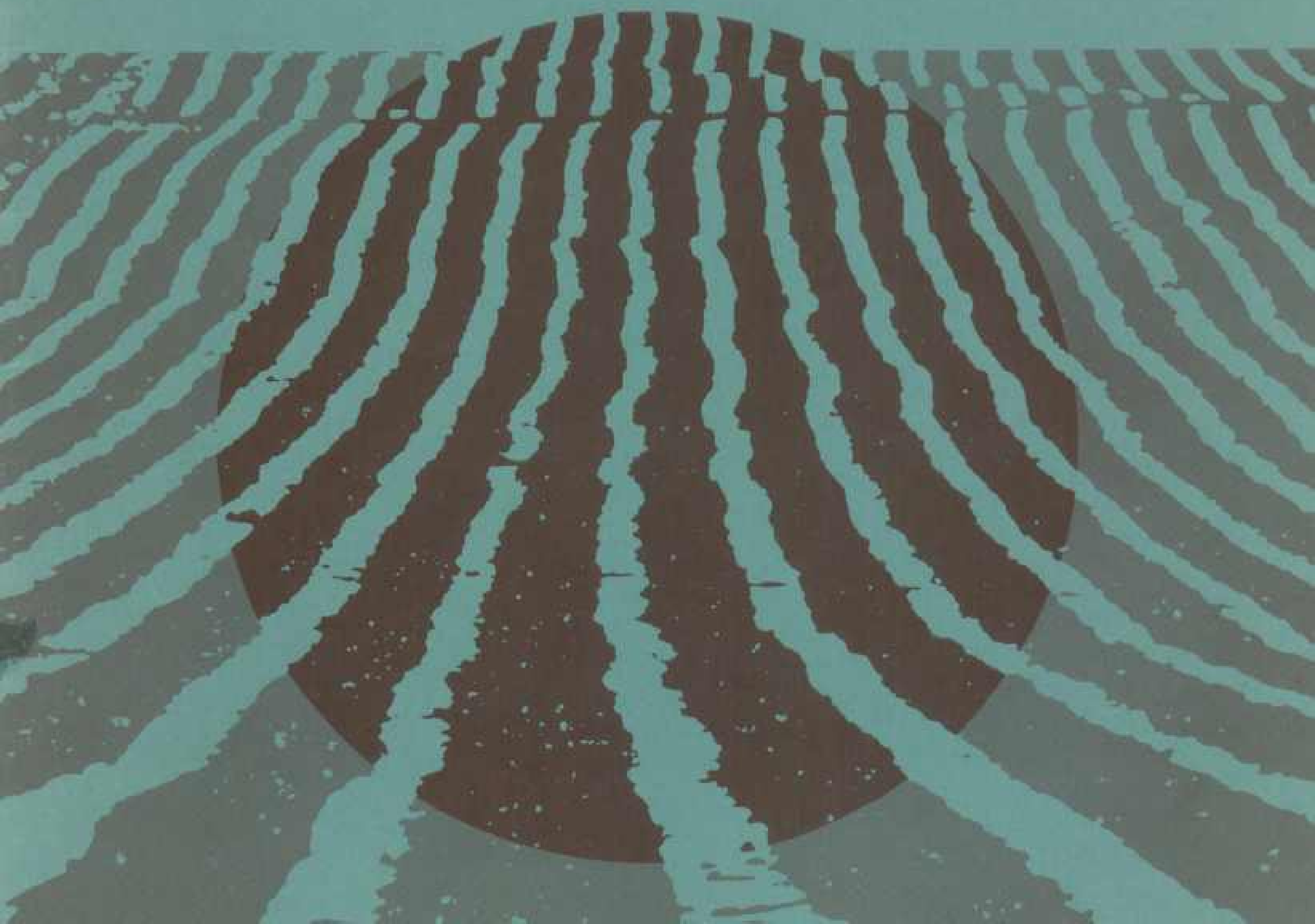
United States
Department of
Agriculture

Economic
Research
Service

Agricultural
Economic
Report
Number 523

# Turning Great Plains Crop Residues and Other Products into Energy

Walter G. Heid, Jr.



**Turning Great Plains Crop Residues and Other Products into Energy,** by Walter G. Heid, Jr., Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 523.

## Abstract

Crop residues, such as corn stover, grain sorghum stover, and wheat straw, are abundant sources of fuel energy in the 10-State Great Plains region. These residues and other wastes, such as manure, may be either burned directly or decomposed into methane gas. However, costs of collecting these residues may be too high to be competitive with coal or other conventional fuels. Bulky crop residues and wastes, expensive to transport, can be economically shipped no more than 50 miles to a conversion plant.

Keywords: Crop residues, municipal solid waste, Great Plains, biomass, energy.

## Acknowledgments

The author expresses appreciation to the many individuals in the energy fields of government, education, and private industry, who supplied information and advice. Special acknowledgment is extended to Verel Benson, formerly with the Natural Resource Economics Division (NRED), Economic Research Service, Lincoln, NE; Edward L. Skidmore, Agricultural Research Service, Manhattan, KS; Jerry S. Lee, Soil Conservation Service, Washington, DC; and William Quinby, NRED, Washington, DC.

## Note

Use of brand or company names in this publication is for identification only and does not imply endorsement by the U.S. Department of Agriculture.

Washington, D.C. 20250 November 1984

# Contents

## Summary

Crop residues, such as corn stover, grain sorghum stover, and wheat straw, are abundant sources of fuel energy in the 10-State Great Plains region. These residues and other wastes, such as manure, may be either burned directly or decomposed into methane gas. However, costs of collecting these residues may be too high to be competitive with coal or other conventional fuels. Bulky crop residues and wastes, expensive to transport, can be shipped economically no more than 50 miles to a conversion plant.

The most economical use of crop residues may be to complement the use of other waste products in generating electricity. Crop residues, which are seasonal, can be combined with livestock manure, agricultural processing wastes, and municipal solid wastes. Municipalities and some processing firms began using the direct burning process in the early eighties. Because crop residues can be stored, they may help to even out supplies of waste products, thus enabling municipalities to use their conversion plants more fully while providing farmers with a market for another product.

For short-distance hauls, crop residues were competitive with coal in the early eighties. Great Plains crop residues were delivered 10 miles to off-farm conversion sites for about $29 per ton (1982 dollars), or $2.07 per million British thermal units (Btu). However, a 50-mile haul cost an additional $22 per ton.

The availability and removal of crop residues raise at least two important policy issues. First the ethical issue of using cropland for fuel production instead of food or feed production may disturb some groups; once conversion plants are constructed, some cropland may be used specifically to produce forages for fuel. The second issue concerns erosion. Much of the Great Plains is susceptible to wind and water erosion. Shortrun gains from the sale of crop residues may remove too much residue and cause serious long-term soil depletion.

Finally, the study addresses several issues that must be considered in the process of choosing the type of conversion plant, its size, and location. These issues include: variations in yield and acreage of principal crops, the feed and fertilizer value of crop residues, storage losses, and the effects of minimum tillage.

## Glossary

**Aftermath grazing:** The practice of allowing livestock to graze the stubble remaining after grain harvest.

**Biomass:** Organic, cellulose materials such as plants, shrubs, trees, or animal manure that can be converted either biologically or thermochemically into fuel (energy).

**CRD:** Crop Reporting Districts, a method used by the State Crop and Livestock Reporting Boards to divide States into smaller areas for convenience in compiling and presenting statistical information.

**FEDS:** Firm Enterprise Data System, the ERS farm budget generating system used at Oklahoma State University.

**K-factor:** A percentage estimate representing the portion of crop residue that cannot be removed from the soil without causing harmful erosion.

**MLRA:** Major Land Resource Area.

**NIRAP:** National-Interregional Agricultural Projections System.

**SERI:** Solar Energy Research Institute.

## Sales Information

Additional copies of this report can be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Ask for the report by name, and write to the above address for price information or call the GPO order desk at (202) 783-3238. You can also charge your purchase to your VISA, MasterCard, or GPO Deposit Account. Bulk discounts available. Foreign address customers, please add 25 percent extra for postage.

Microfiche copies ($4.50 each) can be purchased from the National Technical Information Service, Identification Section, 5285 Port Royal Road, Springfield, VA 22161. Ask for the report by name. Enclose check or money order, payable to NTIS. For additional information, call NTIS at (703) 487-4780.

The Economic Research Service has no copies for free mailing.

# Turning Great Plains Crop Residues and Other Products into Energy

**Walter G. Heid, Jr.***

## Introduction

In times of high energy prices and scarce energy supplies the world seeks alternative energy sources. Economical conversion of crop residues into energy, could ease future energy-shortage problems. Since the 1970's, most of the interest in using agricultural products for fuel production focused on the conversion of grain to ethanol. However, the potential conflict between food, feed, and fuel uses of grain has stimulated interest in using agricultural residues and wastes to produce energy.

This report is part of a national biomass study being conducted by the Economic Research Service (ERS) to identify the quantity, location, and seasonal availability of agricultural biomass suitable for on- and off-farm conversion to energy; to estimate regional costs of collection, transportation, and storage; and to assess the potential economical, institutional, and environmental constraints to converting agricultural biomass to fuels. This report addresses a number of issues associated with the use of crop residues for fuel production and projects the tonnage of crop residues to 1990 in the 10-State Great Plains region.

Figure 1

**The 10-State Great Plains Region**


## Background

The 10-State Great Plains region stretches from North Dakota and Montana to New Mexico and Texas (fig. 1). Annual rainfall gradually increases from 16 inches or less in the West to nearly 40 inches along the eastern edge of the Plains. From west to east, the terrain changes from rugged mountains and the High Plains area to the Red, Sioux, and Missouri River bottomlands. A vast expanse of generally flat terrain spans the central Plains and is subject to frequent strong southwesterly winds. The Great Plains tend to have a higher wind speed during the crop-growing season than any other region of the United States, especially during the critical summer months (*16*).[1]

The Great Plains region is an abundant source of grain for the world. In 1980 the region (North Dakota, South Dakota, Nebraska, Montana, Wyoming, Colorado, Kansas, New Mexico, Oklahoma, and Texas) harvested

* Heid formerly served as an agricultural economist with the Economic Research Service, U.S. Department of Agriculture, stationed at the U.S. Grain Marketing Research Laboratory, Manhattan, KS.

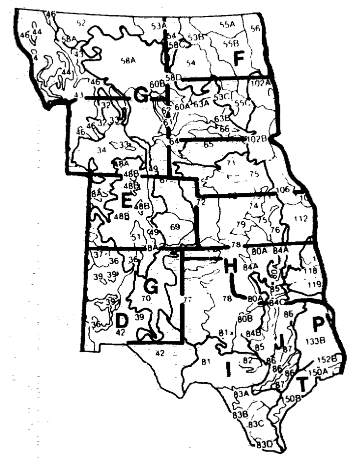
[1]Italicized numbers in parentheses cite sources listed in the Bibliography section.

most major crops, excluding hay, on over 62 million acres. Most U.S. wheat grows on the Great Plains. Other major crops include grain sorghum, corn, barley, oats, soybeans, and cotton. Grain crops grow in a crop-fallow rotation in the dryland west. Farmers tap the Ogallala Aquifer to irrigate in the High Plains. In the higher rainfall area of the central and eastern Great Plains, continuous cropping is the normal practice. In times of surplus grain production, Government programs often idle large acreages there.

Parts of the Great Plains still suffer occasional desert-like conditions because of the flat terrain, low rainfall, and high wind. Farmers must manage their cropping and fallowing practices to allow for these conditions. Summer fallow over much of the western and northern Great Plains and stubble management throughout the center of the Great Plains, from Texas to North Dakota, limit the amount of crop residues which are available for removal. However, in areas where rainfall is more plentiful or irrigation is practiced, high tonnages of crop residues result.

Figure 2

**Major Land Resource Areas in the Great Plains[1]**



[1] Letters indicate land resource regions; numbers indicate major land resource areas. For legend, see (47).

## Methodology

The 10 States had a 1979-82 cropland base of about 187 million acres. The effective base for biomass production excludes 29 million acres of potential cropland which is either idle or in pasture and excludes about 23 million acres devoted to summer fallow and nearly 6 million acres of crop failure on which no production is assumed. Thus the Great Plains' effective farmland base is approximately 129 million acres. The 1978 Census of Agriculture likewise reported about the same base of cropland acres. The National-Interregional Agricultural Projections System's (NIRAP) 1990 projections reflect about the same amount of effective cropland acres for the Great Plains (table 1). NIRAP projects State totals for dryland and irrigated farming practices. The NIRAP data are the basis for the 1990 projections made in this study (*43*).

ERS's Natural Resource Economics Division in Lincoln, NE, grouped these 1978 county data by major land resource areas (MLRA's) (fig. 2).[2] These data also reported both dryland and irrigated harvested acreages.

Before the author expanded the base acreage to 1990 production levels, he adjusted NIRAP State yield projections for each crop to reflect the productivity of soils in MLRA's which were matched as closely as possible to State Crop and Livestock Reporting Services' Crop Reporting Districts (CRD's). Then the variation of CRD yields from State averages for the base period was applied to the NIRAP State yield projections for each crop. Yield coefficients derived through this process served to adjust the harvestable acreage of each crop in each State.

Next the author adjusted the harvestable acres downward from the effective base of 129 million acres to exclude acreage on which residue cannot be removed because of potential soil erosion. This adjustment used crop residue management data, assuming conventional tillage practices (*33*).

The author applied wind and water coefficients to the Great Plains.[3] The wind erosion coefficients are much more conservative than those Larson derived for pre-

[2]Areas of cropland having homogeneous soil and topographical characteristics.

[3]Skidmore and others determined mean soil erodibility and climatic factors for each of 29 MLRA's in the heart of the Great Plains and used these K-factor coefficients to estimate the residues needed to control wind erosion (fig. 1 and table 2).

**Table 1—National Interregional Agricultural Projections Systems 1990 acreage projection, by crop, 10 Great Plains States**

| Crop | Montana | North Dakota | South Dakota | Wyoming | Nebraska | Kansas | Colorado | Oklahoma | Texas | New Mexico | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *1,000 acres* | | | | | |
| Wheat | 6,448 | 10,668 | 2,812 | 290 | 3,444 | 12,902 | 2,812 | 7,537 | 4,529 | 398 | 51,840 |
| Rye | 3 | 86 | 77 | 3 | 24 | 9 | 4 | 20 | 15 | — | 241 |
| Corn | 11 | 440 | 2,376 | 40 | 7,096 | 1,529 | 814 | 74 | 1,489 | 84 | 13,953 |
| Silage | 48 | 303 | 801 | 38 | 423 | 221 | 246 | 42 | 110 | 20 | 2,252 |
| Oats | 181 | 1,059 | 2,285 | 49 | 383 | 115 | 26 | 92 | 625 | — | 4,815 |
| Barley | 1,104 | 1,831 | 371 | 210 | 6 | 58 | 573 | 115 | 166 | 49 | 4,483 |
| Sorghum | — | 431 | 381 | — | 2,334 | 3,774 | 253 | 488 | 3,547 | 150 | 11,358 |
| Flax | 1 | 440 | 219 | — | — | — | — | — | 27 | — | 687 |
| Sugar beets | 59 | 235 | — | 60 | 81 | 26 | 90 | — | 19 | 2 | 572 |
| Dry beans | 8 | 107 | — | 21 | 120 | 11 | 117 | — | — | — | 384 |
| Potatoes | 5 | 122 | 2 | 3 | 3 | 1 | 43 | — | 24 | 3 | 206 |
| Hay | 1,910 | 3,977 | 5,228 | 1,055 | 4,118 | 1,985 | 1,017 | 1,733 | 2,322 | 260 | 23,605 |
| Sweetpotatoes | — | — | — | — | — | — | — | — | 6 | — | 6 |
| Cotton | — | — | — | — | — | — | — | 617 | 5,715 | 137 | 6,469 |
| Sugarcane | — | — | — | — | — | — | — | — | 39 | — | 39 |
| Rice | — | — | — | — | — | — | — | — | 518 | — | 518 |
| Peanuts | — | — | — | — | — | — | — | 98 | 345 | 10 | 453 |
| Dry peas | — | 1 | — | — | — | — | — | — | — | — | 1 |
| Soybeans | — | — | 736 | — | 1,771 | 1,577 | — | 533 | 954 | — | 5,571 |
| Citrus fruit | — | — | — | — | — | — | — | — | — | — | 51 |
| Noncitrus fruit | — | — | — | — | — | 2 | 6 | 54 | 487 | 15 | 564 |
| Vegetables and melons | 1 | — | 2 | 4 | — | — | 18 | 9 | 297 | 18 | 349 |
| Subtotal | 9,779 | 19,700 | 15,288 | 1,773 | 19,803 | 22,210 | 6,019 | 11,412 | 21,285 | 1,148 | 128,417 |
| Other crops | 58 | 209 | 110 | 15 | 127 | 159 | 254 | 208 | 265 | 58 | 1,463 |
| Total | 9,837 | 19,909 | 15,398 | 1,788 | 19,930 | 22,369 | 6,273 | 11,620 | 21,550 | 1,206 | 129,880 |
| Less double-cropping | 17 | 30 | 48 | 3 | 83 | 334 | 34 | 139 | 147 | 12 | 847 |
| Total harvested | 9,820 | 19,879 | 15,350 | 1,785 | 19,847 | 22,035 | 6,239 | 11,481 | 21,403 | 1,194 | 129,033 |
| Failure | 499 | 852 | 652 | 58 | 575 | 846 | 249 | 833 | 1,253 | 35 | 5,852 |
| Pasture and idle | 1,243 | 2,423 | 1,084 | 540 | 568 | 2,602 | 1,277 | 1,911 | 16,763 | 1,053 | 29,464 |
| Summer fallow | 4,903 | 5,399 | 1,595 | 382 | 2,067 | 4,505 | 2,968 | 389 | 793 | 72 | 23,073 |
| Total cropland | 16,465 | 28,553 | 18,681 | 2,765 | 23,057 | 29,988 | 10,733 | 14,614 | 40,212 | 2,354 | 187,422 |

— = Not applicable.

Source: (*43*).

vention of water erosion.[4] In many of the Great Plains MLRA's, all residue should be kept on the land to protect the soil.

