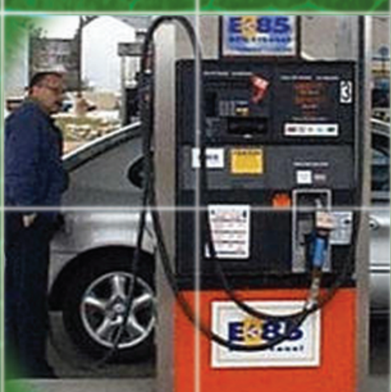
A Billion-Ton Feedstock Supply for a Bioenergy and Bioproducts Industry

Technical Feasibility of Annually Supplying 1 Billion Dry Tons of Biomass



USDA

U.S. Department of Agriculture

U.S. Department of Energy

Biomass as Feedstock for a Bioenergy and Bioproducts Industry:

The Technical Feasibility of a Billion-Ton Annual Supply

February 2005

A Joint Study Sponsored by
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DRAFT

Prepared for the
U.S. Department of Agriculture and
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In collaboration with
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Abbreviations and Acronyms

CAFO	confined animal feeding operation
CRP	Conservation Reserve Program
DOE	U.S. Department of Energy
FIA	Forestry Inventory and Analysis (USDA program)
FTE	Fuel Treatment Evaluator
HFRA	Healthy Forest Restoration Act
LBS	large biomass soybean
MSW	municipal solid waste
quad	quadrillion BTUs
R&D	research and development
RMR	residue maintenance requirement
RUSLE	Revised Universal Soil Loss Equation
SCI	Soil Conditioning Index
TPO	Timber Product Output (USDA)
USDA	U.S. Department of Agriculture

EXECUTIVE SUMMARY

Biomass — any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood wastes and residues, plants (including aquatic plants), grasses, residues, fibers, and animal wastes, municipal wastes, and other waste materials — has great potential to provide renewable energy for America's future. Biomass recently surpassed hydropower as the largest domestic source of renewable energy and currently provides over 3% of the U.S. total energy consumption. In addition to the many benefits common to any renewable energy use, biomass is particularly attractive, because it is the only current renewable source of liquid transportation fuel. This, of course, makes it an invaluable way to reduce oil imports — one of our most pressing energy needs. The U.S. Department of Energy and the U.S. Department of Agriculture are both strongly committed to expanding the role of biomass as an energy source. In particular, they support biomass fuels and products as a way to reduce need for oil and gas imports; to support the growth of agriculture, forestry, and rural economies; and to foster major new domestic industries — biorefineries — making a variety of fuels, chemicals, and other products.

A key question, however, is how large a role biomass could play. Assuming that economic and financial policy and advances in conversion technology make biomass fuels and products more economically viable could the biorefinery industry be large enough to have a significant impact on energy supply and oil imports? Any and all contributions are certainly needed, but would the biomass potential be sufficiently large to justify the necessary capital replacements in the fuels and automobile sectors?

The purpose of this report is to determine whether the land resources of the United States are capable of producing a sustainable supply of biomass sufficient to displace 30% or more of the country's present petroleum consumption. This 30% goal was set by a joint advisory committee to the two departments as a vision for making a major contribution to U.S. energy needs. It would require approximately 1 billion dry tons of biomass feedstock per year.

The short answer to the question of whether that much biomass feedstock can be produced is yes. Looking at just forestland and agricultural land, the two largest potential biomass sources, this study found potential exceeding 1.3 billion dry tons per year (Fig. 1) — enough to produce biofuels to meet more than one-third of the current demand for transportation fuels. This annual potential is based on a more than six-fold increase in production from the amount of biomass currently consumed for bioenergy and biobased products. About 933 million dry tons of sustainably removable biomass could be produced on agricultural lands, and about 368 million dry tons could come from forestlands.

The United States can produce more than 900 million dry tons of biomass annually from agricultural lands and still continue to meet food, feed, and export demands. This projection includes 425 million dry tons of annual crop residues, 377 million dry tons of perennial crops, 56 million dry tons of grains used for biofuels, and 75 million dry tons of animal manures, process residues, and other miscellaneous feedstocks. The critical assumptions are the following:

- yields of corn, wheat, and other small grains have increased by 50%;
- soybeans have an increased residue-to-grain ratio of 2:1;
- harvest technology is capable of taking 75% of annual crop residues (when removal is sustainable);

- all cropland is managed with no-till methods;
- 55 million acres of cropland, idle cropland, and cropland pasture are dedicated to the production of perennial bioenergy crops;
- all manure in excess of that which can applied on-farm for soil improvement under anticipated EPA restrictions is used for biofuel; and
- all other residues and wastes are utilized.

From forestlands, the projection includes 52 million dry tons of fuelwood harvested for residential and commercial applications, 144 million dry tons of residues from wood processing mills and pulp and paper mills, 47 million dry tons of urban wood wastes including construction and demolition debris, 64 million dry tons of residues from logging and site clearing operations, and 60 million dry tons of biomass from fuel treatment operations to reduce fire hazards. All of these forest resources are sustainably available on an annual basis and take into account factors affecting forest access and environmentally sensitive areas, equipment recovery restraints, and merchandizing of recoverable biomass into higher-valued products.

This biomass potential of 1.3 billion dry tons can be produced with relatively modest changes in land use and agricultural and forestry practices. Moreover, this estimated potential should not be thought of as an upper limit. It is just one scenario, and scientists in the Departments of Energy and Agriculture will continue to explore more advanced scenarios that could further increase the amount of biomass available for bioenergy and biobased products.

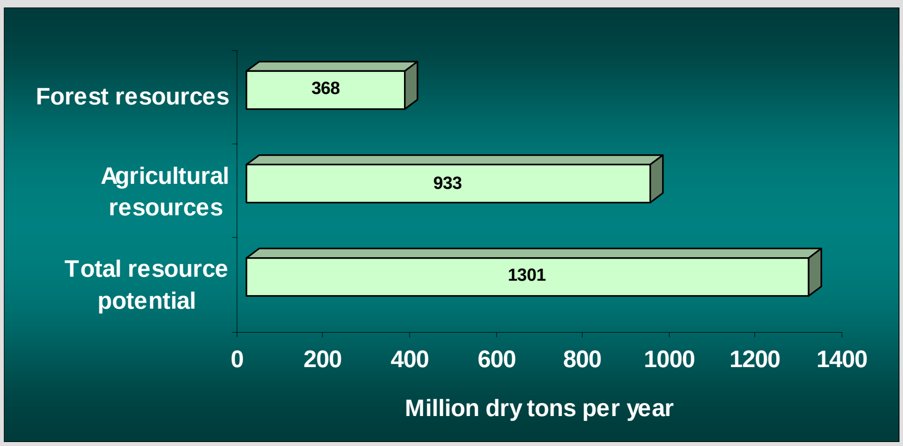


Fig. 1. Annual biomass resource potential — 1.3 billion dry tons.

1. INTRODUCTION

Biomass is already making key energy contributions. It has surpassed hydropower as the largest domestic source of renewable energy. Biomass currently supplies over 3% of the total energy consumption in the United States — mostly through industrial heat and steam production by the pulp and paper industry and electrical generation with forest industry residues and municipal solid waste (MSW). Moreover, biomass has great potential to provide renewable energy for America's future. In addition to the many benefits common to any renewable energy use, biomass is particularly attractive because it is the only current renewable source of liquid transportation fuel. This, of course, makes it an invaluable way to reduce oil imports — one of our most pressing energy and security needs. Biomass also has great potential to provide heat and power to industry and to provide feedstocks to make a wide range of chemicals and materials or bioproducts.

The overall mission of the U.S. Department of Energy (DOE) is to strengthen energy security, environmental quality, and economic vitality in public-private partnerships that enhance energy efficiency and productivity; bring clean, reliable and affordable energy technologies to the marketplace; and make a difference in the everyday lives of Americans by enhancing their energy choices and their quality of life. Consistent with this mission, DOE's Biomass Program supports a research agenda to develop feedstock production and conversion technologies capable of supplying the biomass feedstocks necessary to meet a significant fraction of domestic demands for transportation fuels, electric power, heat, and chemicals and materials.

