17,600	17,600	2,955	2,940	2,925
MASS	5,800	5,800	5,800	710	710	710
MICH	80,000	80,000	80,000	12,300	12,400	12,400
MINN	118,000	118,000	118,000	30,600	30,600	30,600
MISS	85,000	84,000	84,000	17,200	17,100	17,100
MO	139,000	139,000	139,000	32,800	32,700	32,700
MONT	24,600	23,500	22,500	62,500	62,400	62,400
NEBR	69,000	68,000	68,000	48,100	48,000	48,000
NEV	2,000	2,000	2,000	9,000	9,000	9,000
N H	2,600	2,600	2,600	560	560	560
N J	8,000	7,900	7,900	1,030	1,025	1,025
N MEX	11,800	11,800	11,700	47,200	47,200	47,100
N Y	57,000	58,000	58,000	11,200	11,400	11,400
N C	135,000	130,000	125,000	14,000	13,600	13,200
N DAK	41,500	41,000	40,000	41,700	41,600	41,600
OHIO	117,000	117,000	116,000	17,400	17,400	17,300
OKLA	87,000	87,000	86,000	36,900	36,800	36,800
OREG	32,500	32,500	32,500	19,600	19,500	19,500
PA	71,000	72,000	73,000	9,900	10,008	10,220
R I	680	680	680	65	65	65
S C	47,000	47,000	47,000	7,800	7,800	7,800
S DAK	43,500	43,000	43,000	45,500	45,500	45,500
TENN	125,000	125,000	124,000	15,400	15,400	15,300
TEX	209,000	207,000	205,000	141,800	141,800	141,800
UTAH	12,600	12,600	12,600	13,000	13,000	13,000
VT	6,600	6,600	6,600	1,860	1,860	1,860
VA	73,000	73,000	72,000	11,100	11,100	11,000
WASH	40,000	40,000	40,000	16,500	16,500	16,500
W VA	26,500	26,500	26,500	4,850	4,800	4,750
WIS	105,000	104,000	103,000	19,600	19,500	19,400
WYO	8,200	8,100	8,000	35,500	35,500	35,500
U S	2,830,490	2,808,480	2,785,780	1,087,788	1,086,025	1,084,671

1/ PRELIMINARY. 2/ EXCLUSIVE OF GRAZING LAND LEASED FROM U S GOVERNMENT, ALASKA FARMLAND TOTALS ABOUT 70,000 ACRES.

**TABLE A-3, LAND CAPABILITY CLASSES AS REPORTED BY THE
U.S. SOIL CONSERVATION SERVICE**

Class	Capability and Precautions	Primary
(Suitable for Cultivation)		
I	Excellent land, flat, well-drained. Suited agriculture with no special precautions other than good farming practice.	Agriculture
II	Good land with minor limitations, such as slight slope, sandy soils or poor drainage. Suited to agriculture with precautions such as contour farming, strip cropping, drainage, etc.	Agriculture Pasture
III	Moderately good land with important limitations caused by soil, slope or drainage. Requires long rotation with soil-building crops, contouring or terracing, strip cropping or drainage, etc.	Agriculture Pasture Watershed
IV	Fair land with severe limitations caused by soil, slope or drainage. Suited only to occasional or limited cultivation.	Pasture Tree crops Agriculture Urban-industrial
(Not Suitable for Cultivation)		
V	Land suited to forestry or grazing without special precautions other than normal good management.	Forestry Range Watershed
VI	Suited to forestry or grazing with minor limitations caused by danger from erosion, shallow soils, etc. Requires careful management.	Forestry Range Watershed Urban-industrial
VII	Suited to grazing or forestry with major limitations caused by slope, low rainfall, soil, etc. Use must be limited and extreme care must be taken.	Watershed Recreation Wildlife Forestry Range Urban-industrial
VIII	Unsuited to grazing or forestry because of absence of soil, steep slopes, extreme dryness or wetness	Recreation Wildlife Watershed Urban-industrial

TABLE A-3, LAND CAPABILITY CLASSES AS REPORTED BY THE
U.S. SOIL CONSERVATION SERVICE (Con't.)

Subclasses are groups of capability units within classes that have the same kinds of dominant limitations for agricultural use as a result of soil and climate. Some soils are subject to erosion if they are not protected, while others are naturally wet and must be drained if crops are to be grown. Some soils are shallow or droughty or have other soil deficiencies. Still other soils occur in areas where climate limits their use. The four kinds of limitations recognized at the subclass level are: Risks of erosion, designated by the symbol (e); wetness, drainage, or overflow (w); rooting-zone limitations (s); and climate limitation (c). The subclass provides the map user information about both the degree and kind of limitation. Capability Class I has no subclasses.