Skidmore's wind erosion estimates covered the portion of the Great Plains represented by the shaded area in figure 3. Larson's water erosion coefficients spanned the eastern and western edges of the Great Plains. After allowing for protection against these two causes of erosion, the author determined that at least some crop residue could be removed from about 45 million acres, or 35 percent, of the Great Plains cropland area.[5]

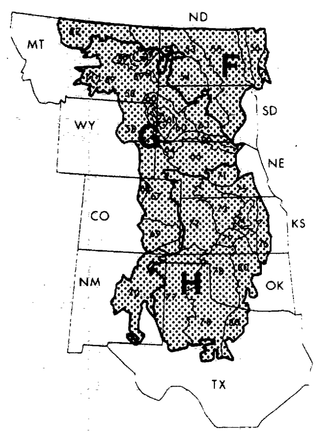
The author estimated crop production in these acres by using the NIRAP yields, adjusted to reflect soil productivity in each MLRA. Next, residue-to-grain ratios were applied to total grain production projections. By adjusting Larson's coefficients, the author applied the following residue-to-grain ratios to the Great Plains production projections data:[6]

| *Crop*[7] | *Ratio* |
|---|---|
| Corn (under 95 bu./acre) | 1.0:1 |
| Corn (95 bu./acre or more) | 1.5:1 |
| Spring wheat (including durum) | 1.3:1 |
| Winter wheat | 1.7:1 |
| Oats | 1.4:1 |
| Barley | 1.5:1 |
| Grain sorghum | 1.0:1 |
| Rye | 1.5:1 |
| Rice | 1.5:1 |
| Other small grains[8] | 1.5:1 |

The sum of total production multiplied by these residue ratios gives the total crop-residue production. Then the author adjusted total residue downward by what is generally known as the K-factor, the portion of residue that cannot be removed from the soil without causing harmful erosion effects (table 2). This downward adjustment produced the available residue tonnages reported in this study. The author did not include downward adjustments for aftermath grazing and storage losses in the Great Plains inventory estimates, although the importance of the adjustment is discussed later in the report.

Figure 3

**Area of Great Plains Where Crop Residue Removal is Restricted by Wind Erosion**




Reproduced with permission from the *Journal of Soil and Water Conservation (33).*

## Great Plains Crop Residues

For the purpose of this study, the author assumed that about the same acreage will be planted to crops in 1990 as was planted at the time of the 1978 Census of Agriculture. This assumption, of course, follows the belief that the area of land in the Great Plains still being converted to cropland will about offset the area being taken out of cropland for urban development and industrial expansion. The study does not consider the effects of soil erosion in the Great Plains, which could seriously damage 25 million acres.[9]

### Residue by Crop and State

In 1990, corn stover should account for a large percentage of the available residue in the Great Plains,

[4]Larson's data are reported in (39).
[5]As experience with crop residue removal is gained, it may be possible to safely remove residue from additional acres by harvesting it in strips or by employing high stubble cut.
[6]Larson's straw/grain ratios appear in (11).
[7]No availabe crop residue was assumed for cotton and soybeans, although Larson reports ratios of 1.0:1 and 1.5:1, respectively.
[8]Census of Agriculture does not identify all crop acreages. Therefore, in most States and MLRA's, available residue is reported but not listed as a specific type.

[9]This estimate is based on excess annual sheet and rill erosion (greater than 5 tons per acre) (47).

**Table 2—Derivation of K-factors for the Great Plains, by Major Land Resource Area and major crops**

| Land resource area[1] | Continuous wheat | | | Fallow wheat | | | Barley[2] | | | Oats | | | Corn | | | Sorghum | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Produced | Available | | Produced | Available | | Produced | Available | | Produced | Available | | Produced | Available | | Produced | Available | |
| | *— Tons/ha —* | | *Percent* | *— Tons/ha —* | | *Percent* | *— Tons/ha —* | | *Percent* | *— Tons/ha —* | | *Percent* | *— Tons/ha —* | | *Percent* | *— Tons/ha —* | | *Percent* |
| 52 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] |
| 53 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | 2.5 | 0.1 | 4 | [3] | [3] | [3] | [3] | [3] | [3] |
| 54 | [3] | [3] | [3] | [3] | [3] | [3] | 2.7 | 0.4 | 15 | 2.6 | .4 | 15 | [3] | [3] | [3] | [3] | [3] | [3] |
| 55 | [3] | [3] | [3] | [3] | [3] | [3] | 2.5 | .4 | 16 | 2.7 | .6 | 22 | [3] | [3] | [3] | [3] | [3] | [3] |
| 56 | 2.6 | 1.9 | 73 | 2.8 | 0.5 | 18 | 3.3 | 1.3 | 39 | 3.1 | 1.2 | 39 | 3.5 | 0.4 | 11 | [3] | [3] | [3] |
| 57 | 2.4 | 1.7 | 71 | 2.6 | 1.6 | 62 | 3.0 | 2.2 | 73 | 3.0 | 2.2 | 73 | 3.3 | 1.9 | 58 | [3] | [3] | [3] |
| 58 | 2.4 | .6 | 23 | 3.5 | .7 | 20 | 2.9 | .6 | 21 | 2.9 | .6 | 21 | 4.5 | 1.0 | 22 | [3] | [3] | [3] |
| 59 | [3] | [3] | [3] | [3] | [3] | [3] | 3.1 | .3 | 10 | 3.1 | .3 | 10 | 4.1 | .2 | 5 | [3] | [3] | [3] |
| 60 | 2.1 | .3 | 14 | 3.2 | .4 | 12 | [3] | [3] | [3] | 2.6 | .3 | 12 | 4.8 | 1.4 | 59 | [3] | [3] | [3] |
| 61 | 2.5 | .9 | 36 | 3.7 | 1.2 | 32 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] |
| 62 | 1.9 | .6 | 32 | 3.3 | .7 | 21 | [3] | [3] | [3] | 2.4 | .2 | 8 | [3] | [3] | [3] | [3] | [3] | [3] |
| 63 | 2.1 | .3 | 14 | 3.3 | .6 | 18 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] |
| 64 | 2.1 | .7 | 29 | 3.5 | .9 | 26 | 2.3 | .1 | 4 | 2.3 | .1 | 4 | 4.7 | 1.3 | 28 | [3] | [3] | [3] |
| 65 | 2.7 | .7 | 26 | 3.7 | .6 | 19 | 2.8 | .2 | 7 | [3] | [3] | [3] | 5.9 | 2.1 | 36 | [3] | [3] | [3] |
| 66 | 2.2 | .5 | 23 | 3.8 | 1.3 | 34 | 2.3 | .2 | 9 | 2.8 | .7 | 25 | [3] | [3] | [3] | [3] | [3] | [3] |
| 67 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | 5.9 | 1.9 | 32 | [3] | [3] | [3] |
| 68 | [3] | [3] | [3] | [3] | [3] | [3] | 3.6 | .9 | 25 | [3] | [3] | [3] | 6.5 | 2.6 | 40 | [3] | [3] | [3] |
| 69 | [3] | [3] | [3] | [3] | [3] | [3] | 3.4 | .5 | 15 | [3] | [3] | [3] | 6.0 | 1.9 | 32 | [3] | [3] | [3] |
| 70 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] |
| 71 | 3.5 | 1.9 | 54 | 4.4 | 1.9 | 43 | 2.6 | .5 | 19 | 2.7 | .6 | 22 | 6.0 | 2.8 | 47 | [3] | [3] | [3] |
| 72 | 2.6 | .1 | 4 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | 6.4 | 2.0 | 31 | [3] | [3] | [3] |
| 73 | 3.2 | 1.2 | 38 | 3.8 | .9 | 24 | 2.8 | .3 | 11 | 2.8 | .3 | 11 | 6.3 | 2.6 | 41 | [3] | [3] | [3] |
| 74 | 3.5 | 1.9 | 54 | 4.0 | 1.7 | 42 | 3.0 | 1.0 | 33 | 2.5 | .6 | 24 | 4.4 | 1.3 | 30 | [3] | [3] | [3] |
| 75 | 3.6 | 2.1 | 58 | 4.5 | 2.3 | 51 | 3.1 | 1.3 | 42 | 3.1 | 1.3 | 42 | 6.5 | 3.5 | 54 | 3.3 | 0.3 | 9 |
| 76 | 3.4 | 2.2 | 65 | [3] | [3] | [3] | 3.2 | 1.6 | 50 | 2.5 | 1.0 | 40 | 3.5 | .9 | 26 | 2.9 | .4 | 14 |
| 77 | [3] | [3] | [3] | [3] | [3] | [3] | 3.6 | .4 | 11 | [3] | [3] | [3] | 7.4 | 2.8 | 38 | [3] | [3] | [3] |
| 78 | 2.6 | .4 | 15 | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | [3] | 5.7 | 2.0 | 35 | [3] | [3] | [3] |
| 79 | 3.1 | 1.0 | 32 | 3.6 | .4 | 11 | 2.9 | .3 | 10 | [3] | [3] | [3] | 6.7 | 2.8 | 42 | [3] | [3] | [3] |
| 80 | 3.4 | 2.0 | 59 | 3.9 | 1.8 | 46 | 2.7 | 1.0 | 37 | 2.6 | .8 | 31 | 5.1 | 2.3 | 45 | [3] | [3] | [3] |

[1]For analysis, it is assumed that rye and other grain crops have the same K-factors as barley.
[2]See figures 2 and 3.
[3]Indicates no residue over the amount needed to protect the soil from wind erosion.

Source: (*33*).

especially in the Northern States (table 3). Corn residues from irrigated areas, primarily in Nebraska, should account for most of this tonnage. Appendix tables 1 through 10 show the future tonnages of each crop by State and by dry and irrigated land. The harvest fraction, shown in table 3 and the appendix tables, indicates the extent of the downward adjustment necessary to prevent unacceptable erosion in the Great Plains.

Yield increases should be the major variable leading to increases in crop residue volume in the Great Plains after 1990. Little increase in total residue is expected because of changes in crop mix or cropped area.

Shorter stemmed winter wheat varieties and higher yielding corn bring all major crops to about the same crop-residue ratio. Therefore readers wanting to estimate crop residue for the eighties or for years after 1990 can multiply actual or estimated yield coefficients by the harvestable crop acres and make the subsequent adjustments shown in appendix tables 1 through 10.

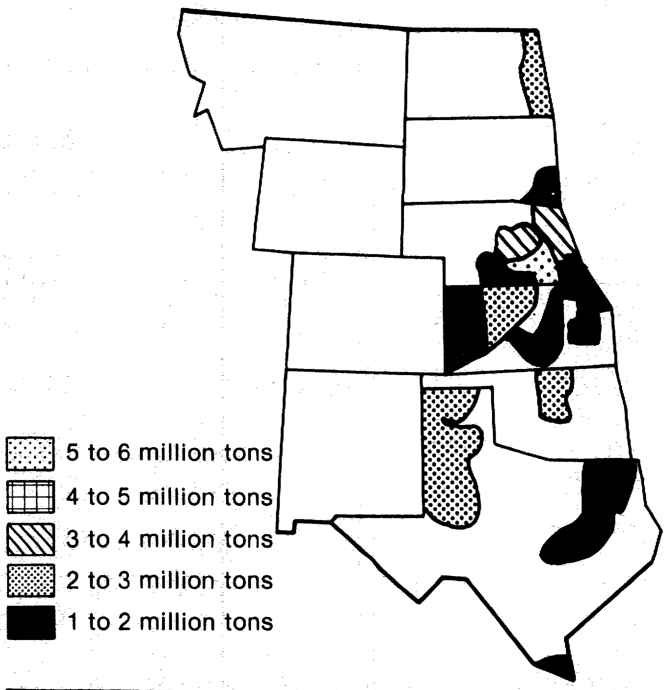
Nebraska, Kansas, and Texas should produce the largest volume, about 75 percent of available crop residue by 1990 (table 4). The remainder will be widely dispersed among the other seven States. Even within the three major States, not all crop residues can be economically collected. Unless sufficient quantities of residues exist within a radius of 10 to 50 miles from a central conversion plant, collecting residues and converting them to fuel will cost too much.

This study identifies areas within the Great Plains where crop-residue concentrations may be heavy enough to warrant the construction of conversion plants by 1990. An MLRA inventory allowed the author to identify 16 areas of high concentration (fig. 4). In each of these MLRA's, the available crop residue exceeded 1 million tons annually (table 5). Of the 16 MLRA'S, 5 were in Nebraska, 5 in Kansas, and 3 in Texas. The remaining three were in North Dakota, South Dakota, and Oklahoma. Total tonnage of available crop residues in these 16 areas is projected at 40.3 million tons by 1990.

MLRA's in the 10-State region, however, vary in size. Some are larger than what might be considered as a reasonable market area (see fig. 4). Therefore these land areas must be treated individually. For example, crop residue from an MLRA extending over an area of

Figure 4

**Projected Concentrations of Crop Residues in the Great Plains, by MLRA's, 1990 Projections**




100 miles or more in length cannot be transported profitably to a central market point.

Appendix tables 11 through 20 show crop residues for irrigated and nonirrigated land and MLRA's for each Great Plains State. (Data in these tables may be related to the MLRA's in figure 2 to identify the location of crop-residue tonnages in MLRA's adjacent to the 16 highly concentrated areas.)

The size and shape of the 16 areas shown in figure 2 illustrate the problem with basing a crop-residue inventory on MLRA. When the shape of an area is not conducive to its treatment as a single trade area, two or more conversion plant sites should be considered. Conversely, for small areas, such as MLRA 102B in South Dakota, additional residues from adjacent MLRA's could be transported to a conversion plant in the 102B area. State boundaries should not limit trade areas.

An inventory analysis should be considered as the first step toward an economic analysis of using crop residues for fuel production. The inventory serves as a basis for selecting plant size, type, and location. The

Table 3—Crop residues that can be safely removed from soil, by crop and subregion, Great Plains, 1990 projections

| Region and crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *1,000 acres* | *Tons* | *1,000 tons* | *Ratio* | *1,000 tons* | *Percent* | *1,000 tons* |
| Northern Great Plains: | | | | | | | |
| Corn | 9,214 | 3.46 | 31,899 | 1.42[6] | 45,168 | 48.20 | 21,772 |
| Spring wheat[5] | 2,158 | 1.06 | 2,289 | 1.30 | 2,978 | 60.28 | 1,795 |
| Winter wheat | 4,398 | .98 | 4,294 | 1.70 | 8,754 | 27.44 | 2,003 |
| Grain sorghum | 1,604 | 2.27 | 3,636 | 1.00 | 3,636 | 40.45 | 1,471 |
| Oats | 3,603 | .89 | 3,210 | 1.40 | 4,494 | 24.39 | 1,096 |
| Barley | 3,641 | 1.17 | 4,267 | 1.50 | 6,400 | 23.83 | 1,525 |
| Rye | 184 | .96 | 176 | 1.50 | 264 | 17.30 | 46 |
| Other small grain | 472 | 1.30 | 614 | 1.50 | 921 | 15.22 | 140 |
| Subtotal | 25,274 | — | 50,385 | — | 71,161 | — | 29,848 |
| Southern Great Plains: | | | | | | | |
| Corn | 3,556 | 4.05 | 14,398 | 1.47[6] | 21,212 | 35.82 | 7,599 |
| Spring wheat[5] | 9 | .94 | 8 | 1.30 | 11 | 13.00 | 1 |
| Winter wheat | 10,133 | 1.16 | 11,706 | 1.70 | 19,900 | 44.11 | 8,779 |
| Grain sorghum | 4,757 | 1.99 | 9,481 | 1.00 | 9,481 | 62.47 | 5,923 |
| Oats | 447 | .70 | 313 | 1.40 | 438 | 25.34 | 111 |
| Barley | 261 | 1.56 | 407 | 1.50 | 610 | 20.38 | 124 |
| Rice | 60 | 3.32 | 199 | 1.50 | 298 | 100.00 | 298 |
| Rye | 13 | .72 | 9 | 1.50 | 14 | 24.67 | 4 |
| Other small grain | 25 | 1.24 | 31 | 1.50 | 46 | 29.95 | 14 |
| Subtotal | 19,261 | — | 36,552 | — | 52,010 | — | 22,853 |
| Total Great Plains: | | | | | | | |
| Corn | 12,770 | 3.63 | 46,297 | 1.43[6] | 66,380 | 44.25 | 29,371 |
| Spring wheat[5] | 2,167 | 1.06 | 2,297 | 1.30 | 2,989 | 60.14 | 1,796 |
| Winter wheat | 14,531 | 1.10 | 16,000 | 1.70 | 27,200 | 39.64 | 10,782 |
| Grain sorghum | 6,361 | 2.06 | 13,117 | 1.00 | 13,117 | 56.37 | 7,394 |
| Oats | 4,050 | .87 | 3,523 | 1.40 | 4,932 | 24.47 | 1,207 |
| Barley | 3,902 | 1.20 | 4,674 | 1.50 | 7,010 | 23.52 | 1,649 |
| Rice | 60 | 3.32 | 199 | 1.50 | 298 | 100.00 | 298 |
| Rye | 197 | .94 | 185 | 1.50 | 278 | 17.67 | 50 |
| Other small grain | 497 | 1.30 | 645 | 1.50 | 967 | 15.92 | 154 |
| Total | 44,535 | — | 86,937 | — | 123,171 | — | 52,701 |

— = Not applicable.
[1]Base-year average, 1978–82.
[2]Based on 1983 ERS-NIRAP projections.
[3]Proportion of total crop residue that can be harvested without significant losses from wind or water erosion.
[4]Total quantity of available crop residue before adjustment for aftermath grazing. An estimated 1.78 percent, or 932,000 tons, of the available residue should be deducted for aftermath grazing in the Great Plains. Farmers, including those who disregard soil conservation needs, use an estimated 7.1 million metric tons for aftermath grazing.
[5]Includes durum.
[6]Reflects adjusted Larson's coefficient.

**Table 4—Available crop residue, 1990**

| Region and State | Available crop residue[1] | |
|---|---|---|
| | *1,000 tons* | *Percent* |
| Northern Great Plains: | | |
| North Dakota | 2,784 | 5.28 |
| South Dakota | 5,047 | 9.58 |
| Nebraska | 20,928 | 39.71 |
| Montana | 922 | 1.75 |
| Wyoming | 167 | .32 |
| Subtotal | 29,848 | 56.64 |
| Southern Great Plains: | | |
| Colorado | 1,435 | 2.72 |
| Kansas | 11,630 | 22.07 |
| New Mexico | 189 | .36 |
| Oklahoma | 2,565 | 4.87 |
| Texas | 7,034 | 13.34 |
| Subtotal | 22,853 | 43.36 |
| Total | 52,701 | 100.00 |

[1]Not adjusted for demand for aftermath grazing and assumed storage losses.

key to a market analysis is determining the amount of crop residue available for conversion, not all existing crop residue. In each case, certain adjustments must be made before one locates and designs conversion plants.