The U.S. Department of Agriculture (USDA) through its agencies and offices has similar goals of reducing foreign oil dependence, improving the environment through the development of new sources of energy, increasing the use of agricultural crops and forest resources as feedstocks for bioenergy and bioproducts, and creating jobs and enhancing income in the rural sector of America's economy.

The Biomass Research and Development Act of 2000 created the Biomass R&D Technical Advisory Committee to provide advice to the secretaries of agriculture and energy on program priorities and to facilitate cooperation among various federal and state agencies and private interests. The Technical Advisory Committee also established a national vision for bioenergy and biobased products. Included in its vision was the setting of a very ambitious goal: biomass will supply 5% of the nation's power, 20% of its transportation fuels, and 25% of its chemicals by 2030.

FEEDSTOCK RESOURCE VISION GOALS ESTABLISHED BY THE BIOMASS RESEARCH & DEVELOPMENT TECHNICAL ADVISORY COMMITTEE (Source: BTAC, 2002a)

Biopower — Biomass consumption in the industrial sector will increase at an annual rate of 2% through 2030, increasing from 2.7 Quads in 2001 to 3.2 Quads in 2010, 3.9 Quads in 2020, and 4.8 Quads in 2030. Moreover, biomass consumption in electric utilities will meet double every 10 years through 2030. Combined, biopower will meet 4% of total industrial and electric generator energy demand in 2010 and 5% in 2020.

Biobased Transportation Fuels — Transportation fuels from biomass will increase significantly from 0.5% of U.S. transportation fuel consumption in 2001 (0.0147 Quads) to 4% of transportation fuel consumption in 2010 (1.3 Quads), 10% in 2020 (4.0 Quads), and 20% in 2030.

Biobased Products — Production of chemicals and materials from biobased products will increase substantially from approximately 12.5 billion pounds, or 5% of the current production of target U.S. chemical commodities in 2001, to 12% in 2010, 18% in 2020, and 25% in 2030.

The goal is ambitious, as it is equivalent to 30% of current petroleum consumption and would require the approximate consumption of one billion dry tons of biomass feedstock annually — a fivefold increase over current consumption (DOE, 2003). The purpose of this report is to assess whether the land resources of the United States have the potential to produce a sustainable supply of biomass that can displace 30% of the country's current petroleum consumption. This report does not attempt to outline R&D and policy agendas to attain this goal, nor does it attempt to assess the economic competitiveness of a billion-ton bioenergy and bioproducts industry and its potential impacts on the energy, agriculture (food and feed production), and forestry sectors of the economy. Many of these issues are partially addressed in the roadmap that accompanied the biomass vision (BTAC, 2002b). The roadmap explores the technical research, development, and demonstrations needed to achieve technical advances in biomass systems, and outlines the institutional and policy changes needed to remove the barriers to economically and environmentally sound development of sustainable biomass systems. To provide some perspective, the next section of this resource assessment summarizes current biomass consumption and the biomass feedstock resource base. The biomass feedstock resource base for forest and agricultural resources are then discussed in more detail in the main body of the report.

2. THE BIOMASS FEEDSTOCK RESOURCE BASE

2.1 Land Resource Base for Biomass Production

The land base of the United States encompasses nearly 2,263 million acres, including the 369 million acres of land in Alaska and Hawaii. About 33% of the land area is classified as forest land, 26% as grassland pasture and range, 20% as cropland, 8% as special uses (e.g., public facilities), and 13% as miscellaneous other uses, such as urban areas, swamps, and deserts (Vesterby and Krupa, 2001; Alig et al., 2003). Nearly one-half of this land has some potential for growing biomass.

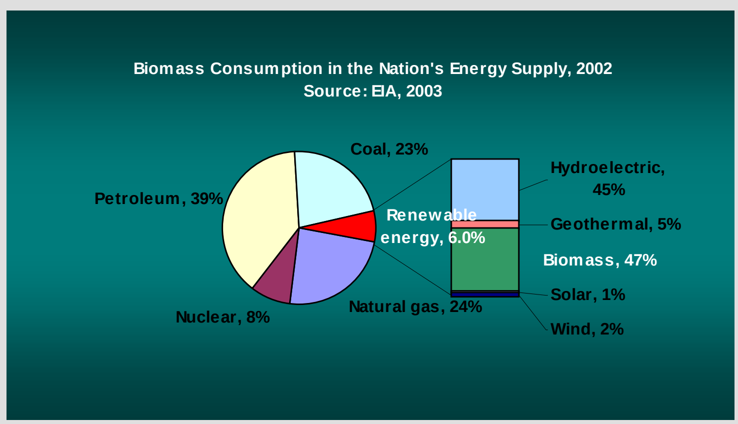
Currently, slightly more than 75% of biomass consumption (about 142 million dry tons) comes from forest lands. The remainder, which includes the biobased products, biofuels, and some waste biomass, comes from cropland.

2.2 Current Biomass Feedstock Consumption

In 2003, biomass contributed nearly 2.9 quadrillion BTUs (quads) to the nation's energy supply, nearly 3% of total U.S. energy consumption of about 98 quads (EIA, 2004a). At 47% of total renewable energy consumption, biomass is the single largest renewable energy resource, recently surpassing hydropower (Fig. 2). More than 70% of this biomass comes from wood residues and pulping liquors generated by the forest products industry. Currently, biomass accounts for approximately

- 13% of renewably generated electricity,
- nearly all (97%) the industrial renewable energy use,
- nearly all the renewable energy consumption in the residential and commercial sectors (84% and 90%, respectively), and
- 2.5% of transport fuel use.

A relatively significant amount of biomass (~6 to 9 million dry tons) is also currently used in the production of a variety of industrial and consumer bioproducts that directly displace petroleum-based feedstocks (Energetics, 2003). Together, the total annual consumption of



Biomass Resource	Million dry tons/year
Forest products industry	
Wood residues	44
Pulping liquors	52
Urban wood & process wastes	35
Fuelwood	
Residential/commercial	24
Electric utilities	10
Biofuels	18
Bioproducts	6
Total	190

Fig. 2. Summary of biomass feedstock resource base.
Source: EIA, 2004b.

biomass feedstock for bioenergy and bioproducts currently approaches 190 million dry tons (Fig. 2).

2.3 Composition of Current Resource Base

The biomass resource base is composed of a wide variety of forestry and agricultural resources, industrial processing wastes, and municipal solid and urban wood wastes (Fig. 3). The forest resources include residues produced during the harvesting of forest products, fuelwood extracted from forestlands, wastes generated at primary forest product processing mills, and forest resources that could become available through initiatives to reduce fire hazards and improve forest health. The agricultural resources include grains used for biofuels production, animal manures and wastes, and crop residues derived primarily from corn and small grains (e.g., wheat straw). A variety of regionally significant crops, such as cotton, sugarcane, rice, and fruit and nut orchards can also be a source of crop residues. Municipal and urban wood wastes are widely available and encompass a variety of materials — yard and tree trimmings, land-clearing wood residues, wooden pallets, packaging materials, and construction and demolition debris.

Forest resources

Primary
- Logging residues from conventional harvest operations and residues from forest management and land clearing operations
- Removal of excess biomass (fuel treatments) from timberlands and other forestlands
- **Fuelwood extracted from forestlands**

Secondary
- Primary wood processing mill wastes
- Secondary wood processing mill wastes
- Pulping liquors (black liquor)

Tertiary
- Urban wood wastes — construction and demolition debris, tree trimmings, packaging wastes and consumer durables

Agricultural resources

Primary
- Crop residues from major crops — corn stover, small grain straw, and others
- Grains (corn and soybeans) used for ethanol, biodiesel, and bioproducts
- Perennial grasses
- Perennial woody crops

Secondary
- Animal manures
- Food/feed processing wastes

Tertiary
- MSW and post-consumer wastes and landfill gases

Fig. 3. The biomass resource base.

The remainder of this report addresses the feedstock potential. The analysis is based on potential future availability of biomass over the long term — the time when large-scale bioenergy and biorefinery industries are likely to exist, say mid-21st century. The report emphasizes primary sources of forest- and agriculture-derived biomass such as logging residues, fuel treatment thinnings, crop residues, and perennially grown grasses and woody crops. These primary sources have the greatest potential to supply large, sustainable quantities of biomass. While we emphasize the primary sources, we also assess secondary and tertiary (or waste) sources of biomass.