Subclass (e) erosion is made up of soils where the susceptibility to erosion is the dominant problem or hazard in their use. Erosion susceptibility and past erosion damage are the major soil factors for placing soils in this subclass.

Subclass (w) excess water is made up of soils where excess water is the dominant hazard or limitation in their use. Poor soil drainage, wetness, high water table, and overflow are the criteria for determining which soils belong in this subclass.

Subclass (s) soil limitations within the rooting zone includes, as the name implies, soils that have such limitations as shallowness of rooting zones, stones, low moisture-holding capacity, low fertility difficult to correct, and salinity or sodium.

Subclass (c) climatic limitation is made up of soils where the climate (temperature or lack of moisture) is the only major hazard or limitation in their use.

TABLE A-4, NATIONAL SUMMARY OF LAND USE IN 1975 BY CAPABILITY CLASS AND SUBCLASS
(ESTIMATED ACRES) AS REPORTED BY THE U.S. SOIL CONSERVATION SERVICE

CLASS & SUBCLASS	CROPLAND	PASTURE AND RANGE	FOREST	OTHER LAND	SUBTOTAL	URBAN	WATER	TOTAL
1-	33388980	6150619	2162593	2011521	43713713	1142967	158331	45015011
2E	87594192	32011225	19085897	6319184	145010498	3024380	126821	148161699
2W	60116021	12280904	14973878	4022246	91393049	1262321	526807	93182177
2S	20450742	2714560	2932839	600735	26698876	575740	48720	27324336
2C	19708624	9772755	587811	581592	30650782	55235	0	30706017
3E	70350772	64141567	27591006	7130100	169213445	1863717	151792	171248954
3W	31376759	13609130	26459233	5685439	77130561	1322953	1589632	80043146
3S	11454939	6971638	6965719	1412403	26808699	320311	0	27129010
3C	9661823	3257362	0	125249	13044464	49608	0	13094072
4E	29693256	52829804	26639428	3688795	112851283	1531727	262886	114645896
4W	3965105	7194259	20871338	2653411	34687113	581111	194810	35463034
4S	5904076	9144931	10242864	2121564	27413435	728050	0	28141485
4C	334266	1548504	0	0	1982770	0	0	1882770
5W	1497320	7503453	16839590	2222596	28062959	221779	670436	28955174
5S	31844	1125464	890656	0	2047964	27781	0	2075745
6E	8794249	123060745	37244441	2239091	171338526	1250788	260154	172849468
6W	562472	3750228	6097512	1181867	11592179	53193	49225	11694597
6S	3501723	40740779	31694342	2027682	77964226	414710	29401	78408337
6C	362024	10678892	0	108202	11149118	70874	0	11219992
7 - 8	1664360	162393894	124185115	25698649	313922218	2111369	2639723	318679309
TOTAL	400416747	570880743	375448062	69830326	1416575878	16635613	6708738	1439920229

TABLE A-5, NATIONAL SUMMARY OF CHANGES IN LAND USE BETWEEN 1967 AND 1975
(ESTIMATED ACRES) AS REPORTED BY THE U.S. SOIL CONSERVATION SERVICE

LAND USE IN 1967	LAND USE IN 1975							
	CROPLAND	PASTURE AND RANGE	FOREST	OTHER LAND	SUBTOTAL	URBAN	WATER	TOTAL
CROPLAND	351651353	52883790	8265402	12976896	425777441	4846473	617636	431241550
PASTURE AND RANGE	31907204	442351639	14095521	14178060	502532424	3210542	1111535	506854501
FOREST	11026751	62469077	348681283	15801145	437978256	4422411	2152205	444552872
OTHER LAND	5831439	13176237	4405856	26874225	50287757	4156187	2827362	57271306
TOTAL	400416747	570880743	375448062	69830326	1416575878	16635613	6708738	1439920229

**TABLE A-6, NATIONAL SUMMARY OF POTENTIAL CROPLAND AND DEVELOPMENT NECESSARY
BY TYPE OF PROBLEM (ESTIMATED ACRES) AS REPORTED BY THE
U.S. SOIL CONSERVATION SERVICE**