## Aftermath Grazing Adjustment

The author estimated the demand for aftermath grazing in the Great Plains by using NIRAP 1990 projections of beef and veal (meat) production, 1980 beef cow numbers as reported by each State Crop and Livestock Reporting Service office in the 10-State region, Firm Enterprise Data System (FEDS) crop-residue consumption by meat animals, and trends in Great Plains hay yields and production (*12*). An average downward adjustment of 1.78 percent should be applied in the Great Plains to account for aftermath grazing. However, the author decided not to apply the adjustment factor because there was no readily available basis for making these changes in MLRA's or by specific crops. Adjustments for aftermath grazing and assumed storage losses should, however, be made in a more detailed county-by-county inventory and feasibility study in highly concentrated crop-residue areas.

Because adjustments for aftermath grazing appear small, little attention is likely to be paid to the K-factor on farms where it is practiced. The amount of aftermath grazing that comes from the residue available for fuel production versus that which is left on soil to prevent erosion cannot be determined. In other regions of the United States, where livestock farming is more intensive and where there is a greater prevalence of grain-livestock enterprises, the adjustment is more significant.

## Residue Storage Adjustment

Postharvest losses of up to 15 percent can sharply reduce availability of crop residues. Losses are directly related to the type of storage, the form and type of the residue in storage, and the amount of precipitation in the region. Koelsch and others reported that loose straw (wheat) stacks were very susceptible to the weather, losing up to 50 percent of their original amount of straw (*15*). Big round and square bales showed little storage loss. Round bales of corn stover, stored outdoors in semiarid areas, lost 10 percent of their content over a 6-month storage period (*8*). When stored in stacks, they lost 15 percent. When straw was stored in poled barns or under plastic, however, losses reached only 5 to 6 percent.

These estimates show a distinct tradeoff between the costs of baling and storage facilities and the percentage of storage loss or the amount of adjustment that should be made in the tonnage of crop residues because storage loss will depend on the assumptions made regarding methods of handling and storage. Postharvest storage losses in most of the Great Plains are generally lower than most estimates suggest. However, because much of the available crop residue in the 10-State region is adjacent to the eastern edge of the Plains, 15-percent storage loss adjustment may be in order (*27*). This adjustment, like that for aftermath grazing, can be made most accurately for specific market areas. The need for storage emphasizes the seasonality of crop residues. The most crop residue would be available from June to October. Other sources of feed stock, discussed in the following section, are far less seasonal.

## Other Agricultural and Municipal Wastes

Great Plains agriculture centers on two major enterprises: grain and livestock. Besides crop residues, the region has other major biomass sources, such as manure; agricultural processing wastes; grain dust; sunflower, peanut, pecan, and rice hulls; cotton gin waste; and fruit and vegetable waste (Lower Rio Grande Valley). The region also produces municipal wastes which can be either combined with the crop residues or used alone to produce fuel. In some cases, these sources may be more economical to use and have fewer constraints than individual crop residues. A major economic advantage of these other sources of biomass is that they are normally available in concentrated volumes at specific locations.

### Livestock Manure

Although livestock manure has value as an organic fertilizer, it may not be used effectively, may be wasted, or may cause pollution from improper storage or disposal.

VanDyne and Gilbertson conducted a complete U.S. inventory of livestock and poultry manure in 1974 (*51*). Other researchers have also studied its use for fuel production (*48, 49, 50*). At the time of a more detailed county-by-county inventory and feasibility study in high crop-residue areas, the volume of available livestock manure, identified by these studies, should be considered.

In 1980 the Great Plains accounted for 63 percent, or 14.7 million head, of fed cattle marketings, over two-thirds of which was concentrated in the five southern Great Plains States (*44*). Projections to 1990 show a 0.4-percent annual increase to about 15.3 million head (table 6). Given the small projected increase, the availability of manure can best be looked upon as a constant and even supply.

Cattle manure, a good fuel source, generally consists of spilled and undigested feed, lignin and hemicellulose material from undigested roughage, and ligno-protein complexes produced in the animals (*48*). Manure production rates from feedlot cattle average 60 wet pounds per head per day, or 6.9 pounds of dry solids. The heat value of dry manure is 8,750 British thermal units (Btu) per pound.

**Table 5—Sixteen major land resource areas ranked by crop-residue concentration, Great Plains, 1990 projections**

| Rank and State | Major land resource area[1] | Volume |
|---|---|---|
| | | *Million tons* |
| 1 (Nebraska) | 75 | 6.0 |
| 2 (Nebraska) | 106 | 5.1 |
| 3 (Nebraska) | 102B | 3.7 |
| 4 (South Dakota) | 102B | 3.6 |
| 5 (Nebraska) | 71 | 3.0 |
| 6 (Kansas) | 73 | 2.6 |
| 7 (Texas) | 77 | 2.4 |
| 8 (Oklahoma) | 80A | 2.2 |
| 9 (North Dakota) | 56 | 2.1 |
| 10 (Kansas) | 112 | 1.7 |
| 11 (Texas) | 86 | 1.5 |
| 12 (Kansas) | 75 | 1.4 |
| 13 (Kansas) | 72 | 1.4 |
| 14 (Nebraska) | 73 | 1.2 |
| 15 (Kansas) | 106 | 1.2 |
| 16 (Texas) | 83D | 1.1 |
| Total | | 40.3 |

[1]Refer to figure 2.

Given these yields, the 10-State region could produce about 19.3 million tons of livestock manure, dry weight, annually, or 337.8 trillion Btu compared with an estimated 73.7 trillion Btu from the 52.7 million tons of available crop residue (table 4).[10, 11]

### Agricultural Processing Wastes

This study does not inventory the agricultural processing wastes in the Great Plains, although these wastes should be included in further research that focuses on the areas of high crop residues (table 6). A study of these processing wastes must consider their other values which, in many cases, will preclude their use for fuel production.

[10]Based on an assumed 7,000 Btu per pound of crop residue, dry basis.
[11]To place Btu in perspective, 1 ton of coal contains about 25,000,000 Btu and 1 kilowatt of electricity equals 3,412 Btu.

**Table 6—Number of Great Plains cattle feedlots and fed cattle marketed, 1980, and cattle projections to 1990**

| State | Feedlots in 1980 | Cattle marketed 1980[1] | Cattle marketed 1990[2] |
|---|---|---|---|
| | *Number* | *1,000 head* | *1,000 head* |
| Northern Great Plains: | | | |
| North Dakota | 1,450 | 73 | 84 |
| South Dakota | 6,000 | 600 | 714 |
| Nebraska | 12,900 | 3,825 | 4,103 |
| Montana | 74 | 83 | 99 |
| Wyoming | NA | NA | NA |
| Subtotal | 20,424 | 4,581 | 5,000 |
| Southern Great Plains: | | | |
| Colorado | 400 | 1,925 | 2,101 |
| Kansas | 3,500 | 3,015 | 3,200 |
| New Mexico | 31 | 332 | 324 |
| Oklahoma | 315 | 650 | 683 |
| Texas | 1,097 | 4,160 | 3,965 |
| Subtotal | 5,343 | 10,082 | 10,273 |
| Total | 25,767 | 14,663 | 15,273 |

NA=Not available.
[1]Data from (*44*).
[2]1990 estimates based on NIRAP State-by-State poundage projections for beef and veal.

Some agricultural processing wastes are used for fuel in the Great Plains, largely on a trial basis. These uses, in most cases, involve the direct burning of such wastes as cotton gin trash, corncobs, rice husks, peanut shells, and sugarcane bagasse. Where these and other waste products exist in, or adjacent to, areas of high crop-residue concentration and sources of municipal solid waste, their availability should be included in the total product flow for fuel production.

## Municipal Solid Wastes

The agricultural wastes previously discussed and municipal solid wastes (sludge and refuse) are complementary. Together the two sources of biomass may make it economically possible to construct and operate resource recovery systems which would not otherwise be feasible. If conversion of the combined sources of waste is not economical, they will not likely be economical when considered separately. Two economic advantages of their complementarity stand out: economies of scale and flow stabilization.

**Municipal Sludge.** Municipal sludge is a combination of human excrement, garbage grindings, industrial plant discharges, silt and grit from storm runoff, and biologically produced solids, all mixed in highly varied proportions. Sludge solids are normally termed solid wastes and volatile solids, which are the organic fraction of solids from which energy may be recovered; both account for about 75 percent of total solids in municipal sludge. Thus, assuming an energy content of 10,000 Btu per pound of volatile solids, the heating value of sludge is 7,500 Btu per pound, just about the same as for crop residues. Three potential methods of energy recovery are: anaerobic digestion, incineration, and pyrolysis, which are the same conversion processes most often considered for animal manure and certain agricultural processing wastes.[12]

**Municipal Refuse.** Municipal refuse includes the normal garbage, such as paper, glass, metal, food waste, textiles, plastics, and wood, regularly collected in all urban areas. Disposal of these materials by burning and burial in landfill becomes increasingly objectionable as population increases and pollution concerns grow. Many city and county commissioners are considering resource recovery systems.

The growth in refuse volume is, of course, closely related to population growth. Landfills in the United States typically receive between 2.3 and 4.5 pounds of refuse per person per day, producing a heat value of about 4,500 Btu per pound which is basically suited to direct burning for powering electrical generators (*38*).

Municipal waste is not produced in a steady volume throughout the year. The volume tends to peak at Christmastime and reaches its low point in the summer when many people vacation. This refuse is not storable for more than 5 days, so if a conversion plant is built to handle peak supply, a supplemental supply of feedstock is needed to keep the plant at full capacity

[12]Anaerobic digestion is a process by which decomposition of matter produces methane gas; incineration is the process of direct burning of biomass, producing energy as hot water or steam; and, pyrolysis is the chemical decomposition of biomass by heat.

**Table 7—Estimated cost of collecting crop residues on the farm, 1982**

| Form | Collection | | | | | Total cost[3] | | Total cost[4] | |
|---|---|---|---|---|---|---|---|---|---|
| | Swath | Rake[1] | Windrow[1] | Package | Onfarm haul[2] | At time of study | Updated to 1982[5] | At time of study | Updated to 1982[5] |
| | *Dollars/ton* | | | | | | | *Dollars/million Btu* | |
| Corn stover: | | | | | | | | | |
| 3-ton stacks | — | — | 4.40 | 6.21 | 4.76 | 15.37 | 17.83 | 1.10 | 1.27 |
| Big round bales | 2.80 | 1.82 | — | 6.35 | 5.96 | 16.93 | 19.63 | 1.21 | 1.40 |
| Conventional bales | 2.80 | 1.82 | — | 10.06 | 9.49 | 24.17 | 28.04 | 1.73 | 2.00 |
| Loose chop | — | — | — | 6.96 | 5.67 | 12.62 | 14.65 | .90 | 1.04 |
| Big rectangular bales | — | 2.03[6] | 4.44 | 10.88 | 8.50 | 25.85 | 29.99 | 1.85 | 2.14 |
| Wheat straw: | | | | | | | | | |
| 3-ton stacks | 4.89 | — | — | 6.48 | 4.62 | 15.99 | 18.55 | 1.07 | 1.24 |
| Big round bales | 3.18 | — | — | 6.03 | 7.31 | 16.52 | 19.16 | 1.10 | 1.28 |
| Conventional bales | 3.18 | — | — | 9.28 | 9.03 | 21.49 | 24.93 | 1.43 | 1.66 |
| Loose chop | — | — | — | 9.25 | 4.86 | 14.11 | 16.37 | .94 | 1.09 |
| Big rectangular bales | 4.89 | — | — | 9.14 | 6.40 | 20.43 | 23.70 | 1.36 | 1.58 |

— = Not applicable.
[1]Not applicable to wheat straw.
[2]The hauling distance is assumed to be 1 mile.
[3]If a power unit is required, it is included in all cost estimates. Total cost does not include a payment to the farmer for the residue's value.
[4]Based on $14.0\times10^6$ Btu per ton of residue for corn stover and $15.0\times10^6$ Btu per ton of wheat straw. (See app. table 25 for energy conversion values.)
[5]Updated using Index (C+D)/2 (app. table 21).
[6]Swath and rake operations usually substitute entirely for the windrow operation. Raking is required in addition to the windrow operation for big rectangular bales because of the large pickup capacity of this type of baler.

Source: (*5*).

throughout the year. Dry, storable agricultural residues, also technically suited for direct burning, are being considered as a fill-in.

Based on the 1980 Great Plains population of about 28 million people, the potential energy output from all municipal refuse alone could range from 289.8 to 567 trillion Btu annually. These volumes could increase to 433.5 and 850.5 trillion Btu by 1990, should the Great Plains population increase by 15 percent.

### Marketing Systems Approach

Analysts must assess all sources of supply for agricultural, silvicultural, industrial, and municipal purposes before a market system analysis is completed. A resource inventory is the first step in determining the marketable supply of biomass, so decisionmakers can recommend conversion plant type, size, and location.

A marketing systems approach should include a review of the seasonal availability of biomass, the type of conversion potential of the waste products, the collection network required, the longrun demand for fuel both in the trade area and in other markets, and the type of conventional fuels used in the area. From an agricultural perspective, the areas of high crop-residue concentration could serve as focal points for a marketing systems analysis. The complementarity of agricultural crop residues and municipal wastes could help solve city refuse disposal problems and provide an additional market for farm products. Municipalities may finance or construct conversion plants that provide a market for crop residues.

Many city or county planning departments have likely conducted an inventory of municipal and other forms of waste products. These inventories, where carried out in high crop-residue areas, should be reviewed before additional research on the conversion of crop residues.

## Costs

This section shows only the total cost (in 1982 dollars) of crop residues delivered to an off-farm conversion site. All costs derived from previous studies are indexed to 1982 levels using the appropriate indexes shown in appendix table 21. The author converts all costs to a per-million-Btu basis. These costs, about $29 per ton, are considered low enough to encourage farmers to deliver crop residues to a fuel conversion facility. However, before the competitiveness of crop residues in a specific trade area can be determined, analysts should consider several factors beyond the scope of this study. Decisionmakers must know the conversion techniques, how the residue will be prepared as a feedstock, average moisture content, and conversion efficiency.

For crop residues to be competitive with conventional fuels, cost per million Btu cannot exceed the costs of conventional fuels per million Btu, each adjusted for derived conversion efficiencies. The costs of using crop residues for fuel include the collection of the residue at the farm and storage. For off-farm use, transportation is also a major cost item.

### Collection

Residues may be baled, stacked in loose form, or chopped and stored outdoors or inside. If moved to off-farm fuel conversion markets, then a transportation and handling charge must be assumed. A cost associated with preparing residues for use in a conversion plant may exist which involves either pelleting or grinding. Finally, the farmer must show a profit on the sale of crop residues to cover the cost of collection.

Crop-residue collection costs greatly depend on the technology used. The wide variation found in collection costs reflects differences in harvesting practices as well as assumptions by researchers (app. table 22). Cost generally drops when farmers harvest residues along with the main crop and use a total harvester or a combine pulling a forage harvester (*21*). If farmers only combine the crop, the residue can be windrowed, left to dry, and collected later with a baler or stacking wagon. Much of the residue of some crops, such as corn and sorghum, may be left standing after grain harvest but must be cut and windrowed before being packaged. The process requires one or two additional passes over the field, not counting either bale pickup or the stacking operation.

Energy conversion values of 7,000 Btu per pound of corn stover and 7,500 Btu per pound of wheat straw are used to estimate collection costs. Collection costs are converted from costs per ton to costs per million Btu for a realistic comparison between fuel from crop-residue sources and conventional fuels. The energy conversion values chosen for this study are within the range reported in previous studies (app. table 23). Estimates for the Great Plains range from $1.04 to $2.14 per million Btu for corn stover and from $1.09 to $1.66 per million Btu for wheat (table 7). Collection costs for grain sorghum, other small grain, and rice straw should be within these ranges.

Corkren and others estimated the costs of collecting crop residues and transporting them to onfarm storage at $1.78 to $2.00 per million Btu if the farmer harvested and $1.05 to $1.68 per million Btu if custom harvested (table 8) (*4*). If farmers own their harvesting equipment, they will likely use it because their variable (out-of-pocket) expenses are less than the custom rate. Farmers may prefer custom harvesting if they do not own harvesting equipment.

### Transportation

The author assumes that crop-residue conversion occurs off-farm. Transporation costs, therefore, are a function of the distance transported, the size of the residue package, the means of transportation, and management of the system.

Equipment is available to move wheat straw from the farm to the conversion site in conventional bales, large round or square bales, and stacks. Trucks or gooseneck trailer units are available for moving up to two stacks or 14 large bales. Flatbed trucks can haul 20 tons of sugarcane at one time in two pallet-type boxes.

Certain residues, such as corn stover, are more cohesive than others and may require special handling. Richey and others found that large round bales and stackwagon stacks are the easiest to transport because package density is higher than the bulk density of chopped stover, allowing heavier loads (*29*). If residues move in wide bales, special permits and precautions may be required to travel on main highways (*21*). Running large-tonnage trucks over inadequate country roads and bridges may cause problems (*30*).

The following questions related to transportation system management must be answered before the com-

**Table 8—Estimated costs of collecting crop residues for onfarm storage, 1982**

| Harvest method | Straw crops | | | Stalk and stem crops | | |
|---|---|---|---|---|---|---|
| | At date of study | Updated to 1982[1,2] | 1983 Btu value[3] | At date of study | Updated to 1982[1,2] | 1982 Btu value[4] |
| | Dollars/ton | | Dollars/ million Btu | Dollars/ton | | Dollars/ million Btu |
| Farmer | 20.00 | 30.00 | 2.00 | 16.60 | 24.90 | 1.78 |
| Custom | 16.80 | 25.20 | 1.68 | 9.80 | 14.70 | 1.05 |

[1]Updated using Index (C+D)/2 (app. table 21).
[2]Total cost does not include payment to the farmer for the residues' value.
[3]Based on $15.0 \times 10^6$ Btu per ton for straw crops.
[4]Based on $14.0 \times 10^6$ Btu per ton for stalk and stem crops.

Source: (*4*).

petitiveness of crop residues as an alternative fuel source can be determined.[13] Will individual farmers be responsible for residue delivery in farm-to-market trucks? Will the conversion plant own a fleet of large trucks? Will the transportation function be operated by a separate trucking firm, having either owned or leased fleets? Will trucks be used solely for moving crop residues, or can they be used for several purposes? For example, in many areas of high concentration of crop residues, the same trucks that move grain from farms to the unit train loadout elevators also may transport crop residues to a conversion plant.

Several studies have examined the costs of transporting crop residues to central sites, usually from farm to conversion plant at ranges of 10 to 50 miles (app. table 24). But some studies have lumped together collection and transportation costs. All cost estimates are indexed to 1982 by use of the procedure shown in appendix table 21. Big round bales, in most cases, appear to be the most economical form in which to transport most crop residues.