3. FOREST-DERIVED BIOMASS RESOURCE ASSESSMENT

The amount of forest-derived biomass is based on an analysis of extant resources and trends in the demand for forest products. The biomass resource potential from cropland is based on creating scenarios that extrapolate from current agriculture and research and development trends. While the forestland area is much larger, agricultural land has the larger biomass resource potential due to a much higher level of management intensity. Forestlands, especially those held publicly, will always be managed less intensively than agricultural lands because forests are expected to provide multiple use multiple-use benefits, including wildlife habitat, recreation, and ecological and environmental services. By contrast, active cropland and, to a lesser extent, idle cropland and cropland pasture are intensively managed, with crops and management practices changing on a year-to-year basis and land moving in and out of active production. Figure 4 shows the breakdown of forestlands by ownership.

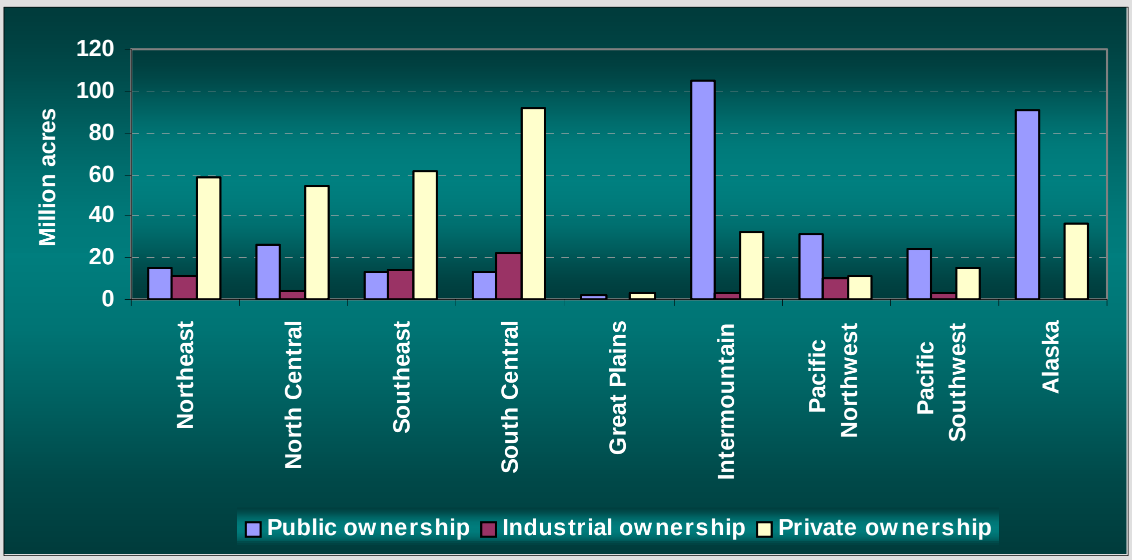


Fig. 4. Ownership of U.S. forestland.

(Source: Alig et al., 2003)

Of the 504 million acres of U.S. timberland, about 29% is publicly owned, 13% is owned by the forest industry, and the remaining 58% is privately owned.

Timberland ownership varies considerably among regions of the country. The eastern United States tends to be dominated by private ownership and the West by public land ownership.

3.1 Forestland Resource Base

The total forestland in the United States is approximately 749 million acres — 33% of the nation's total land area. Two-thirds of the forest land (504 million acres) is classified as timberland, which, according to the Forest Service, is land capable of growing more than 20 ft^3/acre of wood annually (Smith et al., 2004). Although timberland is not legally reserved from harvesting, much of it is inaccessible or inoperable to forestry equipment. In addition, there are 168 million acres of forestland that the Forest Service classifies as "other." This other forest land is generally incapable of growing 20 ft^3/acre of wood annually. The lower productivity is due to a variety of factors or site conditions that adversely affect tree growth (e.g., poor soils, lack of moisture, high elevation, and rockiness). As a result, this land tends to be used for livestock grazing and extraction of some non-industrial wood products. The remaining 77 million acres of forestland are reserved from harvesting and are intended for a variety of non-timber uses, such as parks and wilderness.

The total forestland base considered for this resource analysis includes the 504 million acres of timberland and the 168 million acres of other forestland. The timberland acreage is the source of nearly all current forest-derived bioenergy use and the source of most of the potential. The other forestland is included because it has accumulated excess biomass that poses wildland fire risks and hazards. Much of this excess biomass is not suitable for conventional wood products but could be used for a variety of bioenergy and biobased product uses.

3.2 Forest Resources

The processing of harvested forest products, such as sawlogs and pulpwood, generates significant quantities of mill residues and pulping liquors. These secondary forest residues constitute the majority of biomass in use today (Fig. 5). Secondary wastes generated in the processing of forest products account for nearly 70% of current biomass energy consumption. These materials are used by the forest products industry to manage waste streams, produce energy, and recover important chemicals (Fig. 1). Fuelwood extracted from forestlands for residential and commercial use and electric utility use accounts for about 35 million dry tons of current consumption.

In addition to these existing uses, forestlands have considerable potential to provide biomass from two primary sources:

- residues associated with the harvesting and management of commercial timberlands for the extraction of sawlogs, pulpwood, veneer logs, and other conventional products; and
- currently non-merchantable biomass associated with the standing forest inventory.

This latter source is more difficult to define, but generally would include rough and rotten wood not suitable for conventional forest products and excess quantities of smaller-diameter trees in overstocked forests. A large amount of this forest material has been identified by the Forest Service as needing to be removed to improve forest health and to reduce fire hazard risks (USDA-FS, 2003; Miles, 2004).

These two categories of forest resources constitute what is defined as the primary source of forest residue biomass in addition to the fuelwood that is currently extracted for space heating applications in the residential and commercial sectors and for some feedstocks by electric utilities. Perennial woody crops (also referred to as short-rotation woody crops) are also a potential biomass resource. Because these woody crops would be grown on agricultural lands, they are discussed in the agricultural resources section that follows (Sect. 3.2).

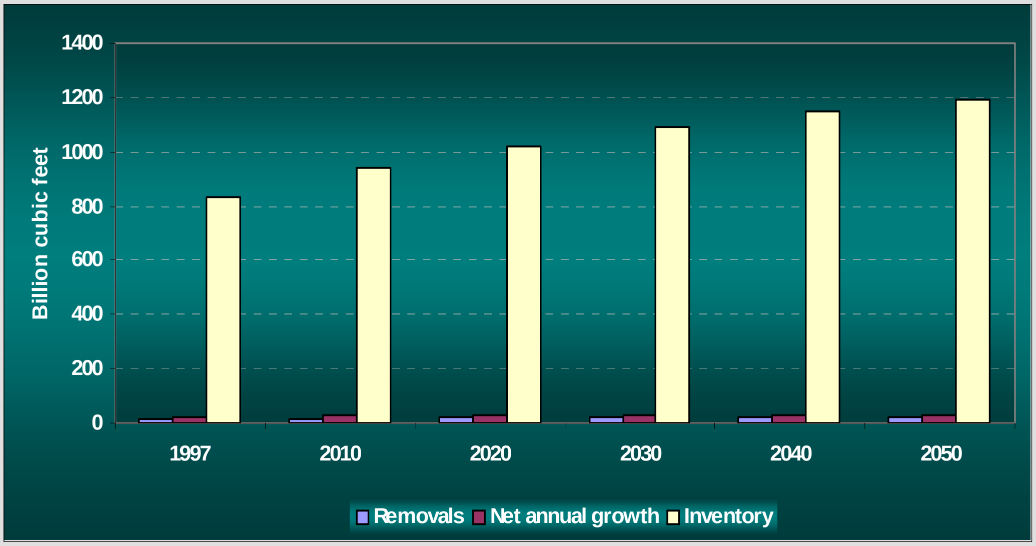


Fig. 5. Projections of timber removals, growth, and inventory

(Source: Haynes, 2003)

Removals from the forest inventory are a small fraction of the total standing inventory. Current removals are also less than net annual forest growth.

Forest inventories are projected to increase relative to removals despite a loss of about 3% (23 million acres) of U.S. forestland by the year 2050. The projected loss is expected as a result of land conversion to urban and developed uses driven primarily by population and income growth (Alig et al., 2003).

There is also a relatively large tertiary, or waste, source of forest biomass in the form of urban wood wastes — a generic category that includes yard trimmings, packaging wastes, discarded durable products, and construction and demolition debris.