POTENTIAL	DEVELOPMENT NECESSARY	PROBLEM						
		NONE	SMALL TRACT	ISOLATED TRACT	SMALL OWNERSHIP UNIT	HELD FOR URBAN USE	COMMITTED TO NONCROP- LAND USES	SHORT GROWING SEASON
HIGH:	NONE	23187815	641811	345235	645717	13257	1718	0
	ON-FARM	11715919	1943713	473727	1139753	0	610224	65188
	MULTI-FARM	0	26090	0	93529	0	0	0
	PROJECT ACTION	0	12153	795729	0	0	0	0
	TOTAL	34903734	2623767	1614691	1878999	13257	611942	65188
MEDIUM:	NONE	46402	523310	81548	976260	221435	853114	1209799
	ON-FARM	19799	1587891	1587311	631101	183947	4908968	87831
	MULTI-FARM	0	102758	0	0	33244	90344	0
	PROJECT ACTION	0	43646	134490	28271	0	167988	1130758
	TOTAL	66201	2257605	1803349	1635632	238626	6020414	2428388
LOW :	NONE	70998	4362586	2007146	1611650	1554793	7651981	848748
	ON-FARM	139250	22156364	34884990	17220870	7427841	88503269	10416730
	MULTI-FARM	0	750428	993965	1057104	742576	2769947	296213
	PROJECT ACTION	0	2003013	17759110	1289609	706103	24313197	7689864
	TOTAL	210248	29272391	55645211	21179233	10531313	123238394	19251555
ZERO:	- - -	0	11589117	44084504	11069421	12539349	96089072	31392621

**TABLE A-6, NATIONAL SUMMARY OF POTENTIAL CROPLAND AND DEVELOPMENT NECESSARY
BY TYPE OF PROBLEM (ESTIMATED ACRES) AS REPORTED BY THE
U.S. SOIL CONSERVATION SERVICE (con't.)**

POTENTIAL	DEVELOPMENT NECESSARY	PROBLEM						
		LACKING DEPENDABLE WATER	HIGH DENSITY FOREST	ENVIRON- MENTAL IMPACT	EROSION CONTROL COSTS	DRAINAGE OUTLET PROBLEM	SEEPAGE	SEASONAL HIGH WATER TABLE
HIGH:	NONE	844891	110224	787185	624769	122572	27917	895056
	ON-FARM	2871537	8272582	731138	5365539	1148486	1092720	8131850
	MULTI-FARM	434143	355712	0	369355	372140	70835	845788
	PROJECT ACTION	1172292	589519	35182	408296	552954	0	1103123
	TOTAL	5322863	9328033	1553505	6767959	2196152	1191472	10975817
MEDIUM:	NONE	48768	46138	0	272766	3905	8465	29671
	ON-FARM	910622	6066315	923214	6882890	639799	428725	2819879
	MULTI-FARM	345088	248605	0	93882	278707	115669	836396
	PROJECT ACTION	612919	675256	1175784	197275	1517129	18010	1879601
	TOTAL	1917397	7036314	2098998	7446813	2439540	570869	5565547
LOW :	NONE	1406431	524066	161543	2013363	121637	76551	669080
	ON-FARM	29540074	75000911	7272656	51388745	11139372	5119096	36564187
	MULTI-FARM	1817577	6390967	305570	1437687	6877870	495984	8158319
	PROJECT ACTION	28822943	11566968	4211062	4162759	5396998	462885	10655823
	TOTAL	51587025	93482912	11950831	59002554	23535877	6154516	56047409
ZERO:	- - -	59897863	84908494	32876191	92998202	19276554	2825539	29714885

**TABLE A-6, NATIONAL SUMMARY OF POTENTIAL CROPLAND AND DEVELOPMENT NECESSARY
BY TYPE OF PROBLEM (ESTIMATED ACRES) AS REPORTED BY THE
U.S. SOIL CONSERVATION SERVICE (con't.)**

POTENTIAL	DEVELOPMENT NECESSARY	PROBLEM						
		WETLAND TYPES 3-20	COMMON FLOODING	HIGH EROSION HAZARD	THICK UNDESIRABLE OVERBURDEN	VERY LOW FERTILITY	STONES OR ROCK OUTCROP	ACCUM- ULATION OF SALTS
HIGH:	NONE	0	1104665	4088773	0	1601539	73266	58376
	ON-FARM	72235	2187201	9694204	135239	2869335	1098130	425367
	MULTI-FARM	0	358962	11111	0	365979	335709	11998
	PROJECT ACTION	0	1140068	352114	0	0	0	0
	TOTAL	72236	4790896	14146202	135239	4836853	1507105	495741
MEDIUM:	NONE	0	0	1887784	24679	267206	4828	175421
	ON-FARM	93332	2155905	8762408	3504	2739197	1921250	39708
	MULTI-FARM	0	621431	115236	0	106831	0	0
	PROJECT ACTION	15712	1374015	0	0	1130758	0	131748
	TOTAL	109044	4151351	10765428	28183	4243992	1926078	346877
LOW :	NONE	0	642439	5217293	203626	1255399	687572	33020
	ON-FARM	2489083	17254766	71357192	2740645	34186428	18872030	1241363
	MULTI-FARM	1865533	3358067	1281668	95956	857800	947676	476388
	PROJECT ACTION	1559433	12474993	7328502	105699	5567026	2581095	3402187
	TOTAL	5913969	33730265	85184655	3145926	41866653	23088373	5152958
ZERO:	- - -	7447874	24827931	139135138	3159849	67335076	66957730	4797968