Koelsch and others estimated the cost of moving wheat straw to a central site from 10 to 40 miles away at \$3.77 to \$5.08 per million Btu (*15*). Costs for two types of residue packages, big round bales and stack, appear in table 9. Large trucks or gooseneck trailer units capable of transporting 14 big round bales or 2 stacks were assumed.

Tyner and others also reported a total delivered cost for selected States for four kinds of crop residues; costs ranged from \$1.67 to \$3.66 per million Btu (table 10) (*39*). Transportation costs were based on a uniform distance of 15 miles, a labor rate of \$5 per hour, and a diesel fuel cost of 50 cents per gallon (1977 dollars). No profit is included in the total cost estimates shown in table 10. Even when one adds a \$10-per-ton residue cost, Tyner's estimates are still lower than Koelsch's estimates.

Dobie and others estimated the costs associated with collecting and transporting rice straw using three packaging methods at \$2.12 to \$3.25 per million Btu, just slightly higher than an estimate for the same residue made by the Stanford Research Institute (table 11) (*6, 35*)

Tyner and others used the following formulas to compute transportation costs (*39*):

| *Residue* | *Formula* |
|---|---|
| Corn stover | $\$2.61 + \frac{\$9.74}{HR} + \$0.276\ D$ |
| Small grain straw | $\$2.69 + \frac{\$8.17}{HR} + \$0.31\ D$ |
| Sorghum stover | $\$2.33 + \frac{\$8.22}{HR} + \$0.276\ D$ |
| Rice and sugarcane residue | $\$6.33 + \frac{\$12.38}{HR} + \$0.155\ D$ |

where
HR = harvestable residue in tons per acre, and
D = the one-way distance to the plant in miles

[13]For a good discussion of truck cost management, see (26). Also refer to *Owner-Operator Truck Cost Guide (45)*.

**Table 9—Costs of wheat straw delivered to a power plant, 1982**

| Driving radius | Cost of straw: At date of study | Cost of straw: Updated to 1982[1] | Collection cost: At date of study | Collection cost: Updated to 1982 | Transportation cost: At date of study | Transportation cost: Updated to 1982 | Total cost: At date to study | Total cost: Updated to 1982 | Total cost: 1982 Btu value[2] |
|---|---|---|---|---|---|---|---|---|---|
| | *Dollars/ton* | | | | | | | | *Dollars/ million Btu* |
| 10 miles: | | | | | | | | | |
| Big round bales | 10.00 | 10.00 | 21.00 | 39.06 | 4.70 | 8.74 | 35.70 | 57.80 | 3.85 |
| Stacks | 10.00 | 10.00 | 18.60 | 34.60 | 6.40 | 11.90 | 35.00 | 56.50 | 3.77 |
| 20 miles: | | | | | | | | | |
| Big round bales | 10.00 | 10.00 | 21.00 | 39.06 | 7.90 | 14.69 | 38.90 | 63.75 | 4.25 |
| Stacks | 10.00 | 10.00 | 18.60 | 34.60 | 9.50 | 17.67 | 38.10 | 62.27 | 4.15 |
| 30 miles: | | | | | | | | | |
| Big round bales | 10.00 | 10.00 | 21.00 | 39.06 | 11.00 | 20.46 | 42.00 | 69.52 | 4.63 |
| Stacks | 10.00 | 10.00 | 18.60 | 34.60 | 12.50 | 23.25 | 41.10 | 67.85 | 4.52 |
| 40 miles: | | | | | | | | | |
| Big round bales | 10.00 | 10.00 | 21.00 | 39.06 | 14.20 | 26.41 | 45.20 | 75.47 | 5.08 |
| Stacks | 10.00 | 10.00 | 18.60 | 34.00 | 15.50 | 28.83 | 44.10 | 73.43 | 4.90 |

[1]Assumes no increase in farm value of straw from 1977 to 1982.
[2]Based on $15.0 \times 10^6$ Btu per ton.

Source: (*15*).

For example, if corn stover yielded 3 tons of residue per acre and transport was 20 miles, then the transportation cost would be $6.41 per ton ($2.61 + $3.25 + $5.52 = $11.38).

Tyner's approach appears to place too much emphasis on residue yields. His formula places transportation costs in high crop-residue concentration areas, like the irrigated High Plains, much lower than other researchers' costs. A major study conducted in the Texas High Plains area confirms the inadequacy of the Tyner formula (*28*). The study covered a 54-county area and represented over 25 million tons of crop residue. Corn, grain sorghum, and wheat residue, packaged as round bales, were assumed to be transported to three possible collection sites. The average transportation costs, adjusted to 1982 for the following three sites, were:

| | |
|---|---|
| Amarillo | 66 cents per million Btu ($7.20/ton) |
| Plainview | 67 cents per million Btu ($7.31/ton) |
| Lubbock | 77 cents per million Btu ($8.47/ton) |

Including collection, the total costs reported in the Texas study were:

| | |
|---|---|
| Amarillo | $2.00 per million Btu ($21.80/ton) |
| Plainview | $2.01 per million Btu ($21.91/ton) |
| Lubbock | $2.12 per million Btu ($23.07/ton) |

Previous studies revealed a wide range of transportation costs because of assumptions employed. This study uses an estimate of $8 per ton, representing a 10-mile haul, to estimate total delivered crop-residue costs. For a 50-mile haul, the cost would be nearly $30 per ton (1982 dollars). The transportation cost for the 10-mile haul was:

| | |
|---|---|
| Corn stover | 57 cents per million Btu |
| Sorghum grain stover | 57 cents per million Btu |
| Wheat straw | 53 cents per million Btu |

## Storage

Crop residues may have to be stored for nearly a year to assure a year-round supply to the conversion plant. The method of storage will depend partly on how the residues are packaged and on whether the residue will be shredded or pelleted. The costs of storage also can vary slightly depending on whether residues are stored onfarm or at a central conversion site. The added cost

**Table 10—Combined collection and transportation cost, by major cost component and by type of crop residue, selected Great Plains States, 1982**

| Crop residue and State | Labor cost[1] | | Fuel cost[2] | | Equipment cost[3] | | Total costs | | |
|---|---|---|---|---|---|---|---|---|---|
| | At date of study | Updated to 1982 | At date of study | Updated to 1982 | At date of study | Updated to 1982 | At date of study | Updated to 1982 | 1982 Btu value[4] |
| | *Dollars/ton* | | | | | | | | *Dollars/ million Btu* |
| Corn stover: Nebraska | 4.81 | 5.92 | 2.22 | 3.42 | 15.97 | 21.72 | 23.00 | 31.06 | 2.22 |
| Small grains straw: South Dakota | 4.67 | 5.74 | 2.03 | 3.13 | 11.92 | 16.21 | 18.62 | 25.08 | 1.67 |
| Grain sorghum stover: Kansas | 8.48 | 10.43 | 3.86 | 5.94 | 25.66 | 34.90 | 38.00 | 51.27 | 3.66 |
| Rice straw: Texas | 4.96 | 6.10 | 1.88 | 2.90 | 14.40 | 19.58 | 21.24 | 28.58 | 2.04 |

[1]Updated using Index G (app. table 21).
[2]Updated using Index C (app. table 21).
[3]Updated using Index B (app. table 21).
[4]Based on $14.0 \times 10^6$ Btu per ton of corn and grain sorghum stover and $15.0 \times 10^6$ Btu per ton for small grain and rice straw.

Source: (*39*).

**Table 11—Costs of collecting and transporting rice straw, 1982**

| Residue package | Collection | | | | Off-farm transportation[1] | | Total costs | | |
|---|---|---|---|---|---|---|---|---|---|
| | Baling | | Onfarm transportation | | | | | | |
| | At date of study | Updated to 1982[2] | At date of study | Updated to 1982[3] | At date of study | Updated to 1982[4] | At date of study | Updated to 1982 | 1982 Btu value[5] |
| | *Dollars/ton* | | | | | | | | *Dollars/ million Btu* |
| Three-wire rectangular bales | 11.13 | 20.92 | 4.63 | 7.36 | 5.00 | 9.30 | 20.76 | 37.58 | 2.68 |
| Big round bales (6 ft. long) | 4.88 | 9.17 | 3.35 | 5.33 | 16.67 | 31.01 | 24.90 | 45.51 | 3.25 |
| Big round bales (4 ft. long) | 4.90 | 9.21 | 4.00 | 6.36 | 7.62 | 14.17 | 16.52 | 29.74 | 2.12 |

[1]Transport distance of 10 miles for 2,400 tons of rice straw per year.
[2]Updated using Index (C+D)/2 (app. table 21).
[3]Updated using Index B (app. table 21).
[4]Updated using Index (B+C)/2 (app. table 21).
[5]Based on $14.0 \times 10^6$ Btu per ton of rice straw.

Source: (*6*).

of storage space at conversion sites is probably more than offset by savings associated with less handling and greater ease of handling if the residue is transported directly from field to plant. Bale stacks, especially those containing square bales, may partially collapse when ties come loose and may hamper loading.

According to Tyner and others, packaged residue should be kept onfarm until needed at the conversion plant (*39*). However, residue must not be left in the field because collection trucks cannot get into muddy or snowy fields. Residue storage must allow for easy shipment to a conversion plant (for example, storage should be beside an all-weather road or driveway). However, storage loss decreases when residue is stored in well-drained areas. Other reasons for not storing crop residues in fields include when: bales or stacks might interfere with the following year's crop, space for storing big round bales may equal 1 percent of the acreage from which the residues are produced, and residues are moved from the field to an onfarm storage site, say 0.5 to 2 miles, increasing handling costs and losses. Space for storing big round bales may equal 1 percent of the acreage from which the residues are produced (*13*).

If crop residue are stored outside, losses may run from 5 to 50 percent. Several factors affect outside storage losses, including wind and precipitation, type of package, type of residue, size of package, and handling. Residues containing over 20-percent moisture are likely to mold (*23*). Given knowledge of grain and other crop-drying costs, no estimates of artificial drying costs for residues (which would be uneconomical) appear in this report.

Richey and others concluded that big round bales or stackwagon stacks are usually adequately waterproofed for outdoor storage without serious deterioration (*29*). Conversely, estimated storage losses for corn stover for a 6-month period ranged from 5 to 20 percent, according to Flaim and Young (table 12) (*8*). Conditions in the northern and western parts of the Great Plains are most typical of arid storage conditions.

Abdallah reported onfarm storage costs for corn stover for three forms of packaging (*1*): 3-ton stacks, about 21 cents per million Btu; big round bales, about 14 cents per million Btu; and loose chop, just over 14 cents per million Btu.

**Table 12—Estimated 6-month storage losses for corn stover**

| Climate and form | Outside | | Inside |
|---|---|---|---|
| | In open | Under plastic | In pole barn |
| | *Percent* | | |
| Humid: | | | |
| Big round bales | 15 | 7 | 5 |
| Stacks | 20 | NA | 5 |
| Arid: | | | |
| Big round bales | 10 | 6 | 5 |
| Stacks | 15 | NA | 5 |

NA=Not available.

Source: (*8*).

Wheat straw stored in Kansas was also studied for 6 months by Koelsch and others (*15*). Big round bales showed little storage loss but required a large storage area because they could not be stacked. Losses in loose straw stacks ran up to 50 percent. Conventional square bales showed little deterioration, but the stacks partially collapsed, which made them difficult to handle and transport. Koelsch and others showed no storage cost in their analysis (*15*). Corkren and others concurred with Koelsch and others stating that storage costs would be negligible if the residues were stacked outside or put in sheds or buildings which otherwise would go unused (*4*). In a technical sense, however, costs occur whenever crop residues are stored.

Off-farm storage would likely be outdoors because of the prohibitive expense of enclosed storage. Therefore, the cost would be related, primarily, to the area needed. Farmers would need 37.5 $ft^2$ per ton, assuming big round bales, each weighing 1,500 pounds and requiring 30 $ft^2$ of space when stored one layer deep. At this rate, farmers would need to store 1,162 tons per acre. The location of conversion plants will likely be adjacent to major cities and towns near the agricultural production areas just as are grain elevators. According to Schnake and Stevens, a land value of $1,300 per acre for such commercial facilities is appropriate for estimating space costs (*30*). At this land value and assuming interest on investment of 12 percent, the storage costs per ton would equal 13 cents per ton ($1,300 ÷ 1,162 tons = land cost per ton x 12 percent = 13 cents per ton annual interest on investment charge). Total storage costs also would include charges for taxes and insurance and possibly some charge for handling. Energy costs would be about $0.009 per million Btu. If conversion plants should receive loose chop, then a warehouse storage facility would be required. Additional research would help determine if crop residues could be economically stored in such facilities. This research should include an economic analysis of the type of conversion plant, size, and location.

### Total Costs of Residue Feedstock

Total delivered costs of crop residues will vary by distance, form, type of residue, and type of storage. A review of recent studies indicates a wide range in cost estimates, roughly from $25 to $75 per ton (1982 dollars), or from about $1.67 to $5.36 per million Btu. To place these costs in perspective, Bhagat and others estimated that coal delivered at a cost of $1.25 to $2.50 per million Btu (1982 prices) competes with crop residues delivered in the range of $24 to $36 per ton (*2*). The author's $29-per-ton estimate is in this range.

Assuming 6,000 Btu per pound of corn stover and a preparation cost of $10 per ton at the power plant, Buchele found that a power plant could pay up to $28 per ton (1982 dollars) (*3*). Buchele also concluded that at this price the farmer would net about $4.50 per ton of corn stover. Koelsch and others concluded that wheat straw and other crop residues can be used effectively to generate electricity as a replacement for fossil fuels (*15*). They estimated 40 miles to be a maximum distance for wheat straw to remain competitive with low-sulfur, high-Btu coal delivered to Kansas at $35 per ton. These researchers found that crop residue would be competitive with coal only if its delivered cost per ton stayed below coal's.

## Constraints

Before farmers, investors, and policymakers decide to use crop residues and other biomass for fuel production, they should be aware of several important precautions. This section addresses some of the major constraints in long-term U.S. agricultural policy surrounding the use of crop residues as an alternative energy source.

### Soil Erosion

The Great Plains States are particularly susceptible to long periods of drought and severe wind erosion, making soil conservation important when one considers the use of crop residues (which help hold soil) for fuel production. Does this practice agree with long-term soil conservation needs and policy? Soil erosion is already a serious problem in some areas of the Great Plains, although not as serious a problem as in some Corn Belt and Delta States, according to the RCA study (*47*). Residues should be removed from only about 45 million acres, or 35 percent, of the Great Plains cropland base, according to the soil scientists whose recommendations (K-factors) were used in this study.

However, some Great Plains soil scientists say that no residue should be removed from most soils. These scientists may have the best perspective of the long-term effects of crop-residue removal practices. If a market is established for crop residues, will farmers adhere to scientific recommendations, or will they let shortrun economic gain (assuming the use of crop residues is, or becomes, economical) outweigh longrun soil conservation needs? Thus, in the short run, protection against soil erosion may be less constraining than indicated in this study. However, in the long run, the sale of crop residues for fuel production could seriously affect crop production.

### Competition for Cropland

The concern that biomass crops will compete with food crops conflicts with the ethical issue of eliminating world hunger. If users decide that conversion of crop residues is feasible and that capital investments in conversion plants are assured, will they stop at using only waste products or will the economic system allow for the use of cropland to produce forages specifically for fuel?[14] The production of energy crops, in the long run, can be fully justified, both in economic and moral terms only as long as plant breeders and farmers aim for dual-purpose crops, that is, having high-yielding food-grade grain on top of a longer stem variety bred for fuel use.

The high-energy sorghums developed by the Texas Agricultural Experiment Station at Weslaco, TX, and other locations, which yield over 5,000 pounds of oilseed and over 7 tons of biomass per acre, offer promise as a food and fuel crop.

[14]Several federally subsidized ethanol plants, using grain as their feedstock, were already operating at the time of this study.

The use of dual-purpose crops, such as sunflowers, may increase in the Great Plains. Although recent crop-breeding efforts have been directed toward short-stemmed, high-oil varieties, some agronomists consider sunflowers the best crop for biomass production. Varieties producing 3,000 to 4,000 pounds of seed per acre and at least 15 tons of dry-weight biomass per acre may provide strong competition for other Great Plains crops.

Both high-energy sorghums and sunflowers are adaptable to large parts of the Great Plains. The sorghums, however, are still in the experimental stage. Farmers grew sunflowers on 2.9 million acres in Texas, North Dakota, and South Dakota in 1980. Sunflower acreages in the Great Plains have increased in recent years, displacing small grains. In each State, current sunflower production corresponds with locations identified as areas of high crop-residue concentration and, therefore, would add to the inventory of available crop residues.

Dual-purpose crops will compete for cropland acreage as they are developed. As long as these crops satisfy the dual-purpose criteria, they should not detract from the food production capacity of the Great Plains. If, however, fuel crops become more profitable, then a policy to prevent them from replacing crops used for food production may be needed, not for economic purposes but for humanitarian reasons.

## Yield and Acreage Variations

Another constraint is the great variation in yields and, therefore, production in the Great Plains. Caused largely by the vagaries of weather common in the Great Plains, corn yield, by State, varied by 15 to 139 percent from one year to the next in the 1971-80 period. Winter wheat yields varied from 26 to 120 percent during the same period (table 13). Most of these yield variations appeared to be weather related. Yield variations should be considerably less in irrigated areas which include major portions of about half of the 16 areas of high crop-residues concentration.

The author believes that these wide ranges in yields represent ranges in crop-residue yields. Thus they are a major constraint to the reliance on crop residues as a sole fuel source, an important factor that conversion plant designers should take into account.

Major acreage adjustments resulting from farm programs designed to maintain a balance between supply and demand for grain and other crops also may contribute to instability in crop-residue supplies. U.S. harvested wheat acreage, for example, fluctuates greatly. From 1962-83, acreages varied as follows:

| *Year* | *Million acres harvested* |
|---|---|
| 1962 | 43.8 |
| 1967 | 58.4 |
| 1970 | 113.6 |
| 1976 | 70.8 |
| 1978 | 56.9 |
| 1981 | 81.0 |
| 1983 | 61.0 |

The payment-in-kind (PIK) program announced for marketing year 1983-84 sharply reduced the 1983 acreage of corn, wheat, and grain sorghum. This acreage accounted for over 30 percent of the available crop residues in the Great Plains. Farmers likely idled 32 million acres of wheat and 39 million acres of corn and grain sorghum in 1 year (*34*). Actual farmland reduction totaled 54 million acres (*40*). The consequences of these annual variations could seriously affect the profitability and dependability of conversion plants as an alternative source of energy.