All of these forest resources can contribute about 225 million dry tons to the approximately 143 million dry tons of biomass now used, out of a total timber biomass of 24 billion dry tons (Fig. 6). Specifically, these forest resources include the following:

- **The recovery of residues generated by traditional logging activities and residues generated from forest cultural operations or clearing of timberlands.** Currently, about 67 million dry tons of residues are generated annually from these activities (Smith et al., 2003; USDA-FS, 2004a). About 41 million dry tons of this biomass material is potentially available for bioenergy and biobased products after consideration of equipment recovery limitations (Table A.3, Appendix A).

- **The recovery of residues generated from fuel treatment operations on timberland and other forestland.** Well over 8 billion dry tons of biomass has been identified for fuel treatment removal (Miles, 2004). The amount of this biomass potentially available for bioenergy and biobased product uses is estimated at 60 million dry tons annually. This estimate takes into consideration factors affecting forest access, residue recovery, and the merchandizing of the recoverable biomass into higher-valued fractions (conventional

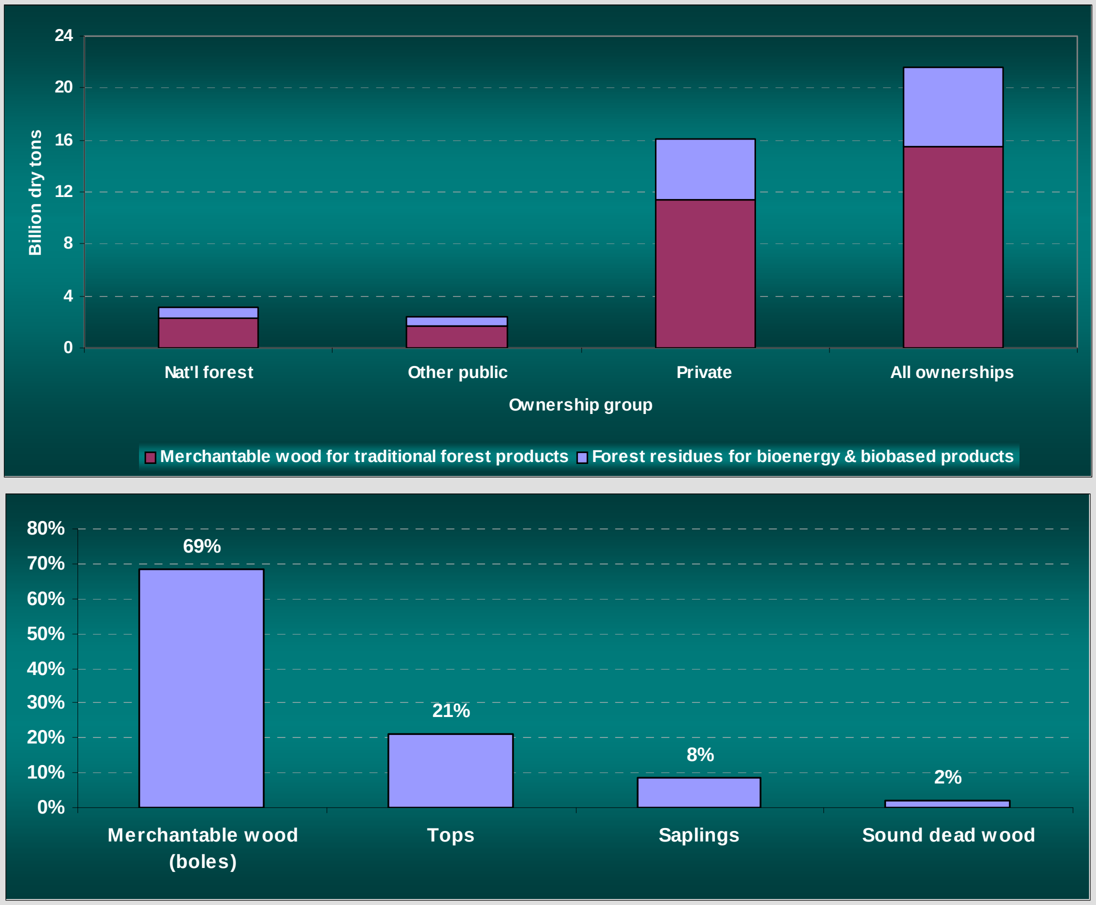


Fig. 6. Total timberland biomass — 24 billion dry tons

(Source: Smith et al., 2004)

The merchantable wood or the conventional forest products component includes the boles and sound dead wood.

The forest residue fraction suitable for bioenergy and biobased products includes the tops and some fraction of saplings considered to be overstocked.

The total forest residue resource is about 6.7 billion dry tons.

wood products) and lower-valued fractions (the biomass suitable for bioenergy and biobased product uses) (Table A.5-7, Appendix A). The fraction that could be available for bioenergy and biobased products is less than 1% of the total size of the fuel treatment biomass.

- **The direct conversion of roundwood to energy (fuelwood) in the residential, commercial, and electric utility sectors**. Thirty-five million dry tons of biomass is currently extracted by the residential and commercial sectors and by the electric power sector. Most of the fuelwood used by the residential and commercial sectors is used for space-heating applications.

- **Forest products industry wastes and urban wood wastes.** Utilization of unused wastes generated by the forest products industry; urban wood wastes discarded from construction and demolition activities; and wastes from the disposal of tree trimmings, packaging wastes, and wood-based consumer durables can annually provide 36 million dry tons to the current 108 million dry tons currently used.

- **Forest growth and increase in the demand for forest products.** In the long-term time period, a continuation of current trends in the demand and supply of forest products could increase the potential contribution of forest biomass by another 89 million dry tons annually. The additional 89 million dry tons results from a combination of sources and changing circumstances. An increase in the harvest of traditional forest products will create additional logging residues, and more efficient equipment will allow the recovery of a greater fraction of the logging residue. However, this increase will be offset somewhat by more efficient logging practices that will generate less wood residue per unit volume of harvested forest products (Haynes, 2003). Demand growth for conventional forest products will create additional mill residue and pulping liquors and urban wood wastes. However, the rate of increase in these secondary and tertiary forest residue sources will be tempered by product substitution, recycling and reuse, and more efficient manufacturing processes.

A summary of the amounts of biomass available annually and on a sustainable basis from forest resources is summarized in Fig. 7. The approximate total quantity is 368 million dry tons annually. As noted, this includes about 142 million dry tons of biomass currently being used, primarily by the forest products industry, as well as the 89 million dry tons annually that could result from a continuation of trends in the forest products industry

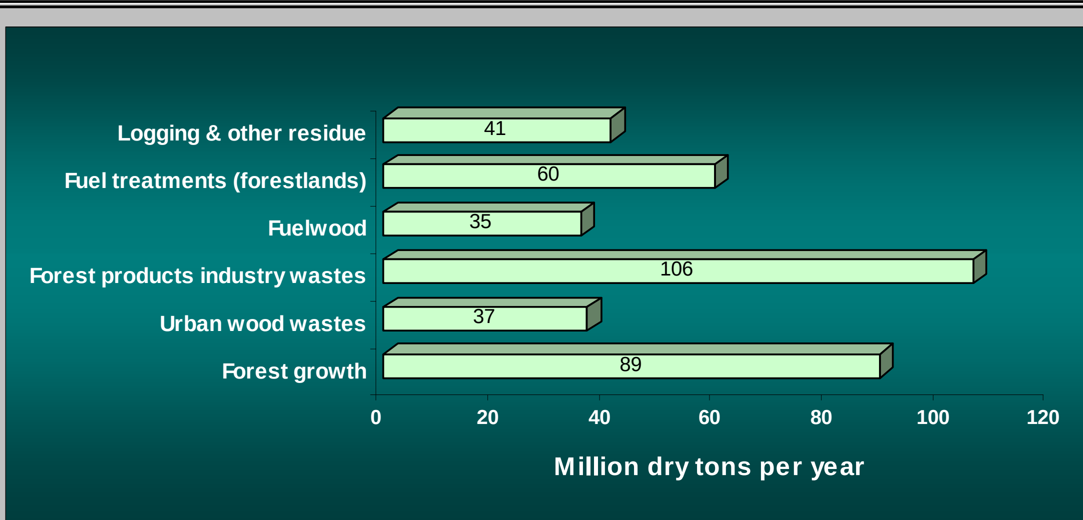


Fig. 7. Estimate of the sustainably recoverable forest biomass.