## Fertilizer Value

Nutrients must be replaced to maintain soil fertility when any amount of crop residue is removed. Richey and others estimated that if all but 1 ton per acre of corn stover were removed from the soil, replacing the nutrient loss would cost just under $10 per acre (*29*). Lipinsky and others suggested a fertilizer replacement cost of $2.45 per ton of harvested corn stover (*19*). Koelsch and others estimated replacement of nitrogen loss from wheat straw to cost 66 cents per acre, assuming anhydrous ammonia at $155 per ton (*15*).

Corkren and others estimated the fertilizer value of all major crop residues (table 14) (*4*). Their value per ton ranged from $6.02 for soybeans to only 69 cents for sugarcane. For most of the residues in the Great Plains, corn and grain sorghum stover and wheat straw, the fertilizer value ranged from $2.68 to $4.02 per ton. Stover is valued at nearly 26 cents and wheat straw at about 18 cents per million Btu as a fertilizer.[15]

**Table 13—Variation in corn and winter wheat yields, 10-State Great Plains region compared with the United States, 1971–80**

| Crop and State | 1972 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | Range | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Absolute[1] | Relative[2] |
| | *Bushels/acre* | | | | | | | | | | | *Percent* |
| Corn: | | | | | | | | | | | | |
| North Dakota | 58.0 | 67.0 | 56.0 | 49.0 | 51.0 | 40.0 | 73.0 | 79.0 | 76.0 | 58.0 | 39.0 | 98.0 |
| South Dakota | 46.0 | 64.0 | 54.0 | 33.0 | 37.0 | 31.0 | 59.0 | 67.0 | 74.0 | 53.0 | 43.0 | 138.7 |
| Nebraska | 85.0 | 104.0 | 94.0 | 68.0 | 85.0 | 85.0 | 99.0 | 113.0 | 115.0 | 85.0 | 47.0 | 69.1 |
| Montana | 76.0 | 78.0 | 73.0 | 70.0 | 73.0 | 75.0 | 68.0 | 72.0 | 77.0 | 74.0 | 10.0 | 14.7 |
| Wyoming | 78.0 | 85.0 | 89.0 | 71.0 | 80.0 | 87.0 | 85.0 | 81.0 | 87.0 | 97.0 | 26.0 | 36.6 |
| Colorado | 88.0 | 102.0 | 102.0 | 101.0 | 93.0 | 102.0 | 116.0 | 110.0 | 117.0 | 135.0 | 47.0 | 53.4 |
| Kansas | 95.0 | 104.0 | 100.0 | 76.0 | 84.0 | 96.0 | 96.0 | 102.0 | 117.0 | 94.0 | 41.0 | 53.4 |
| New Mexico | 55.0 | 75.0 | 70.0 | 77.0 | 100.0 | 105.0 | 90.0 | 105.0 | 109.0 | 85.0 | 54.0 | 98.2 |
| Oklahoma | 77.0 | 89.0 | 90.0 | 88.0 | 80.0 | 93.0 | 82.0 | 65.0 | 110.0 | 70.0 | 45.0 | 69.2 |
| Texas | 80.0 | 86.0 | 95.0 | 92.0 | 103.0 | 120.0 | 98.0 | 100.0 | 105.0 | 90.0 | 40.0 | 50.0 |
| United States | 88.1 | 97.1 | 91.2 | 71.4 | 86.2 | 87.9 | 90.7 | 101.2 | 109.7 | 91.0 | 38.3 | 53.6 |
| Winter wheat: | | | | | | | | | | | | |
| North Dakota | 30.0 | 33.0 | 32.0 | 29.5 | 25.5 | 28.0 | 23.0 | 29.9 | 22.0 | 15.0 | 18.0 | 120.0 |
| South Dakota | 36.0 | 36.0 | 32.0 | 27.0 | 30.0 | 18.0 | 25.0 | 26.0 | 19.0 | 22.0 | 18.0 | 100.0 |
| Nebraska | 42.0 | 37.0 | 35.0 | 34.0 | 32.0 | 32.0 | 35.0 | 32.0 | 34.0 | 38.0 | 10.0 | 31.2 |
| Montana | 30.0 | 27.0 | 26.5 | 29.5 | 35.0 | 32.0 | 29.0 | 31.0 | 25.5 | 25.5 | 9.5 | 25.5 |
| Wyoming | 33.0 | 35.0 | 23.0 | 25.0 | 25.0 | 24.0 | 20.0 | 26.0 | 22.0 | 28.0 | 13.0 | 65.0 |
| Colorado | 28.0 | 24.0 | 24.5 | 25.5 | 22.5 | 21.5 | 22.0 | 23.0 | 26.0 | 32.0 | 10.5 | 48.8 |
| Kansas | 34.5 | 33.5 | 37.0 | 27.5 | 29.0 | 30.0 | 28.5 | 30.0 | 38.0 | 35.0 | 10.5 | 38.2 |
| New Mexico | 24.0 | 25.5 | 29.5 | 18.0 | 26.0 | 23.0 | 21.0 | 19.0 | 22.0 | 21.0 | 8.0 | 44.4 |
| Oklahoma | 20.0 | 23.0 | 30.0 | 21.0 | 24.0 | 24.0 | 27.0 | 27.0 | 38.0 | 30.0 | 18.0 | 90.0 |
| Texas | 21.0 | 22.0 | 29.0 | 16.0 | 23.0 | 22.0 | 25.0 | 20.0 | 30.0 | 25.0 | 14.0 | 87.5 |
| United States | 35.4 | 34.0 | 33.1 | 29.6 | 32.0 | 31.5 | 31.6 | 32.1 | 36.9 | 36.8 | 7.3 | 24.7 |

[1]Highest yield minus lowest yield.
[2]Absolute range divided by the lowest yield multiplied by 100.

Source: (*42*).

**Table 14—Quantity of anhydrous ammonia, super phosphate, and muriate of potash per ton of crop residues and fertilizer values of residues per ton, 1982**

| Crop source of residue | Fertilizer[1] | | | Value[2] |
|---|---|---|---|---|
| | Anhydrous ammonia | Super phosphate | Muriate of potash | |
| | *Pounds/ton* | | | *Dollars/ton* |
| Barley | 13.0 | 2.0 | 21.4 | 3.21 |
| Corn | 18.8 | 3.0 | 22.4 | 4.02 |
| Cotton | 32.4 | 4.0 | 26.8 | 5.92 |
| Dry beans | 16.0 | 2.0 | 21.6 | 3.55 |
| Flax | 21.2 | 1.8 | 30.0 | 4.72 |
| Grain sorghum | 18.2 | 2.6 | 22.2 | 3.90 |
| Oats | 11.2 | 2.8 | 29.2 | 3.69 |
| Peanuts | 28.8 | 2.4 | 22.6 | 5.06 |
| Rice | 10.8 | 1.6 | 21.0 | 2.91 |
| Rye | 9.0 | 2.2 | 12.6 | 2.14 |
| Soybeans | 39.4 | 3.8 | 18.4 | 6.02 |
| Sugar beets | 9.2 | .8 | 1.6 | 1.20 |
| Sugarcane | 4.4 | .6 | 2.2 | .69 |
| Wheat | 11.8 | 1.2 | 17.0 | 2.68 |

[1]Data from (*17*).
[2]Based on average prices paid in 1982 by Great Plains farmers of $215, $213, and $150, respectively, for anhydrous ammonia, super phosphate (46-percent $P_2O_5$), and muriate of potash (60-percent $K_2O$).

Source: (*4*).

## Livestock Feed Demand

Long-term demand for crop residue for livestock feed is another constraint which could affect the supply of available crop residues. By 1990, this demand will depend on several factors, including the number of cattle in the Great Plains, the world demand for food and feed grains and other crops produced in the Great Plains, yields in roughage-producing acres, and the urban and industrial pressure on agricultural land in the region. The primary concern for livestock producers is that additional acres of grazed land will be cropped by 1990 and that crop residues will be in greater demand as livestock roughage.

The number of beef cattle in the Great Plains may increase at an annual rate of only 0.5 percent during the 1980's, reaching over 18 million head by 1990 (table 15). Crop residues can add to forage supplies and are economically feasible to use as feed (*4*). Either way, residues cannot be fed in place of concentrates. If the United States pursues a strong grain export policy, crop residues will be important in livestock rations.

Corkren and others directly compared quantities of crop residues with an amount of other (priced) roughage having nutritional content equal to that of the residue (*4*). For example, if 16 pounds of wheat straw has a total net energy content equal to 12 pounds of fescue hay worth 2 cents per pound, then the wheat straw has an estimated value of 1.5 cents per pound.[16] By using parametric programming, Corkren solved problems associated with the need to supplement crop residues with protein and the further computational difficulty of balancing rations containing these substitutes.[17] Ranges in feed values for crop residues were derived from adding each residue to four different steer

[15]The contribution of these residues in providing organic matter and reducing erosion may be the greatest constraint to their removal, exceeding their value as fertilizer. For more detail on the value of crop residues as organic matter and for soil erosion prevention, see Corkren and others (*4*).

[16]A problem with this procedure is that, even if wheat straw or other crop residue could be fed to stomach capacity, animals could not maintain body weight.

[17]Refer to Corkren and others (*4*) and Tyner and others (*39*) for further information on estimating the feed value of crop residues.

rations. These feeding values, updated to 1982 price levels, ranged from $2.40 to $17.40 per ton for sugarcane bagasse to $85.80 to $92.20 per ton for oat straw (table 16). Of the residues accounting for the largest tonnage of Great Plains crop residues, corn stover had a feeding value of $73.20 to $78.40 per ton; grain sorghum, $79.00 to $85.00 per ton; and wheat $54.60 to $70.60 per ton. In terms of energy value, corn stover showed $5.22 to $5.60 per million Btu; grain sorghum stover, $5.64 to $6.07 per million Btu; and wheat straw, $3.64 to $4.71 per million Btu. Thus the value of crop residues for feed was greater than for fertilizer (see table 14).

All products, including crop residues, flow to their highest value market use. Price, in the absence of policy, will determine the flow of crop residues. Therefore, price relationships will dictate the availability of crop residues for fuel production; they will determine the use of biomass for fertilizer, feed, or fuel. Similarly, price relationships will determine the availability of agricultural processing wastes for livestock feed versus other uses.

**Table 15—Number of beef cows in Great Plains States, 1980 and 1990 projected**

| State | Beef cows | |
|---|---|---|
| | 1980[1] | 1990[2] |
| | *Thousands* | |
| Northern Great Plains: | | |
| North Dakota | 962 | 1,101 |
| South Dakota | 1,530 | 1,822 |
| Nebraska | 1,950 | 2,092 |
| Montana | 1,427 | 1,700 |
| Wyoming | 620 | 604 |
| Subtotal | 6,489 | 7,319 |
| Southern Great Plains: | | |
| Colorado | 853 | 931 |
| Kansas | 1,716 | 1,821 |
| New Mexico | 626 | 610 |
| Oklahoma | 2,160 | 2,270 |
| Texas | 5,585 | 5,323 |
| Subtotal | 10,940 | 10,955 |
| Total | 17,429 | 18,274 |

[1]1980 data from (*41*).
[2]1990 estimates based on NIRAP State-by-State projections for beef and veal.

**Table 16—Estimated values of residues**

| Residue | Range in value computed in 1978 | Range in value updated to 1982[1] |
|---|---|---|
| | *Dollars/ton* | |
| Barley | 45.00–58.00 | 61.60–79.20 |
| Corn | 53.60–57.40 | 73.20–78.40 |
| Cotton | 46.80–61.60 | 64.00–84.20 |
| Dry beans | 57.80–59.60 | 79.00–81.40 |
| Flax | 49.40–64.00 | 67.60–87.40 |
| Grain sorghum | 57.80–62.20 | 79.00–85.00 |
| Grass seed | 35.20–53.20 | 48.20–72.80 |
| Oats | 62.80–67.40 | 85.80–92.20 |
| Peanuts | 35.40–55.60 | 48.40–76.00 |
| Rice | 30.00–53.80 | 41.00–73.60 |
| Rye | 44.20–55.40 | 60.40–75.80 |
| Soybeans | 40.40–54.80 | 55.20–75.00 |
| Sugar beets | 30.60–40.60 | 41.80–55.60 |
| Sugarcane | 1.80–12.80 | 2.40–17.40 |
| Wheat | 40.00–51.60 | 54.60–70.60 |

[1]Updated from 1978 to 1982 price levels using production multiplied by index shown in appendix table 21.

Source: (*4*).

## Conventional Versus Reduced Tillage

Conventional tillage methods also sharply limit the volume of crop residues which can be removed from soils in the Great Plains. According to the 1980 RCA study, farmers still applied conventional tillage methods to 75 percent of the Great Plains cropland (*46*). However, conservation tillage is becoming more popular. Most soil scientists agree that the degree of effectiveness in conserving soils and the amount of residues available for energy conversion are determined largely by tillage practice. As tillage declines, crop residues become plentiful. The amount of residue available from wheat, with a soil loss tolerance level of 5 tons per acre, is 0.9 ton per acre with conventional tillage, 1.2 tons per acre with conservation tillage, and just over 1.4 tons per acre with conservation tillage plus mulching. The amount of the increase in available crop residues may range from 2 to 10 times that of conventionally tilled land, a substantial increase for the Great Plains. Even with reduced tillage, however, land slope is a major constraint to crop-residue removal (*11*).

## Literature Review

At least four major crop-residue inventory studies were written before this study (table 17). Each study differs slightly, but all are based on estimates of residue-to-grain ratios provided by staff scientists of the U.S. Department of Agriculture's Agricultural Research Service (ARS). These scientists, however, do not agree on the accuracy of these ratios, so published estimates have been revised from time to time. The same is true of erosion coefficients. Larson and others, including Gupta, have published a set of coefficients (*11*). Larson has revised his estimates several times because of disagreement from other soil scientists over these estimates. According to Corkren and others, their disagreement on the relationship between crop yields and quantities of residues reflects a need for more reliable information on this subject (*4*).

Tyner recognized three studies written before his Purdue study. Two were not completely detailed inventories. According to Tyner, the three most significant studies on a national scale were: the Stanford Research Institute (SRI) study conducted for the National Science Foundation (*36*); the study by the Midwest Research Institute (MRI) in Kansas City (*23*); and the study by ARS with coordination by Larson (*17*).

SRI calculated total amounts of residue produced by county, using a residue-to-grain ratio of 0.55 for corn in all States except Texas. This value appears low because measurements from other studies have values of about 1.0, but the values may have resulted from an assumption that 55 percent of corn residues were harvested and fed to livestock. Actually only a small percentage of the harvested corn acreage was harvested residues. SRI values came from average county yields and acreages of 1971-73 crops reported by States. SRI included many low-acreage crops. Tyner, critical of the SRI study, stated that it does not use accurate factors for calculating residue amounts and contains errors.

MRI appears to have used the SRI values; however, rather than reporting averages by State, they gave the results by MLRA. MRI placed counties into the MLRA's, which were mostly contained within the MLRA boundary, and calculated values for forage and grassland as well as cropland. Tyner said that the MRI study contained many of the same errors as the SRI study.

According to Tyner, the Larson study was the most useful for his report because it used realistic factors for multiplying by grain yields to obtain the total resource base. Larson's crop-residue base was evaluated for each MLRA within each State so that values could be reported both by State and MLRA. The Larson study analyzed four regions of the country: the Corn Belt, the Great Plains, the western wheat area, and six Southeastern States.

Tyner used data supplied by Larson to calculate usable residues for energy production. Like Larson, he correctly used wind erosion coefficients for a major portion of the Great Plains. He estimated total residues based on yield data for 1975 through 1977 and multiplied the tons of grain produced by the appropriate factor for each crop. Surplus residues from soybeans and cotton were assumed uncollectable. Although he

**Table 17—Summary of national crop residue inventory studies**

| Agency and source | Date | Inventory | Study |
|---|---|---|---|
| Science and Education Administration/Agricultural Research Service and Economic Research Service (*4*) | 1975 data, 1979 publication | State-by-State County-by-county | Feasibility and effects of increased use of crop residues in beef cattle rations |
| Purdue University, Office of Technology Assessment, U.S. Congress (*39*) | 1975–77 data, 1979 publication | Major States | The potential of producing energy from agriculture |
| Stanford Research Institute (*35*) | 1971–73 data, 1977 publication | State-by-State County-by-county | Crop-, forestry-, and manure-residue inventory: continental United States |
| Solar Energy Research Institute (*21*) | 1978 data, 1981 draft | State-by-State County-by-county | Feasibility of using agricultural residues for energy production |

stated that he tabulated crop residues by MLRA, Tyner reported only State data. His data also appeared to be marked by imprecise estimates. For example, his yield estimates were too low in major irrigation areas of the Great Plains. In Nebraska Tyner reported a corn grain yield of only 63 bushels per acre. In 1980 Nebraska's corn yields were 101 and 48 bushels per acre on irrigated and dry land, respectively, and the State's irrigated acreage accounted for well over two-thirds of the total acreage. Not only were Tyner's yield assumptions low, he did not adjust Larson's coefficient (ratio of residue to grain) upward for irrigated corn. Agronomists at the 1982 Vegetable Oils and Fuel Symposium, Fargo, ND, and others, agreed that the added forage on high-yielding irrigated acreage makes a ratio of 1.5:1 bushels more realistic. Although Tyner recognized the importance of areas of high crop-residue concentration, he was satisfied only with reporting State totals for crops yielding 1.5 million tons or more of usable residue. An extensive review of the literature suggests that most researchers involved in conversion plant location and assembly costs limit their trade area to no more than a 50-mile radius, so State totals are insufficient for a subsequent plant location analysis.

The Corkren study based its crop-residue ratio on data from "senior ARS scientists." The report does not indicate if it includes Larson. The fact that the coefficients are decidedly different would suggest thinking independent of the Larson estimates. At any rate, Corkren's results are inaccurate because of the inclusion of rather high residue coefficients for cotton (3.00) and soybeans (2.14). Much of Corkren's methodology is not explained; however, his State-by-State totals show that he, unlike Tyner, correctly accounted for the effects of irrigation. Also, he correctly identified Nebraska and Kansas as the Great Plains States with the largest available crop-residue tonnage.

The Solar Energy Research Institute (SERI) based its county-level study on the 1978 Agricultural Census. SERI's estimates appear to have been properly adjusted for erosion prevention and to have been independently developed. SERI's sorghum ratio appeared high and the corn ratio low. SERI did not allow any sensitivity in residue coefficients by State or high yield area, such as the irrigated High Plains. SERI erroneously determined that there was collectable residue from soybeans. The SERI and Corkren studies showed very similar results for some States but no pattern of consistency in others. In fact some State totals were so inconsistent that it is impossible, in the absence of further studies, to conclude that either is correct.

A similar pattern of inconsistency between studies existed for estimates of Btu per pound of agricultural crop residues. For example, studies showed corn energy values in a range of 6,000 to 8,000 Btu per pound; grain sorghum, 6,000 to 7,500 Btu per pound; and wheat, 6,650 to 8,539 Btu per pound. Part of this apparent inconsistency may be traced to unexplained assumptions concerning moisture content or calorific values of crude fiber versus combustible matter (*7*). A study by Oursbourn and others presents a well-documented review of energy conversion values (*28*). However, for corn and grain-sorghum residue, their values were among the most conservative reported, but were about average for wheat and other small-grain residues. This report used the following value for the major sources of crop residue:

| | |
|---|---|
| Corn | 7,000 Btu/lb. |
| Grain sorghum | 7,000 Btu/lb. |
| Wheat | 7,500 Btu/lb. |

Results of this report show the Corkren study to be the most accurate. None of the previous studies explicitly identified major areas of high crop-residue concentration, although county studies contained these areas.

## Conclusions

By 1990 nearly 125 million tons of crop residues may stay in fields following harvest; nearly 53 million tons could be removed without causing erosion. Except for a few areas in the Great Plains, however, these residues will continue to span a wide area. Collection costs in the early 1980's suggest that farmers will collect crop residues for fuel production only in isolated areas of short-haul shipping. However, some processing plants in the Great Plains may economically burn wastes from agricutural processing.

If, by 1990 and beyond, fuel prices continue to escalate as expected, then crop residues may become an economical source of energy, probably in those areas of high concentration identified in this report. In most cases, these residues will probably be combined with the direct burning of municipal solid wastes. Many more municipalities, unable to find suitable dump sites, are constructing conversion plants. This trend may lead to, at least, a limited off-farm market for crop residues as feedstock flow stabilizers by 1990 regardless of the rise in conventional fuel costs.

As markets for crop residues develop, policies must work to limit soil erosion and to encourage forage production or cropland specifically for fuel. In both cases, the temptation for shortrun economic gain may prevail over the wisdom of conservation and humanitarian concern for world hunger.

## Bibliography


(1) Abdallah, Mohammed H. "Economics of Corn Stover as a Coal Supplement in Steam-Electric Power Plants in the North Central United States." Ph.D. dissertation, Ohio State Univ., Columbus, 1978.

(2) Bhagat, N., and others. *Crop Residues as a Fuel for Power Generation.* BNL 59082, Brookhaven National Laboratory, Upton, NY, July 1979.

(3) Buchele, Wesley. "Direct Combustion of Crop Residues in Furnace Boilers." Paper No. J 8791, Agriculture and Home Economics Experiment Station, Ames, IA, 1976.

(4) Corkren, R., and others. *Feasibility and Effects of Increased Use of Crop Residues in Beef Cattle Rations, An Exploratory Study.* ESCS staff paper, U.S. Dept. Agr., Econ. Stat. Coop. Serv., May 1979.

(5) Dauve, Jan, and Silvio Flaim. *Agricultural Crop Residue Collection Costs.* SERI/RR-353-354, Solar Energy Research Institute, Golden, CO, Dec. 1979.

(6) Dobie, John, and others. "Management of Rice Straw for Utilization," *Transactions of the ASAE,* Vol. 20, No. 6, 1977.

(7) Flaim, Silvio, and Daniel Urban. *The Costs of Using Crop Residues in Direct Combustion Application.* SERI/TR-353-513, Solar Energy Research Institute, Golden, CO, Mar. 1980.

(8) Flaim, Silvio, and Marty Young. *Biomass Storage Costs for Grain and Crop Residues.* SERI/TR-134-895, Solar Energy Research Institute, Golden, CO, 1981.

(9) Green, Farno L. "Energy Potential from Agricultural Field Residues." Paper presented to Special Non-Nuclear Technology Session of the American Nuclear Society, New Orleans, LA, 1975.

(10) Griffin, Anselm. "Fuel Value and Ash Control of Ginning Wastes," *Transactions of the American Society of Agricultural Engineers,* Vol. 19, No. 1, pp. 156-158, 1976.

(11) Gupta, S. C., and others."Predicting the Effects of Tillage and Crop Residue Management on Soil Erosion." Published in *Effects of Tillage and Crop Residue Management on Erosion, Runoff, and Plant Nutrients.* Special Report No. 25, Soil Conservation Society of America, Ankeny, IA, 1979.

(12) Heid, Walter G., Jr. "Aftermath Grazing: Methodology for Computing Economic Importance." Unpublished paper, U.S. Dept. Agr., Econ. Res. Ser., Dec. 17, 1982.

(13) Horsfield, Brian C., and others. *Agricultural Residues as an Alternative Source of Energy for the Pacific Gas and Electric Company.* Research report prepared by Dept. Agr. Eng., Univ. of California, Davis, for Pacific Gas and Electric Co., San Francisco, Aug. 1979.

(14) Kawaksing, P., and H. M. Lapp. "Feasibility for Energy Recovery from Cereal Crop Residues." Paper presented at Annual Meeting of Canadian Society of Agricultural Engineering, 1975.

(15) Koelsch, R. K., and others. *Use of Crop Residues to Support a Municipal Electric Utility.* Final report, CES No. 41, The Center for Energy Studies, College of Engineering, Kansas State Univ., Manhattan, Apr. 1977.

(16) Lansford, R. R., and others. *Economics of Wind Energy for Irrigation Pumping.* Final report, DOE/SEA-7315-20741/81/2, prepared by U.S. Dept. Agr., Agr. Res. Serv., for the U.S. Dept. Energy, Jul. 14, 1980.

(17) Larson, W. E., and others. "Residues for Soil Conservation," Chapter 1 in *Crop Residue Management and Systems.* American Society of Agronomy, Madison, WI, 1978.

(18) Larue, Jacob L. "The Heat Value of Various Agricultural Crop Residues and Sewage Sludge Compost," *1975 National Student Journal of American Society of Agricultural Engineers,* 1975.

(19) Lipinsky, Edward S., and others. *Systems Study of the Potential Integration of U.S. Corn Production and Cattle Feeding with Manufacture of Fuels Via Fermentation.* Vol. 1, BMI-2033, Battelle Columbus Laboratories, Columbus, OH, 1979.

(20) Marks, Lionel S. *Mechanical Engineer's Handbook.* Sixth edition. McGraw Hill Book Co., Inc., New York, 1958.

(21) Max, Wendy, and others. *Feasibility of Using Agricultural Residues for Energy Production, Vol. 1, Methodology.* SERI draft prepared under Task No. 6727.40, Solar Energy Research Institute, Golden, CO, Sept. 1981.

(22) McCaskill, O. L., and R. A. Wesley. "Energy from Cotton Gin Waste," *Ginner's Journal and Yearbook,* 1976.

(23) Midwest Research Institute, and Battelle Columbus Laboratories. Proceedings of the "Biomass—A Cash Crop for the Future?" Conference, Kansas City, MO, Mar. 1977.

(24) Miles, T. R. "Btu's by the Bale." Paper presented at the Pacific Northwest Bio-conversion Workshop, Portland, OR., Oct. 1978.

(25) Miller, Dwight L. "Agricultural and Industrial Energy." Proceedings of Eighth National Conference on Wheat Utilization Research, Manhattan, KS, 1972.

(26) Miller Publishing Co. "Truck Cost Management in the Feed Industry," *Feedstuffs,* Vol. 53, No. 31, Minneapolis, MN, Jul. 27, 1981.

(27) Office of Technology Assessment. *Energy from Biological Processes, Vol. II, Technical and Environment Analyses.* U.S. Congress, Sept. 1980.

(28) Oursbourn, C. D., and others. *Energy Potential of Texas Crops and Agricultural Residues.* MP-1361, Center for Energy and Mineral Resources, Texas A&M Univ., College Station, Feb. 1978.

(29) Richey, C. B., and others. "Corn Stover Harvest for Energy Production," *Transactions of the American Society of Agricultural Engineers,* Vol. 25, No. 4, pp. 834-839, 1982.

(30) Schnake, L. D., and Carl A. Stevens, Jr. *Inland Grain Elevator Operating Costs and Capital Requirements, 1982.* Kansas Agr. Expt. Stat., Bull. 644, Kansas State Univ., Manhattan, Sept. 1983.

(31) Schooley, Fred, and others. *Waste and Land Availability for Energy Farming.* Final Report, DOE/ET/20076-T1, prepared for the U.S. Dept. Energy by Stanford Research Institute, Menlo Park, CA, Oct. 1979.

(32) Short, C., and others. "The Cost of Crop Residues as an Auxiliary Fuel Source for Coal Fired Power Plants." Proceedings of Fifth Annual UMR-DNR Conference and Exposition on Energy, Rolla, MO, Oct. 1978.

(33) Skidmore, E. L., and others. "Crop Residue Management for Wind Erosion Control in the Great Plains." *Effects of Tillage and Crop Residue Removal on Erosion, Runoff, and Plant Nutrients.* Special Report No. 25, Soil Conservation Society of America, Ankeny, IA, 1979.

(34) Sosland Publishing Co. "Wheat Farmers to Idle 35.3% of Acreage." *Milling and Baking News,* Kansas City, MO, Mar. 29, 1983.

(35) Stanford Research Institute. *An Evaluation of the Use of Agricultural Residues as an Energy Feedstock, Vol. I.* Prepared for the National Science Foundation, Washington, DC, 1976.

(36) ________. *An Evaluation of the Use of Agricultural Residues as an Energy Source, Vol. 1.* Menlo Park, CA, July 1977.

(37) Steffgen, Fred W. "Energy from Agricultural Products." Paper presented at the American Society of Agronomy, Las Vegas, NV, 1973.

(38) Systems Technology Corp. *Preliminary Feasibility Analysis of a County-wide Resource Recovery Facility for Cameron County, Texas, Final Report.* SYSTECH Proj. No. 493, Xenia, OH, Jan. 1981.

(39) Tyner, Wallace E. *The Potential of Producing Energy from Agriculture*. Final report prepared for the Office of Technology Assessment, U.S. Congress, by Purdue Univ., West Lafayette, IN, May 1979.

(40) U.S. Department of Agriculture. Statistical Reporting Service. *Crop Production*. Annual summaries, various issues.

(41) ________. Statistical Reporting Service. *Agricultural Statistics, 1981*.

(42) ________. Economic Research Service. *Agricultural Outlook*. Various issues.

(43) ________. Economic Research Service, International Economics Division. National-Interregional Agricultural Projections Systems (NIRAP), unpublished projections, 1983.

(44) ________. Economic Research Service. *Livestock and Meat Statistics, Supplement for 1980*. SB-522, Sept. 1981.

(45) ________. Office of Transportation. *Owner-Operator Truck Cost Guide*. OT-3, Apr. 1980.

(46) ________. *RCA Soil, Water, and Related Resources in the United States: Status, Condition, and Trends, 1980 Appraisal, Part I*. Directed by Soil and Water Resources Conservation Act, Mar. 1981.

(47) ________. *RCA Soil, Water, and Related Resources in the United States: Analysis of Resource Trends, 1980 Appraisal, Part II*. Directed by Soil and Water Resources Conservation Act, Aug. 1981.

(48) U.S. Department of Energy. Office of Environmental Assessment. *A Technology Assessment of Solar Energy Systems: Environmental Residuals and Capital Cost of Energy Recovery from Municipal Sludge and Feedlot Manure*. DOE/EV-0107, Sept. 1980.

(49) ________. *Anaerobic Fermentation of Agricultural Residues—Potential for Improvement and Implementation*. TID-28736, report prepared by the College of Agriculture and Life Sciences, Cornell Univ., Ithaca, NY, 1978.

(50) ________. *Analysis of Digester Design Concepts*. C00-2991-42, report prepared by Dynatech Research and Development Co., Cambridge, MA, Jan. 1979.

(51) VanDyne, Donald, L., and C. B. Gilbertson. *Estimating U.S. Livestock and Poultry Manure and Nutrient Production*. ESCS-12, U.S. Dept. Agr., Econ. Stat. Coop. Serv., Mar. 1978.

**Appendix table 1—North Dakota: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 148,025 | 1.75 | 259,458 | 1.00 | 259,458 | 11 | 28,540 |
| Barley | 2,247,678 | 1.12 | 2,524,555 | 1.50 | 3,786,834 | 24 | 912,784 |
| Spring wheat | 1,376,887 | 1.12 | 1,536,606 | 1.30 | 1,997,588 | 73 | 1,458,239 |
| Oats | 1,075,002 | .95 | 1,019,474 | 1.40 | 1,427,264 | 17 | 242,591 |
| Rye | 101,891 | 1.01 | 102,865 | 1.50 | 154,297 | 15 | 23,591 |
| Other small grain | 377,089 | 1.32 | 497,726 | 1.50 | 746,589 | 16 | 115,717 |
| Subtotal | 5,326,572 | — | 5,940,684 | — | 8,372,030 | — | 2,781,462 |
| Irrigated: | | | | | | | |
| Corn | 1,771 | 2.06 | 3,650 | 1.00 | 3,650 | 11 | 402 |
| Barley | 1,292 | 1.68 | 2,174 | 1.50 | 3,261 | 15 | 505 |
| Spring wheat | 672 | 1.94 | 1,300 | 1.30 | 1,690 | 73 | 1,234 |
| Oats | 1,410 | 1.26 | 1,774 | 1.40 | 2,484 | 10 | 251 |
| Other small grain | 1,029 | 2.07 | 2,129 | 1.50 | 3,194 | 16 | 511 |
| Subtotal | 6,174 | — | 11,027 | — | 14,279 | — | 2,903 |
| Total | 5,332,746 | — | 5,951,711 | — | 8,386,309 | — | 2,784,365 |

— = Not applicable. [1]Base-year average, 1978–82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing.

**Appendix table 2—South Dakota: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 1,948,384 | 2.20 | 4,280,141 | 1.00 | 4,287,733 | 75 | 3,204,091 |
| Grain sorghum | 146,500 | 2.02 | 295,625 | 1.00 | 295,625 | 70 | 206,937 |
| Barley | 445,590 | 1.24 | 552,236 | 1.50 | 828,353 | 32 | 263,333 |
| Winter wheat | 649,092 | .95 | 615,563 | 1.70 | 1,046,456 | 26 | 276,093 |
| Spring wheat | 722,548 | .95 | 689,894 | 1.30 | 896,862 | 36 | 318,496 |
| Oats | 2,006,539 | .85 | 1,702,379 | 1.40 | 2,383,331 | 30 | 726,133 |
| Rye | 44,320 | 1.10 | 48,909 | 1.50 | 73,365 | 23 | 16,621 |
| Other small grain | 27,448 | 1.35 | 37,130 | 1.50 | 55,695 | 15 | 8,355 |
| Subtotal | 5,990,421 | — | 8,221,877 | — | 9,867,420 | — | 5,020,059 |
| Irrigated: | | | | | | | |
| Corn | 23,390 | 3.05 | 71,442 | 1.25[5] | 89,625 | 28 | 25,446 |
| Barley | 810 | 1.35 | 1,093 | 1.50 | 1,640 | 16 | 262 |
| Oats | 4,154 | 1.18 | 4,894 | 1.40 | 6,851 | 12 | 834 |
| Subtotal | 28,354 | — | 77,429 | — | 98,116 | — | 26,542 |
| Total | 6,018,775 | — | 8,299,306 | — | 9,965,536 | — | 5,046,601 |

— = Not applicable. [1]Base-year average, 1978–82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 3—Nebraska: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 1,919,580 | 3.01 | 5,784,131 | 1.43[5] | 8,281,266 | 45 | 3,748,443 |
| Grain sorghum | 1,306,244 | 2.20 | 2,875,636 | 1.00 | 2,875,636 | 38 | 1,096,797 |
| Barley | 10,968 | 1.08 | 11,875 | 1.50 | 17,808 | 20 | 3,632 |
| Winter wheat | 1,816,110 | 1.02 | 1,859,917 | 1.70 | 3,161,859 | 34 | 1,075,758 |
| Oats | 349,325 | .91 | 318,288 | 1.40 | 445,604 | 18 | 79,818 |
| Rye | 33,930 | .63 | 21,395 | 1.50 | 32,073 | 16 | 5,265 |
| Other small grain | 938 | 1.06 | 995 | 1.50 | 1,493 | 8 | 119 |
| Subtotal | 5,437,095 | — | 10,872,237 | — | 14,815,739 | — | 6,009,832 |
| Irrigated: | | | | | | | |
| Corn | 5,133,272 | 4.17 | 21,382,949 | 1.50[5] | 32,074,424 | 46 | 14,709,477 |
| Grain sorghum | 151,404 | 3.07 | 464,523 | 1.00 | 464,523 | 36 | 166,977 |
| Barley | 2,281 | 1.44 | 3,282 | 1.50 | 4,923 | 5 | 256 |
| Winter wheat | 29,275 | 1.62 | 47,294 | 1.70 | 80,400 | 51 | 41,310 |
| Oats | 1,630 | 1.10 | 1,791 | 1.40 | 2,508 | 8 | 196 |
| Subtotal | 5,317,862 | — | 21,899,839 | — | 32,626,778 | — | 14,918,216 |
| Total | 10,754,957 | — | 32,772,076 | — | 47,442,517 | — | 20,928,048 |

— = Not applicable. [1]Base-year average, 1978–82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 4—Montana: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 2,527 | 1.93 | 4,882 | 1.00 | 4,882 | 25 | 1,216 |
| Barley | 626,279 | 1.01 | 632,919 | 1.50 | 949,379 | 19 | 176,378 |
| Winter wheat | 1,780,921 | .91 | 1,618,652 | 1.70 | 2,751,710 | 20 | 557,321 |
| Spring wheat | 41,150 | .84 | 34,627 | 1.30 | 45,016 | 21 | 9,453 |
| Durum wheat | 2,050 | .88 | 1,795 | 1.30 | 2,334 | 21 | 490 |
| Oats | 92,973 | .87 | 80,540 | 1.40 | 113,154 | 21 | 23,405 |
| Rye | 3,456 | .81 | 2,797 | 1.50 | 4,196 | 4 | 168 |
| Other small grain | 64,300 | 1.17 | 75,292 | 1.50 | 112,939 | 13 | 15,226 |
| Subtotal | 2,613,656 | — | 2,451,504 | — | 3,983,610 | — | 783,657 |
| Irrigated: | | | | | | | |
| Corn | 6,468 | 3.53 | 22,819 | $1.50^5$ | 34,229 | 24 | 8,198 |
| Barley | 177,073 | 1.71 | 303,014 | 1.50 | 454,521 | 21 | 93,571 |
| Winter wheat | 36,079 | 1.62 | 58,738 | 1.70 | 99,854 | 21 | 20,486 |
| Spring wheat | 12,750 | 1.80 | 22,891 | 1.30 | 29,758 | 21 | 6,249 |
| Oats | 23,404 | 1.35 | 31,575 | 1.40 | 44,204 | 21 | 9,283 |
| Other small grain | 129 | 1.99 | 257 | 1.50 | 386 | 21 | 81 |
| Subtotal | 255,903 | — | 439,294 | — | 662,952 | — | 137,868 |
| Total | 2,869,559 | — | 2,890,798 | — | 4,646,562 | — | 921,525 |