3.3 Increased Biomass Resources from Forests

3.3.1 Logging Residues and Other Removals from the Forest Inventory

A recent analysis shows that annual removals from the forest inventory totaled nearly 20.2 billion ft^3. Of this volume, 78% was for roundwood products, 16% was logging residue, and slightly more than 6% was classified as "other removals" (Smith et al., 2004). The total annual removals constitute about 2.2% of the forest inventory on timberland and are less than net annual forest growth. The logging residue fraction is biomass removed from the forest inventory as a direct result of conventional forest harvesting operations. This biomass material is largely tree tops and small branches left on site because these materials are currently uneconomical to recover either for product or energy uses. The remaining fraction, other removals, consists of timber cut and burned in the process of land conversion or cut as a result of cultural operations such as precommercial thinnings and timberland clearing.

Forest Inventory and Analysis

The Forest Inventory and Analysis (FIA) program of the Forest Service has been in continuous operation since 1930 with a mission to "make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and rangelands of the United States." FIA is the nation's forest census. FIA reports on status and trends in forest areas and locations; on the species, size, and health of trees; on total tree growth, mortality, and removals by harvest; on wood production and utilization rates by various products; and on forest land ownership. FIA is the only program which provides consistent, credible, and periodic forest data for all forest lands (public and private) within the United States. FIA covers all U.S. forestlands, including Alaska, Hawaii, Puerto Rico, the U.S. Virgin Islands, and U.S. Pacific territories. FIA has been in operation under various names (Forest Survey, Forest Inventory and Analysis) for some 70 years. The program is managed by the R&D organization within the USDA Forest Service in cooperation with state and private forestry and national forest systems. More information can be found at http://www.fia.fs.fed.us/. This analysis uses data from the FIA databases.

Data on the total amount of logging residue and other removals generated are available from the USDA Forestry Inventory and Analysis (FIA) program's Timber Product Output (TPO) Database Retrieval System (USDA-FS, 2004a). This database provides volumetric information on roundwood products (e.g., sawlogs, pulpwood, veneer logs, and fuelwood), logging residues, other removals, and mill residues. For the United States, total logging residue and other removals currently amount to nearly 67 million dry tons annually: 49 million dry tons of logging residue and 18 million dry tons of other removal residue (Table A.1, Appendix A).

Not all of this resource is potentially available for bioenergy and biobased products (Fig. 8). Generally, these residues tend to be relatively small pieces

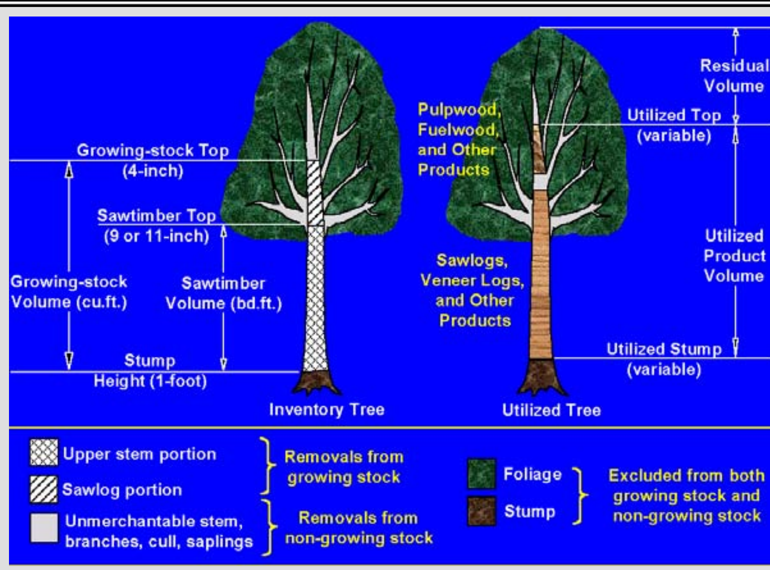


Fig. 8. Forest utilization relationships.

(Source: Northeastern Forest Inventory & Analysis Program, http://www.fs.fed.us/ne/fia/studies/TPO/)

consisting of tops, limbs, small branches, and leaves. Stokes reported a wide range of recovery percentages, with an average of about 60% potential recovery behind conventional forest harvesting systems (Stokes, 1992). With newer technology, it is estimated that current recovery is about 65%. Other removals, especially from land-clearing operations, usually produce different forms of residues and are not generally as feasible or as economical to recover. It is expected that only half of the residues from other removals can be recovered. Of course, not all of this material should be recovered. Some portion of this material, especially the leaves and parts of tree crown mass, should be left on site to replenish nutrients and maintain soil productivity.

Since many forest operations involve the construction of roads that provide only temporary access to the forest, it is assumed that these residues are removed at the same time as the harvest or land clearing operations that generate the residues. Limiting the recoverability of logging and other removal residue reduces the size of this forest resource from about 67 million to 41 million dry tons (Fig. 9; Table A.2-4, Appendix A). About three-fourths of this material would come from the logging residue. Further, because of ownership patterns most of the logging residue and nearly all residues from other sources (e.g., land clearing operations) would come from privately owned land.

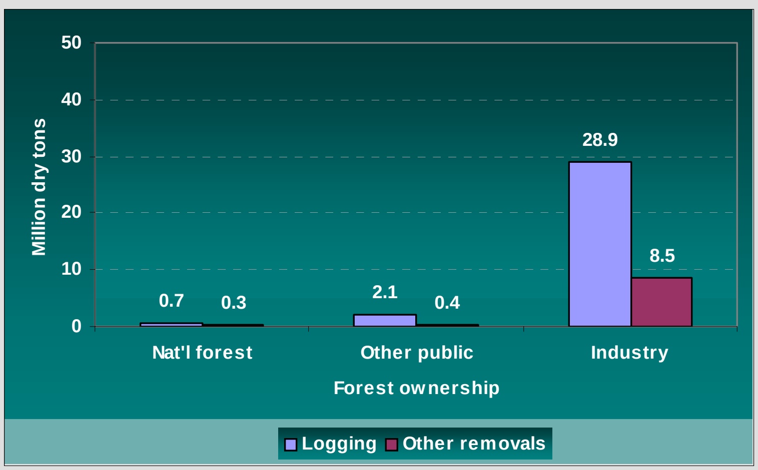


Fig. 9. Logging and Other Removal Residues

41 million dry tons of logging and other removal residue is currently available annually for recovery.

Most of this resource would come from privately owned timberland.

3.3.2 Forest Residues from Fuel Treatment Thinning

Vast areas of U.S. forestland are overstocked with relatively large amounts of woody materials. This excess material has built up over years as a result of forest growth and alterations in natural fire cycles. Over the last ten years, federal agencies have spent more than $8.2 billion fighting forest fires, which have consumed over 49 million acres (Fig. 10). The cost of fighting fires does not include the costs of personal property losses, ecological damage, loss of valuable forest products, nor loss of human life. The Forest Service and other land management agencies are currently addressing the issue of hazardous fuels buildup and looking at ways to restore ecosystems to more fire-adaptive conditions. The removal of excess woody material would also improve forest health and productivity (Graham, McCaffrey, and Jain, 2004).

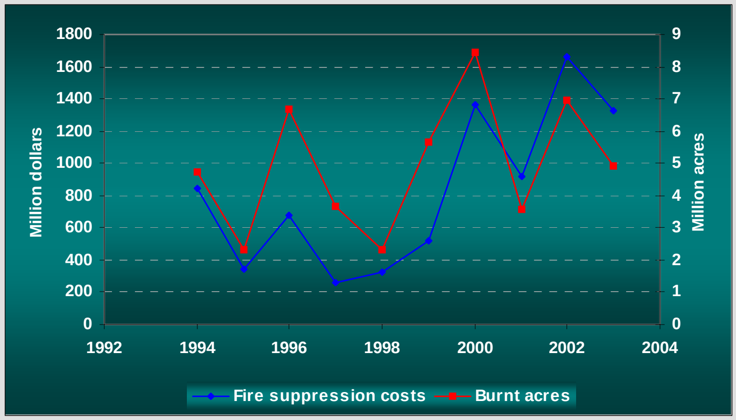


Fig. 10. Fire suppression cost and acres burned.