— = Not applicable. [1]Base-year average, 1978–82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 5—Wyoming: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 595 | 1.31 | 780 | 1.00 | 780 | 34 | 264 |
| Barley | 16,763 | .83 | 13,936 | 1.50 | 20,903 | 21 | 4,390 |
| Winter wheat | 83,871 | 1.08 | 90,277 | 1.70 | 153,472 | 20 | 31,133 |
| Spring wheat | 1,900 | .64 | 1,225 | 1.30 | 1,592 | 21 | 334 |
| Oats | 23,585 | .76 | 17,969 | 1.40 | 25,157 | 18 | 4,432 |
| Rye | 85 | .70 | 60 | 1.50 | 90 | 20 | 18 |
| Other small grain | 682 | .98 | 670 | 1.50 | 1,005 | 20 | 201 |
| Subtotal | 127,481 | — | 124,917 | — | 202,999 | — | 40,772 |
| Irrigated: | | | | | | | |
| Corn | 30,335 | 2.91 | 88,399 | $1.50^5$ | 132,692 | 35 | 45,873 |
| Barley | 112,578 | 1.97 | 221,817 | 1.50 | 332,725 | 21 | 69,872 |
| Winter wheat | 2,594 | 1.41 | 3,659 | 1.70 | 6,220 | 21 | 1,278 |
| Spring wheat | 1,700 | 1.40 | 2,382 | 1.30 | 3,097 | 21 | 650 |
| Oats | 24,573 | 1.25 | 30,828 | 1.40 | 43,159 | 21 | 9,037 |
| Subtotal | 171,780 | — | 347,085 | — | 517,893 | — | 126,710 |
| Total | 299,261 | — | 472,002 | — | 720,892 | — | 167,482 |

— = Not applicable. [1]Base-year average, 1978–82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 6—Kansas: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 490,613 | 2.76 | 1,356,261 | 1.46[5] | 1,985,634 | 30 | 588,574 |
| Grain sorghum | 2,263,112 | 2.14 | 4,836,436 | 1.00 | 4,836,436 | 50 | 2,446,645 |
| Barley | 31,278 | 1.23 | 38,343 | 1.50 | 57,509 | 32 | 18,363 |
| Wheat | 6,497,201 | 1.21 | 7,859,093 | 1.70 | 13,360,509 | 43 | 5,816,366 |
| Oats | 46,374 | .78 | 36,314 | 1.40 | 50,840 | 33 | 16,865 |
| Rye | 600 | .93 | 558 | 1.50 | 837 | 12 | 98 |
| Other small grain | 159 | 1.43 | 227 | 1.50 | 340 | 11 | 37 |
| Subtotal | 9,329,337 | — | 14,127,232 | — | 20,292,105 | — | 8,886,948 |
| Irrigated: | | | | | | | |
| Corn | 1,099,610 | 4.49 | 4,937,270 | 1.50[5] | 7,405,905 | 35 | 2,605,389 |
| Grain sorghum | 31,575 | 3.57 | 112,874 | 1.00 | 112,874 | 30 | 34,419 |
| Barley | 183 | 1.68 | 307 | 1.50 | 460 | 10 | 46 |
| Wheat | 109,841 | 1.65 | 181,353 | 1.70 | 308,300 | 33 | 103,103 |
| Subtotal | 1,241,209 | — | 5,231,804 | — | 7,827,539 | — | 2,742,957 |
| Total | 10,570,546 | — | 19,359,036 | — | 28,119,644 | — | 11,629,905 |

— = Not applicable. [1]Base-year average, 1978-82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 7—Colorado: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 21,479 | 0.70 | 14,986 | 1.00 | 14,986 | 32 | 4,759 |
| Grain sorghum | 1,200 | .82 | 978 | 1.00 | 978 | 70 | 685 |
| Barley | 15,637 | .63 | 9,793 | 1.50 | 14,689 | 13 | 1,926 |
| Winter wheat | 205,700 | .64 | 131,717 | 1.70 | 223,919 | 13 | 29,109 |
| Spring wheat | 7,800 | .87 | 6,809 | 1.30 | 8,852 | 13 | 1,151 |
| Oats | 7,000 | .56 | 3,927 | 1.40 | 5,498 | 13 | 714 |
| Other small grain | 4,066 | .59 | 2,391 | 1.50 | 3,586 | 15 | 538 |
| Subtotal | 262,882 | — | 170,601 | — | 272,508 | — | 38,882 |
| Irrigated: | | | | | | | |
| Corn | 678,359 | 4.13 | 2,803,583 | 1.50[5] | 4,205,011 | 32 | 1,339,605 |
| Grain sorghum | 1,400 | 2.34 | 3,269 | 1.00 | 3,269 | 70 | 2,288 |
| Barley | 125,363 | 1.96 | 246,281 | 1.50 | 369,422 | 13 | 48,212 |
| Winter wheat | 4,700 | 1.65 | 7,741 | 1.70 | 13,160 | 13 | 1,710 |
| Spring wheat | 1,100 | 1.43 | 1,569 | 1.30 | 2,039 | 13 | 265 |
| Oats | 20,400 | 1.15 | 23,500 | 1.40 | 32,900 | 13 | 4,276 |
| Other small grain | 97 | 1.64 | 159 | 1.50 | 238 | 15 | 36 |
| Subtotal | 831,419 | — | 3,086,102 | — | 4,626,039 | — | 1,396,392 |
| Total | 1,094,301 | — | 3,256,703 | — | 4,898,547 | — | 1,435,274 |

— = Not applicable. [1]Base-year average, 1978-82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 8—New Mexico: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 1,488 | 0.84 | 1,250 | 1.00 | 1,250 | 38 | 475 |
| Barley | 1,869 | .62 | 1,165 | 1.50 | 1,748 | 20 | 351 |
| Wheat | 4,980 | .66 | 3,287 | 1.70 | 5,588 | 60 | 3,353 |
| Subtotal | 8,337 | — | 5,702 | — | 8,586 | — | 4,179 |
| Irrigated: | | | | | | | |
| Corn | 72,983 | 1.22 | 88,735 | 1.50[5] | 133,103 | 42 | 55,753 |
| Barley | 25,169 | 1.66 | 41,905 | 1.50 | 62,858 | 46 | 28,661 |
| Grain sorghum | 30,590 | 3.31 | 101,187 | 1.00 | 101,187 | 70 | 70,832 |
| Wheat | 13,980 | 2.08 | 29,143 | 1.70 | 49,543 | 60 | 29,726 |
| Subtotal | 142,722 | — | 260,970 | — | 346,691 | — | 184,972 |
| Total | 151,059 | — | 266,672 | — | 355,277 | — | 189,151 |

— = Not applicable.
[1]Base-year average, 1978–82.
[2]Based on 1983 ERS-NIRAP projections.
[3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion.
[4]Total quantity of available crop residue before adjustment for aftermath grazing.
[5]Reflects adjusted Larson's coefficient.

**Appendix table 9—Oklahoma: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 27,965 | 1.61 | 44,946 | 1.13[5] | 50,851 | 40 | 20,204 |
| Grain sorghum | 84,194 | .75 | 62,888 | 1.00 | 62,888 | 70 | 44,021 |
| Barley | 34,777 | 1.08 | 37,486 | 1.50 | 56,228 | 33 | 18,302 |
| Wheat | 2,506,387 | 1.10 | 2,757,520 | 1.70 | 4,687,790 | 51 | 2,390,665 |
| Oats | 64,764 | .79 | 51,264 | 1.40 | 71,769 | 24 | 16,919 |
| Rye | 6,609 | .70 | 4,626 | 1.50 | 6,938 | 31 | 2,161 |
| Other small grain | 419 | 1.36 | 568 | 1.50 | 852 | 25 | 217 |
| Subtotal | 2,725,115 | — | 2,959,298 | — | 4,937,316 | — | 2,492,489 |
| Irrigated: | | | | | | | |
| Corn | 25,362 | 4.27 | 108,235 | 1.49[5] | 161,659 | 38 | 61,646 |
| Grain sorghum | 4,952 | 1.21 | 5,988 | 1.00 | 5,988 | 70 | 4,191 |
| Barley | 462 | 1.31 | 604 | 1.50 | 906 | 11 | 100 |
| Wheat | 7,064 | 1.36 | 9,592 | 1.70 | 16,306 | 35 | 5,659 |
| Oats | 294 | 1.04 | 305 | 1.40 | 427 | 20 | 85 |
| Rye | 160 | .98 | 157 | 1.50 | 236 | 37 | 87 |
| Subtotal | 38,294 | — | 124,881 | — | 185,522 | — | 71,768 |
| Total | 2,763,409 | — | 3,084,179 | — | 5,122,838 | — | 2,564,257 |

— = Not applicable. [1]Base-year average, 1978–82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 10—Texas: Crop residue available for fuel production, by farming practice and crop, 1990 projections**

| Crop | Harvestable area[1] | Yield per acre[2] | Total grain production | Residue-to-grain ratio | Total crop residue | Harvest fraction[3] | Residues available after adjusting for K-factor[4] |
|---|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Tons* | *Ratio* | *Tons* | *Percent* | *Tons* |
| Dryland: | | | | | | | |
| Corn | 307,651 | 2.07 | 638,230 | 1.07[5] | 681,726 | 42 | 298,174 |
| Grain sorghum | 2,209,153 | 1.77 | 3,901,384 | 1.00 | 3,901,384 | 74 | 2,897,052 |
| Barley | 14,290 | .89 | 12,758 | 1.50 | 19,055 | 28 | 5,399 |
| Wheat | 767,970 | .91 | 696,985 | 1.70 | 1,184,830 | 33 | 386,836 |
| Oats | 304,387 | .64 | 193,909 | 1.40 | 271,471 | 26 | 71,109 |
| Rye | 5,128 | .66 | 3,368 | 1.50 | 5,052 | 20 | 1,035 |
| Other small grain | 11,984 | .77 | 9,260 | 1.50 | 13,900 | 49 | 6,859 |
| Subtotal | 3,620,563 | — | 5,455,894 | — | 6,077,418 | — | 3,666,464 |
| Irrigated: | | | | | | | |
| Corn | 830,178 | 5.31 | 4,404,566 | 1.49[5] | 6,571,565 | 40 | 2,624,311 |
| Grain sorghum | 131,257 | 3.47 | 455,949 | 1.00 | 455,949 | 70 | 422,490 |
| Barley | 12,074 | 1.50 | 18,140 | 1.50 | 27,210 | 11 | 2,993 |
| Wheat | 15,651 | 1.88 | 29,350 | 1.70 | 49,895 | 20 | 12,144 |
| Oats | 3,772 | 1.03 | 3,876 | 1.40 | 5,427 | 20 | 1,086 |
| Rye | 580 | 1.33 | 770 | 1.50 | 1,155 | 11 | 127 |
| Rice | 60,000 | 3.32 | 198,900 | 1.50 | 298,350 | 100 | 298,350 |
| Other small grain | 7,917 | 2.28 | 18,042 | 1.50 | 27,063 | 20 | 6,085 |
| Subtotal | 1,061,429 | — | 5,129,593 | — | 7,436,614 | — | 3,367,586 |
| Total | 4,681,992 | — | 10,585,487 | — | 13,514,032 | — | 7,034,050 |

— = Not applicable. [1]Base-year average, 1978-82. [2]Based on 1983 ERS-NIRAP projections. [3]Proportion of total crop residues that can be harvested without significant losses from land or water erosion. [4]Total quantity of available crop residue before adjustment for aftermath grazing. [5]Reflects adjusted Larson's coefficient.

**Appendix table 11—North Dakota: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 53A | 1,926 | 27 | 1,953 |
| 53B | 20,414 | 18 | 20,432 |
| 54 | 89,345 | 468 | 89,813 |
| 55A | 275,282 | 53 | 275,335 |
| 55B | 306,183 | 701 | 306,884 |
| 56 | 2,088,312 | 1,636 | 2,089,948 |
| Total | 2,781,462 | 2,903 | 2,784,365 |

[1]Refer to figure 2.

**Appendix table 12—South Dakota: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 53B | 5,976 | — | 5,976 |
| 53C | 8,107 | — | 8,107 |
| 54 | 12,648 | — | 12,648 |
| 55B | 57,885 | 128 | 58,013 |
| 55C | 102,859 | 172 | 103,031 |
| 58A | 107,408 | — | 107,408 |
| 60A | 34,397 | 10,958 | 45,355 |
| 62 | 1,083 | 10 | 1,093 |
| 63A | 67,252 | — | 67,252 |
| 63B | 36,847 | — | 36,847 |
| 64 | 47,861 | 15,274 | 63,135 |
| 102A | 957,108 | — | 957,108 |
| 102B | 3,580,628 | — | 3,580,628 |
| Total | 5,020,059 | 26,542 | 5,046,601 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 13—Nebraska: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 63B | 8,648 | — | 8,648 |
| 64 | 73,211 | 47,862 | 121,073 |
| 65 | 99,232 | 754,283 | 853,515 |
| 67 | 992 | 141,749 | 142,741 |
| 71 | 245,756 | 2,824,369 | 3,070,125 |
| 72 | 16,113 | 719,217 | 735,330 |
| 73 | 295,924 | 908,179 | 1,204,103 |
| 75 | 878,989 | 5,090,899 | 5,969,888 |
| 102B | 2,243,135 | 1,453,153 | 3,696,288 |
| 106 | 2,147,832 | 2,978,505 | 5,126,337 |
| Total | 6,009,832 | 14,918,216 | 20,928,048 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 14—Montana: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 53A | 7,440 | 36 | 7,476 |
| 54 | 2,343 | — | 2,343 |
| 58A | 643,228 | 82,830 | 726,058 |
| 44 | 130,646 | 55,002 | 185,648 |
| Total | 783,657 | 137,868 | 921,525 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 15—Wyoming: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 58B | 30,101 | 7,730 | 37,831 |
| 62 | 7,985 | 16 | 8,001 |
| 67 | 208 | 32,534 | 32,742 |
| 32 | — | 76,381 | 76,381 |
| 34 | 2,478 | 10,049 | 12,527 |
| Total | 40,772 | 126,710 | 167,482 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 16—Kansas: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 72 | 6,440 | 1,352,693 | 1,359,133 |
| 73 | 2,005,095 | 580,894 | 2,585,989 |
| 74 | 843,899 | 31,010 | 874,909 |
| 75 | 1,144,403 | 269,025 | 1,413,428 |
| 76 | 602,841 | 1,891 | 604,732 |
| 77 | 659 | 122,940 | 123,599 |
| 78 | 148,933 | 111,983 | 260,916 |
| 79 | 377,582 | 180,884 | 558,466 |
| 80A | 886,776 | 8,245 | 895,021 |
| 84A | 14,998 | — | 14,998 |
| 106 | 1,170,764 | 26,958 | 1,197,722 |
| 112 | 1,684,558 | 56,434 | 1,740,992 |
| Total | 8,886,948 | 2,742,957 | 11,629,905 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 17—Colorado: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 67 | 16,010 | 671,464 | 687,474 |
| 69 | 1,417 | 51,846 | 53,263 |
| 72 | 12,089 | 574,384 | 586,473 |
| 51 | — | 39,625 | 39,625 |
| 48A | 9,366 | 59,073 | 68,439 |
| Total | 38,882 | 1,396,392 | 1,435,274 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 18—New Mexico: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 77 | 632 | 13,290 | 13,922 |
| 36 | 3,475 | 19,321 | 22,796 |
| 42 | 72 | 152,361 | 152,433 |
| Total | 4,179 | 184,972 | 189,151 |

[1]Refer to figure 2.

**Appendix table 19—Oklahoma: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 77 | 7,003 | 60,206 | 67,209 |
| 78 | 3,926 | — | 3,926 |
| 80A | 2,225,845 | 4,658 | 2,230,503 |
| 84A | 123,117 | 6,867 | 129,984 |
| 85 | 5,755 | 37 | 5,792 |
| 112 | 96,307 | — | 96,307 |
| 118 | 23,860 | — | 23,860 |
| 119 | 6,676 | — | 6,676 |
| Total | 2,492,489 | 71,768 | 2,564,257 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 20—Texas: Crop residue available for fuel production, by farming practice and major land resource area, 1990 projections**

| Major land resource area[1] | Dryland | Irrigated | Total |
|---|---|---|---|
| | | *Tons* | |
| 77 | 43,043 | 2,378,114 | 2,421,157 |
| 78 | 656 | 8,740 | 9,396 |
| 80A | 54,068 | — | 54,068 |
| 80B | 128,488 | 42 | 128,530 |
| 81 | 95,148 | 3,997 | 99,145 |
| 82 | 464 | 452 | 916 |
| 83A | 281,683 | 57,309 | 338,992 |
| 83B | 3,659 | 68 | 3,727 |
| 83C | 195,090 | — | 195,090 |
| 83D | 573,302 | 546,351 | 1,119,653 |
| 84B | 19,535 | 11,155 | 30,690 |
| 85 | 270,281 | — | 270,281 |
| 86 | 1,166,688 | 315,790 | 1,482,478 |
| 87 | 104,815 | 5,355 | 110,170 |
| 152B | 145,127 | 24,390 | 169,517 |
| 133B | 584,417 | 15,823 | 600,240 |
| Total | 3,666,464 | 3,367,586 | 7,034,050 |

— = Not applicable.
[1]Refer to figure 2.

**Appendix table 21—Index of prices paid by farmers, U.S. average, 1978–82, and indexes selected for updating recent studies of crop-residue collection, storage, and transportation costs**

| Item | 1978 | 1979 | 1980 | 1981 | 1982 |
|---|---|---|---|---|---|
| | | | *1977=100* | | |
| Published indexes: | | | | | |
| A—Production items | 109 | 125 | 138 | 148 | 149 |
| B—Autos and trucks | 106 | 117 | 123 | 143 | 159 |
| C—Fuels and energy | 105 | 137 | 188 | 213 | 211 |
| D—Tractors and self-propelled machinery | 109 | 122 | 136 | 152 | 165 |
| E—Other machinery | 108 | 119 | 132 | 146 | 160 |
| F—Building and fencing | 108 | 118 | 128 | 134 | 135 |
| G—Interest, taxes, and wages | 109 | 125 | 139 | 150 | 154 |
| Indexes used in study: | | | | | |
| (C+D)/2 (Collection) | 107 | 125 | 162 | 183 | 188 |
| (F+G)/2 (Storage) | 109 | 122 | 134 | 142 | 145 |
| (B+C)/2 (Transportation) | 106 | 127 | 156 | 178 | 186 |

Source: (*42*).

**Appendix table 22—Cost estimates for crop-residue harvesting, selected crop residues**

| Source and date of study | Form | Cost: At time of study | Cost: Updated to 1982[1] | Custom rate: At time of study | Custom rate: Updated to 1982[1] |
|---|---|---|---|---|---|
| | | *Dollars/ton* | | | |
| Corn stover: | | | | | |
| (*5*) 1980 | 3-ton stacks | 15.37 | 17.84 | 16.88 | 19.59 |
| | Big round bales | 16.93 | 19.89 | 18.83 | 21.85 |
| | Conventional bales | 24.17 | 28.05 | 21.88 | 25.39 |
| | Loose chop | 12.63 | 14.66 | NA | NA |
| | Big rectangular bales | 25.85 | 30.00 | NA | NA |
| (*19*) 1978 | Conventional bales | 15.70 | 27.59 | NA | NA |
| | 1-ton stacks | 15.15 | 26.62 | NA | NA |
| | 3-ton stacks | 12.90 | 22.67 | NA | NA |
| (*4*) 1979 | 3-ton stacks | 16.60 | 24.97 | 9.80 | 14.74 |
| Rice straw: | | | | | |
| (*6*) 1977 | Conventional bales | 15.75 | 29.61 | NA | NA |
| | Big round bales | 12.70 | 23.88 | NA | NA |
| (*13*) 1977 | Big round bales | 8.23 | 15.47 | NA | NA |
| | Loose chop | 10.00 | 18.80 | NA | NA |
| Wheat straw: | | | | | |
| (*15*) 1977 | Big round bales | 27.30 | 51.32 | 6.89 | 12.95 |
| | Conventional bales | 17.20 | 32.34 | 6.82 | 12.82 |
| | Stacks | 17.10 | 32.15 | 7.13 | 13.40 |
| (*5*) 1980 | 3-ton stacks | 15.99 | 18.56 | 16.48 | 19.12 |
| | Big round bales | 16.52 | 19.17 | 21.20 | 24.60 |
| | Conventional bales | 21.49 | 24.94 | 22.78 | 26.44 |
| | Loose chop | 14.11 | 16.37 | NA | NA |
| | Big rectangular bales | 20.43 | 23.71 | NA | NA |
| (*4*) 1979 | Conventional bales | 20.00 | 30.08 | 16.80 | 25.27 |

NA = Not available.
[1]Updated using Index (C+D)/2, appendix table 21.

**Appendix table 23—Energy conversion rates**

| Crop residue | Source |
|---|---|
| | *Btu/lb*[1] |
| Corn stover | 6,000 (*9, 25*); 7,900 (*15*); 7,245 (*7, 13*); 7,500 (*21*); 6,000–8,000 (*1*) |
| Cotton (with field trash) | 7,000 (*22*); 8,000 (*15*) |
| Gin trash only: | |
| Spindle harvested | 7,000 (*10, 20, 22*) |
| Stripper harvested | 7,000 (*10, 20, 22*) |
| Grain sorghum stover | 6,000 (*9*); 7,500 (*21*) |
| Wheat straw | 7,500 (*9, 18, 21, 25*); 7,000 (*15*); 6,650 (*7*) |
| Barley straw | 7,500 (*9, 14, 21, 35*) |
| Oat straw | 7,500 (*9, 14, 21, 35*) |
| Rice straw | 6,000 (*35, 37*); 7,500 (*21*); 7,039 (*13*) |
| Rye straw | 7,500 (*16, 21, 35*) |
| Flax straw | 8,000 (*16, 18*); 6,930 (7) |
| Soybean stems | 7,000 (*35*); 7,800 (*15*); 7,500 (*21*) |
| Peanut stems | 7,000 (*35*) |
| Sugarcane bagasse | 8,000 (*20, 35*) |
| Sunflower stalks | 8,000 (*18, 35*); 8,500 (*15*); 6,740 (*7*) |
| Hay | 7,500 (*35*) |

[1]Dry weight.

**Appendix table 24—Cost estimates for transporting crop residues to central conversion sites**

| Source and date of study | Form | Distance | Transportation cost: At time of study | Transportation cost: Updated to 1982[1] | Transportation cost: At time of study | Transportation cost: Updated to 1982[1] |
|---|---|---|---|---|---|---|
| | | | *Dollars/ton* | | *Dollars/ton mile* | |
| Corn stover: | | | | | | |
| (*19*) 1979 | Big round bales | NA | 4.75 | 6.89 | NA | NA |
| | 1-ton stacks | NA | 4.50 | 6.52 | NA | NA |
| | 3-ton stacks | NA | 5.45 | 7.90 | NA | NA |
| (*1*) 1978 | Big round bales[2] | NA | NA | NA | 0.17 | 0.30 |
| | Stacks[3] | NA | NA | NA | .34 | .60 |
| | Loose chop | NA | NA | NA | .39 | .68 |
| Rice straw: | | | | | | |
| (*6*) 1977 | Conventional rectangular bales | NA | 15.75 | 29.30 | NA | NA |
| | Big round bales | NA | 10.43 | 19.40 | NA | NA |
| (*13*) 1977 | Big round bales | 50 | 22.70 | 42.22 | .45 | .84 |
| | Loose chop | 50 | 22.66 | 42.15 | .45 | .84 |
| Wheat straw: | | | | | | |
| (*15*) 1977 | Big round bales[5] | 10 | 4.70 | 8.74 | .47 | .87 |
| | Stacks[6] | 10 | 6.40 | 11.90 | .64 | 1.19 |
| | Big round bales[5] | 20 | 7.90 | 14.69 | .40 | .73 |
| | Stacks[6] | 20 | 9.50 | 17.67 | .48 | .88 |
| | Big round bales[5] | 30 | 11.00 | 20.46 | .37 | .68 |
| | Stacks[6] | 30 | 12.50 | 23.25 | .42 | .78 |
| | Big round bales[5] | 40 | 14.20 | 26.41 | .36 | .66 |
| | Stacks[6] | 40 | 15.50 | 28.83 | .39 | .72 |
| Other: | | | | | | |
| (*28*) 1978 | Big round bales | 20 | 2.19 | 3.83 | .11 | .19 |
| | Big round bales | 40 | 4.27 | 7.47 | .11 | .19 |
| | Big round bales | 75 | 4.60 | 8.05 | .06 | .11 |
| (*32*) 1978 | Big round bales | NA | NA | NA | .10 | .18 |
| (*24*) 1978 | Stacks | NA | NA | NA | .32 | .56 |
| (*31*) 1979 | Loose chop | 15 | 2.25 | 3.30 | .15 | .22 |

NA = Not available.
[1]Updated using Index (B+C)/2, appendix table 21.
[2]Big round bales transported using gooseneck trailer.
[3]Stacks transported using stack mover.
[4]Loose chop transported using tractor trailer truck.
[5]Hauling 14 bales or 3.59 tons per load.
[6]Hauling two stacks per load.
[7]Combined costs for corn and grain sorghum stover and wheat straw or type of crop residue unknown.

# If Your Business is Oils...
# You Need These Reports

**Statistics on Oilseeds and Related Data, 1965-82** ($5.00; 72 pages; SB-695). USDA's lastest annual estimates on production, stocks, disposition, exports, imports, and prices. We've done the legwork for you by culling these statistics from diverse sources and putting them in a convenient one-volume format. The numbers represent the most accurate assessments of Government and private sources, including the Departments of Agriculture and Commerce, the Institute of Shortening, the Chemical Marketing Reporter, and the National Provisioner Report.

More than 100 tables give you the breakdown for cottonseed, flaxseed, linseed, peanuts, soybeans, sunflowers, and edible fats and oils.

**U.S. Peanut Industry** ($4.75; 52 pages; AER-493). A comprehensive picture of the last three decades of peanut production, consumption, and world trade. The United States accounts for about 10 percent of world exports of peanut oil and is the third largest producer of peanuts (behind India and China). With 10 figures and more than 30 tables, the report tells you:

- Major markets for peanut exports.
- Primary uses for different peanut varieties.
- Causes of yield increases over the last 30 years.
- Major production and marketing practices.
- Effects of Government programs on peanut farmers.

**To Order These Reports . . .**

Write to *Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.* Make your check or money order payable to *Superintendent of Documents.* You can charge your order on VISA, MasterCard, or with a GPO deposit account; call GPO's order desk at (202) 783-3238. No additional charges for postage to domestic addresses; but foreign addresses, please add 25 percent extra. Bulk discounts available.

# Mineral Tax Laws Reviewed

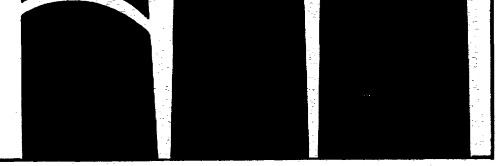
State taxes on mineral production yielded more than $4 billion in revenues for 17 major mineral-producing States in 1980 and accounted for more than 20 percent of total tax revenues in 7 States. Yet, raising State revenues seems to be only a minor reason for many States in taxing mineral resources. In addition, taxing minerals presents problems unlike those involved in other kinds of taxes (how and when to assess the value of the minerals, for example).

*State Mineral Taxes, 1982*, summarizes the mineral tax laws in 31 States and includes special uses for which the tax revenues are earmarked.

The report tells you:

- Why States levy special taxes on minerals. The explanations usually given include recovering the cost of increased State services, mitigating adverse effects of increased economic activity, and ensuring a fair return to citizens (including future generations) for depleting the State's natural heritage.
- How State laws have fared in legal challenges and the reasons given by the courts in overturning some tax laws while upholding others.
- The most common kinds of severance taxes levied on minerals, how they differ from one another, and how they compare with one another on factors like ease of administration, equity, and so forth.

For your copy of *State Mineral Taxes, 1982* (Thomas F. Stinson and George S. Temple; 72 pages; $4.50), write to Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Make your check or money order payable to Superintendent of Documents; ask for stock number 001-000-04317-0. For faster service, call GPO's order desk at (202) 783-3238 and charge your purchase to your VISA, MasterCard, or GPO deposit account. Bulk discounts available.



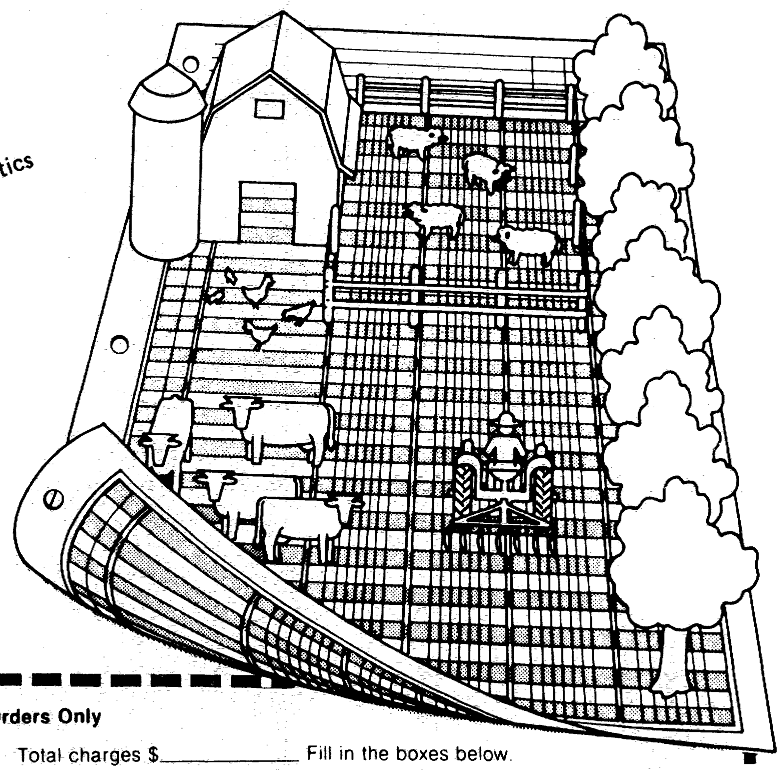
# Economic Indicators of the Farm Sector series

Keep tabs on farm income and expenses with the *Economic Indicators of the Farm Sector* series.

This series of five separate reports, offered now on a subscription basis, explores the economic status of U.S. farms to give you a comprehensive update on where U.S. agriculture is headed.

Here are the titles you will be receiving:

Income and Balance Sheet Statistics
State Income and Balance Sheet Statistics
Farm Sector Review
Production and Efficiency Statistics
Costs of Production



**Economic Indicators of the Farm Sector Order Form**

Enclosed is $ ________ ☐ check, ☐ money order, or charge to my Deposit Account No. ☐☐☐☐☐☐☐–☐

Order No. ____________

**Mail to:**
**Superintendent of Documents**
**U.S. Government Printing Office**
**Washington, D.C. 20402**

**For Office Use Only**

| Quantity | | Charges |
|---|---|---|
| ______ | Enclosed | ______ |
| ______ | To be mailed | ______ |
| ______ | Subscriptions | ______ |
| | Postage | ______ |
| | Foreign handling | ______ |
| | MMOB | ______ |
| | OPNR | ______ |
| ______ | UPNS | |
| ______ | Discount | |
| ______ | Refund | |

**Credit Card Orders Only**

VISA

Total charges $__________ Fill in the boxes below.

Credit Card No. ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

MasterCard

Expiration Date Month/Year ☐☐☐☐

Please enter my subscription to **Economic Indicators of the Farm Sector** (ECIFS) for one year at **$15.00 Domestic; $18.75 Foreign.**

Name—First, Last

Company name or additional address line

Street address

City | State | ZIP Code

(or Country)

**PLEASE PRINT OR TYPE**

Make checks payable to: Superintendent of Documents.

# Northern Great Plains Coal Mining

What are the likely effects of expanded coal mining in Montana, Wyoming, and North Dakota on the small towns and communities there? Mining activity in the sparsely populated region has grown dramatically over the last decade—from less than 20 million tons of coal in 1970, to 100 million tons in 1978, with projections for 350 million tons per year by the mid-1980's.

The Fort Union coal formation, which straddles those three States contains nearly 40 percent of the Nation's coal reserves. Its coal is highly desirable because:

—It is low in sulfur, meaning that it can be burned by utility companies with less air pollution than other coal.

—It is in thick seams (some seams up to 200 feet thick), and can be recovered by strip mining.

To try to ascertain the effects of development on the region, the authors of this report used computerized simulations of various levels of coal activity to see if the communities could afford the increased level of government services and upgraded infrastructure required by new energy projects and the larger population attracted by those projects.

In the long run (10 years or more), most communities in the region will be able to pay for the services required by the new coal-related development, provided that they can tax the new developments. Without taxing authority (for instance, if the mine lies outside the taxing district of a locality), they will have problems.

*Northern Great Plains Coal Mining: Regional Impacts* (by Thomas F. Stinson, Lloyd D. Bender, and Stanley W. Voelker; AIB-452; July 1982; 36 pages; color illustrations; $5; stock no. 001-000-04265-3).

**Order from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Make your check or money order payable to Superintendent of Documents. For faster service, call GPO's order desk at (202) 783-3238 and charge your purchase to your VISA, MasterCard, or GPO Deposit account. Bulk discounts also available.**

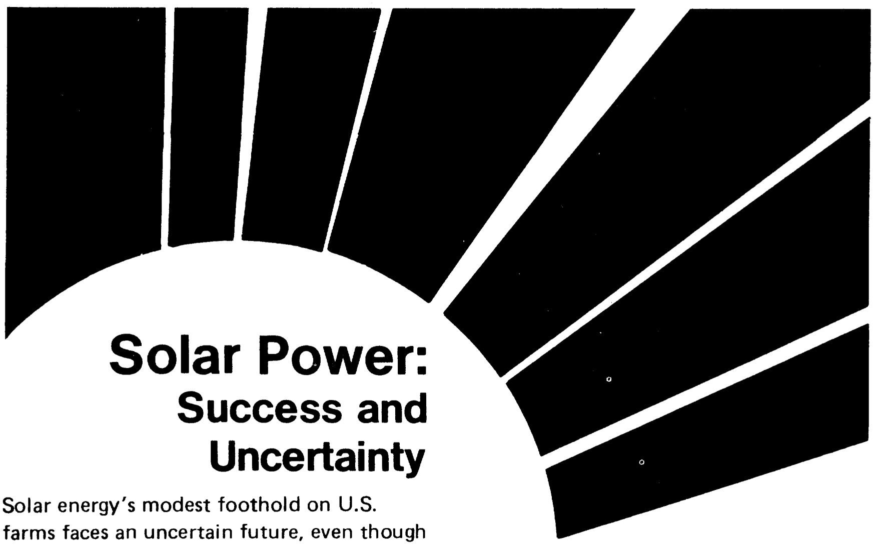
**United States**
**Department of Agriculture**

Washington, D.C.
20250

OFFICIAL BUSINESS
Penalty for Private Use, $300

Postage and Fees Paid
U.S. Department of Agriculture
AGR-101

**THIRD CLASS BULK RATE**



# Solar Power:
## Success and Uncertainty

Solar energy's modest foothold on U.S. farms faces an uncertain future, even though its applications to date have been fairly successful.

*Progress of Solar Technologies and Potential Farm Uses* explores the advances and problems in developing solar applications on the farm. Many low-cost homemade solar collectors, with multiple uses and a payback of less than 5 years, are currently being used on farms.

But solar's future role in agriculture will depend on energy prices of alternative energy sources (such as nuclear and hydroelectric power) and on the competitiveness of redesigned conventional power systems.

In addition, the solar industry, which to date has not focused on farm needs, has to show more interest in marketing low-cost systems specifically developed for agriculture.

The report highlights the advantages and drawbacks for the following solar farm applications:

- Solar-heated farrowing and nursery barns
- Solar-heated water for dairies
- Solar-heated houses for brooding broilers
- Solar-heated greenhouses

---

*Progress of Solar Technology and Potential Farm Uses* (by Walter G. Heid, Jr., and Warren K. Trotter; AER-489; September 1982; 112 pages; $5). Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Make your check or money order payable to Superintendent of Documents. For faster service, call GPO's order desk at (202) 783-3238 and charge your purchase to your VISA, MasterCard, or GPO Deposit account. Bulk discounts available.

---