On average, nearly 5 million acres have been burned each year over the last 10 years.

Fire suppression costs average nearly $170 per acre.

In August 2000, the National Fire Plan was developed to help respond to severe wildland fires and their impacts on local communities while ensuring sufficient firefighting capacity for future fires. The National Fire Plan specifically addresses firefighting capabilities, forest rehabilitation, hazardous fuels reduction, community assistance, and accountability. Recently, the Healthy Forest Restoration Act (HFRA) of 2003 was enacted to encourage the removal of hazardous fuels, encourage utilization of the material, and protect, restore, and enhance forest ecosystem components. HFRA is also intended to support R&D to overcome both technical and market barriers to greater utilization of this resource for bioenergy and other commercial uses from both public and private lands. Removing excess woody material has the potential to make relatively large volumes of forest residues and small-diameter trees available for bioenergy and biobased product uses.

The Forest Service has identified timberland and other forestland areas that have tree volumes in excess of prescribed or recommended stocking densities, that require some form of treatment or thinning operation to reduce fire risks and hazards, and that are in close proximity to people and infrastructure (USDA-FS, 2003b). For timberlands, this was accomplished with the development of an assessment tool, the Fuel Treatment Evaluator (FTE) (USDA-FS, 2004c; Miles, 2004). The FTE is used to assist in the identification, evaluation, and prioritization of fuel treatment opportunities and facilitate the implementation of HFRA on all timberland areas.

The FTE uses a stand density index approach to identify stands that are minimally fully stocked. Stands that exceed this threshold are identified as potential candidates for thinning treatments. Treatable land areas are then classified into fire regime condition classes to measure how much a given area has departed from natural wildfire conditions. The condition classes range from minimally altered areas to areas that are significantly altered from historical norms and pose significant fire risks due to the heavy fuel loadings.

The FTE program requires individual tree data. Because this information was not collected on all “other forestland” areas prior to 1998, Forest Service personnel implemented FTE procedures manually for other forestland areas where individual tree data were available. The results for these areas were then extrapolated to similar areas, based on forest type and ecoregion, where individual tree data were not available. Since 1998 the FIA program has been collecting individual tree data on all forestland nationwide.

Application of the FTE nationwide identified slightly more than 7.8 billion dry tons of treatable biomass on timberland and another 0.6 billion dry tons of treatable biomass on other forestland (Fig. 11; Table A.5, Appendix A). Only a fraction of this approximately 8.4 billion dry tons is considered potentially available for bioenergy and biobased products on a sustainable annual basis. Many factors reduce the size of this primary biomass resource (USDA-FS, 2003).

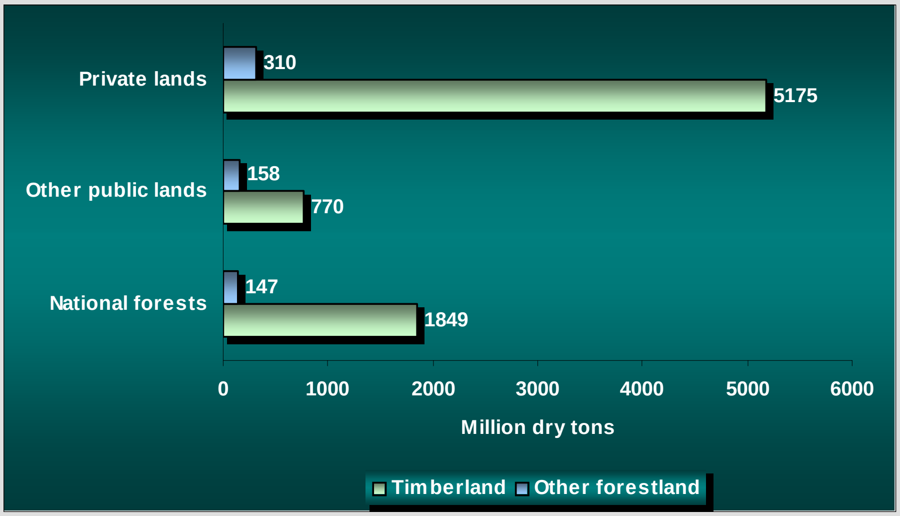


Fig. 11. Total treatable biomass resource on timberlands and other forestlands.

About 8.4 billion dry tons of treatable biomass is potentially available for bioenergy and biobased products.

The first of these limiting factors is accessibility to the material from the standpoint of having roads to transport the material and operate logging/collection systems (Table A.6, Appendix A). This is rarely a technology limiting factor, since there is equipment for nearly any type of terrain and for removing wood a long distance, even without roads (e.g., via helicopters, two-stage hauling, or long-distance cableways). However, there are usually economic and political constraints that inhibit working in roadless areas and more difficult terrain. Estimates of operational accessibility assume conventional types of operations by limiting the areas of consideration to roaded forestland. About 60% of the North American temperate forest is considered accessible (not reserved or high-elevation and within 15 miles of major transportation infrastructure) (FAO, 2001). The Forest Service final environmental impact statement for roadless area conservation indicates that about 65% of Forest Service acreage falls within roaded or non-restricted designations (USDA-FS, 2004b). Road density is much higher in the eastern United States, and in most cases, the topography is more accessible.

Operational accessibility is further limited by the need to avoid adverse impacts to soil and water. Steep slopes, sensitive sites, regeneration difficulty, or lack of adequate resource information may exclude an area from operational treatments. A summary of national forest land management plans from 1995 found about 60% of the western national forest timberland base is considered “suitable” for timber production operations (Timko, 2003). This would be a conservative estimate for other landowners as well, and an even more conservative estimate for eastern U.S. timberlands.

The more significant restriction is economic feasibility. Operating in steep terrain, in unroaded areas, or with very low-impact equipment is expensive. The value of the biomass (in its broad sense, meaning a combination of product value and treatment value) has to be weighed against the cost of removing the material. For example, May and LeDoux (1992) compared FIA data for hardwood inventory with economic modeling of the cost of harvest and concluded that only 40% of the inventory volume in Tennessee was economically available. Biomass, with a lower product value, would be even less available if the biomass has to cover the entire cost of the operation. If the biomass were to be produced as part of an integrated operation, it would be at most 40% available in the eastern hardwood example. The primary economic factor is the cost of transportation to processing mills.

The recoverability (i.e., the fraction of standing biomass removed offsite) of wood for bioenergy and biobased products is a function of tree form, technology, and timing of the removal of the biomass from the forests. In most cases, merchantable wood is removed, and the forest residues — in the form of limbs and tops and small, non-merchantable trees — remain scattered across the harvest area. This practice reduces recoverability when the biomass is removed in a second pass. However, when all biomass is harvested and processed in an integrated system, recovery is usually greatly improved, even greater than 90%. For example, a study by Stokes and Watson (1991) found that 94.4% of the standing biomass could be recovered when using a system to recover multiple products if the biomass from in-woods processing was actually utilized for bioenergy.

There is concern about removal of large quantities of biomass from stands because of long-term site productivity and loss of diversity and habitat associated with down-wood debris. Although the consequences are very site-specific, most negative impacts can be eliminated or minimized by leaving leaves, needles, and a portion of the woody biomass on site (Burger 2002).

The 8.6 billion dry tons of treatable biomass that is potentially available for bioenergy and biobased products was reduced by the following factors (Table A.6, Appendix A):

- To allay any concerns about site impacts, recovered material using an integrated system is limited to 85%.
- Only 60% of the identified treatable areas are assumed to be accessible.
- Fuel treatment material is recovered on a 30-year cycle before any sites are reentered.
- Harvested fuel treatment biomass is allocated into two utilization groups:
  (1) merchantable trees suitable for conventional or higher-valued forest products as well as rotten trees, brush and understory, small saplings, and polewood trees; (2) the residues (e.g., tops, limbs, and branches) from the harvested larger trees suitable for bioenergy and biobased product uses. The conventional forest products fraction assumed is 70%, and the residue or bioenergy and biobased product fraction is 30% (USDA-FS, 2003).

The combination of these factors significantly reduces the amount of fuel treatment biomass that can be sustainably removed on an annual basis. About 49 million dry tons can potentially be removed annually from timberlands, and about 11 million dry tons can be removed annually from other forestlands (Fig. 12; Table A.7, Appendix A). Most of the fuel treatment biomass from timberlands would come from privately owned lands; slightly less than 20% of the material would come from national forests. In contrast, proportionately more of the fuel treatment biomass allocated to bioenergy and biobased products on other forestland land would come from publicly held lands. Most of these lands are located in the western regions of the country. The 60 million dry tons of fuel treatment biomass assumes that a relatively large percentage (70%) goes to higher-valued products. If feedstock prices for biomass were to increase relative to conventional forest products, the amount of biomass available for bioenergy and biobased products could increase substantially.

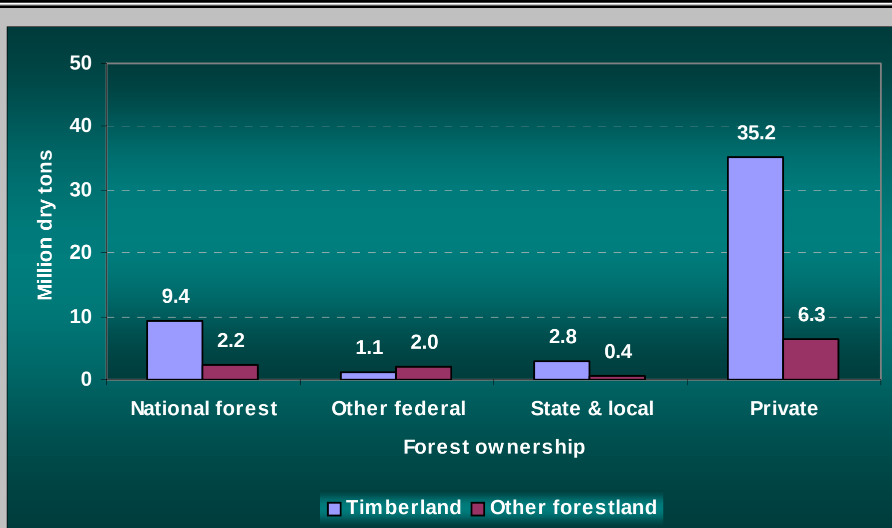


Fig. 12. Fuel treatments on timberland and other forestland.

About 60 million dry tons can be removed from timberlands and other forestlands for fuel treatments.

3.3.3 Forest Products Industry Processing Wastes

Primary wood processing mills

The Forest Service classifies primary mill wastes into three categories — bark, coarse residues (chunks and slabs), and fine residues (shavings and sawdust). In each of these categories, residues are further segmented into hardwoods and softwoods. Data on waste quantities are reported at any user-specified spatial scale, ranging from data of individual counties to state and national totals. Primary mill wastes are desirable for energy and other purposes because they tend to be clean, uniform, and concentrated and have a low moisture content (<20%). These desirable physical properties, however, mean that nearly all of these materials are currently used as inputs in the manufacture of products or as boiler fuel. Very little of this resource is currently unused. According to Forest Service estimates, about 80% of bark is used as fuel and about 18% is used in low-value products such as mulch (USDA-FS, 2004a). For coarse residues, about 85% is used in the manufacture of fiber products and about 13% is used for fuel. About 55% of the fine residues are used as fuel and 42% used in products.

Primary timber processing mills (facilities that convert roundwood into products such as lumber, plywood, and wood pulp) produced 91 million tons of residues in the form of bark, sawmill slabs and edgings, sawdust, and peeler log cores in 2002 (USDA-FS, 2004a). Nearly all of this material is recovered or burned, leaving slightly less than 2 million tons available for other bioenergy and biobased product uses (Table A.8, Appendix A).

Secondary wood processing mills

Wastes are also generated at secondary processing facilities — mills utilizing primary mill products. Examples of secondary wood processing mill products include millwork, containers and pallets, buildings and mobile homes, furniture, flooring, and paper and paper products. Since these industries use an already processed product, they generate smaller quantities of residues. In total, the secondary mill residue resource is considerably smaller (less than 15%) than the primary mill resource (Rooney, 1998; McKeever, 1998). The type of residues generated at secondary mills includes sawdust and sander dust, wood chips and shavings, board and cut-offs, and miscellaneous scrap wood.

At the larger secondary mills most of the residue produced is used on site to meet energy needs (such as heat for drying operations) or is recycled into other products. This is in contrast to practices at the smaller mills, where much of the residue material goes unused (Bugelin and Young, 2002). The recovery of residue at smaller mills is more constrained because it may be generated seasonally and may be more dispersed.

Neither the Forest Service nor any other federal agency systematically collects data on secondary mill residue. One of the few estimates of the amount of secondary mill waste available is provided by Fehrs (1999). He estimates that 15.6 million dry tons is generated annually, with about 40% of this potentially available and recoverable. The remaining fraction is used to make higher-valued products and is not available (Table A.8, Appendix A).

Pulp and paper mills

In the manufacture of paper products, wood is converted into fiber using a variety of chemical and mechanical pulping process technologies. Kraft (or sulfate) pulping is the most common processing technology, accounting for over 80% of all U.S.-produced pulp. In Kraft pulping, about half the wood is converted into fiber. The other half becomes black liquor, a by-product containing unutilized wood fiber and valuable chemicals.

Pulp and paper facilities combust black liquor in recovery boilers to produce energy (i.e., steam), and, more importantly, to recover the valuable chemicals present in the liquor. The amount of black liquor generated in the pulp and paper industry is the equivalent of 52 million dry tons of biomass (Table A.8, Appendix A). Because the amount of black liquor generated is insufficient to meet all mill needs, recovery boilers are usually supplemented with fossil and wood waste–fired boilers. The pulp and paper industry utilizes enough black liquor, bark, and other wood wastes to meet nearly 60% of its energy requirements. Currently, the forest products industry along with DOE are looking at black liquor gasification to convert pulping liquors and other biomass into gases that can be combusted much more efficiently.

3.3.4 Urban Wood Wastes

There are two principal sources of urban wood wastes: municipal solid waste (MSW) and construction and demolition debris. MSW consists of a variety of items ranging from organic food scraps to discarded furniture and appliances. In 2001, nearly 230 million tons of MSW was generated (EPA, 2003). Wood and yard and tree trimmings are the two sources within this waste stream that are potentially recoverable for bioenergy and biobased product applications. The wood component includes discarded furniture, pallets, containers, packaging materials, lumber scraps (other than new construction and demolition), and wood residuals from manufacturing. McKeever (2004) estimates the total wood component of the MSW stream at slightly more than 13 million dry tons (Table A.9, Appendix A). About 55% of this material is either recycled as compost, burned for power production, or unavailable for recovery because of excessive contamination. In total about 6 million dry tons of MSW wood is potentially available for recovery for bioenergy and biobased products. The other component of the MSW stream — yard and tree trimmings — is estimated at 8.2 million dry tons. However, only 1.5 million dry tons is considered potentially available for recovery.

The other principal source of urban wood waste is construction and demolition debris. These materials are considered separately from MSW since they come from much different sources. These debris materials are correlated with economic activity (e.g., housing starts), population, demolition activity, and the extent of recycling and reuse programs. McKeever (2004) estimates annual generation of construction and demolition debris at 11.6 and 27.7 million dry tons, respectively. About 8.6 million dry tons of construction debris and 11.7 million dry tons of demolition debris are considered potentially available for bioenergy and biobased products (Table A.9, Appendix A). Unlike construction debris, which tends to be relatively clean and can be more easily source-separated, demolition debris is often contaminated, making recovery much more difficult and expensive.

All these sources of urban wood waste total nearly 28 million dry tons. As noted by McKeever (1998), many factors affect the availability of urban wood wastes, such as size and condition of the material, extent of commingling with other materials, contamination, location and concentration, and, of course, costs associated with acquisition, transport, and processing.

3.3.5 Forest Growth and Increase in the Demand for Forest Products

The Fifth Resources Planning Act Timber Assessment projects the continued expansion of the standing forest inventory despite the estimated conversion of about 23 million acres of timberland into more developed uses (Haynes, 2003). The size of the standing forest inventory will increase because annual forest growth will continue to exceed annual harvests and other removals from the inventory. The forest products industry will continue to become more efficient in the way it harvests and processes wood products. The demand for forest products are also projected to increase. However, the increase will be less than historical growth owing to a general declining trend in the use of paper and paperboard products relative to GNP and the relatively stable forecast of housing starts (Haynes, 2003). The increase in the consumption of forest products will be met by an increase in timber harvests; an increase in log, chip, and product imports; and an increase in the use of recovered paper. Further, consumers will become more efficient in the use of wood products by generating fewer wood wastes and increasing recycling rates.

These changes and trends will affect the availability of forest residues for bioenergy and biobased products. An overall increase in the amount of biomass available due to changes in the demand and supply for forest products will increase the availability and use of forest residues by about 89 million dry tons annually.

3.4 Forest Resources Summary

Biomass derived from forestlands currently contributes about 142 million dry tons to total annual consumption in the United Sates of 190 million dry tons. Based on the assumptions and conditions outlined in this analysis, the amount of forestland-derived biomass that can be sustainably produced is approximately 368 million dry tons annually — more than 2.5 times current consumption. This estimate includes 35 million dry tons of fuelwood that is extracted annually from forestland for residential and commercial uses, about 98 million dry tons of residues generated annually and used by the forest products industry, and about 10 million dry tons of urban wood waste. As discussed previously, there are relatively large amounts of forest residue produced by logging and land clearing operations that goes uncollected (41 million dry tons per year) and significant quantities of forest residues that can be collected from fuel treatments to reduce fire hazards (60 million dry tons per year). Additionally, there are some unutilized wastes from wood processing mills and unutilized urban wood. These sources total about 36 million dry tons annually. The distribution of the resource potential is summarized below in Fig. 13. About 48% of these resources are derived directly from forestlands. About 39% are secondary sources of biomass from the forest products industry. The remaining fraction would come from tertiary or collectively from a variety of urban sources.

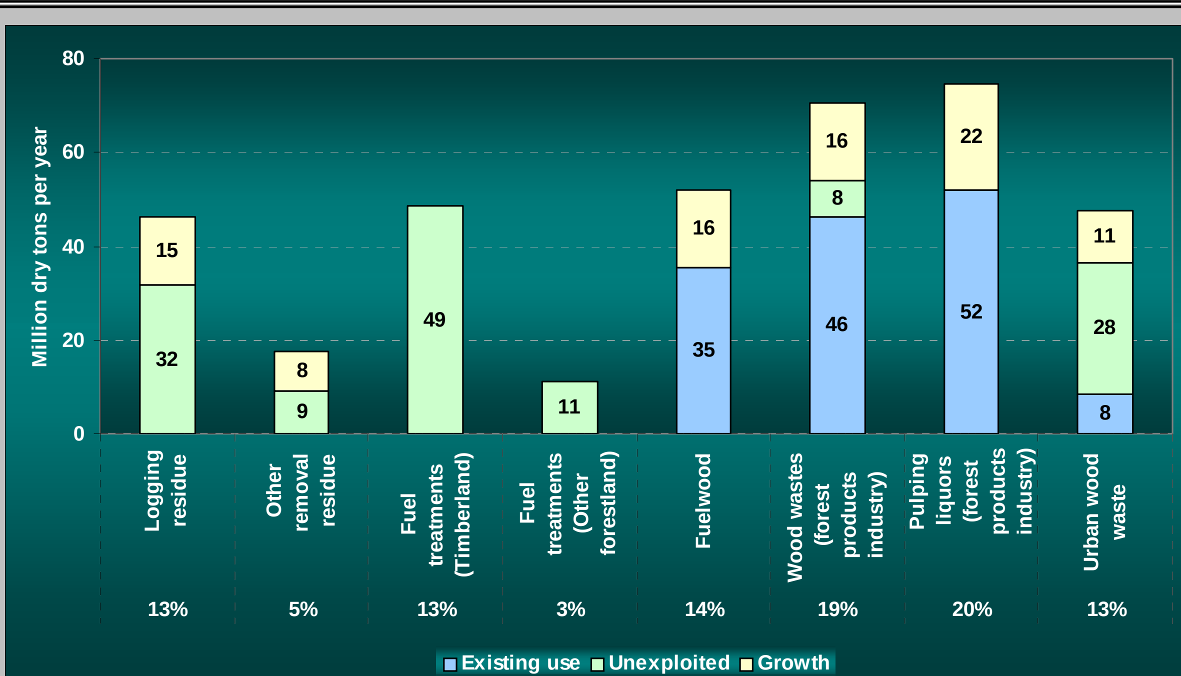


Fig. 13. Summary of potentially available forest resources.

4. AGRICULTURE-DERIVED BIOMASS RESOURCES

4.1 Agricultural Land Resource Base

Agriculture is the third largest single use of land in the United States. In 1997, the year of the most recent complete land inventory, agricultural land totaled some 455 million acres — 349 million acres of land in active use to grow crops, 39 million acres of idle cropland [including land enrolled in the Conservation Reserve Program (CRP)], and 67 million acres of cropland used as pasture (Fig. 14) (USDA-NRCS, 2003a). In the contiguous 48 states, the amount of agricultural land actively used to grow crops has varied from 330 to 380 million acres over the last 30 years. Cropland tends to move in and out of active production because of soil and weather conditions at planting time, expected crop prices, and the presence of government programs. Some cropland is also permanently converted to other nonagricultural uses. Between 1997 and 2001, seven million acres of active cropland were lost to other uses (USDA-NRCS 2003a).

The agricultural land base considered for this resource analysis includes 342 million acres of active cropland, 39 million acres of idle cropland, and 67 million acres of cropland used as pasture (448 million acres total). All cropland acres are assumed to be potential contributors to agriculturally derived biomass feedstocks. Permanent pasture land might be another potential resource, but it is not considered in this analysis.

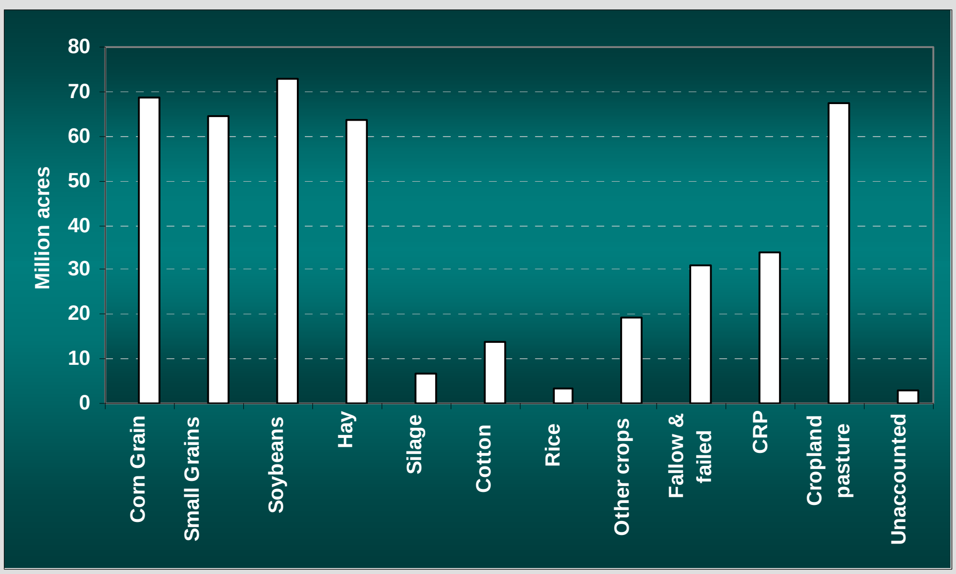


Fig. 14. Summary of cropland uses, idle cropland, and cropland pasture in the contiguous United States.

(Source: Vesterby and Krupa, 2001)

Corn grain, small grains (primarily wheat), and soybeans account for 60% of cropland use.

4.2 Agricultural Resources

Grains and oilseeds are the primary feedstocks used to produce most of the ethanol, biodiesel, and bioproducts consumed today. Food and feed processing wastes and tertiary post-consumer wastes are also used to generate a modest amount of electricity. These agriculture-derived biomass resources account for nearly 25% of current biomass consumption. This amount of biomass, however, is small relative to currently available agricultural biomass resources and tiny relative to agriculture's full potential. With appropriate economic incentives and improved cropping practices and technologies, such as higher-yielding plants and more efficient harvest equipment, significant amounts of agricultural crop residues and food and feed processing wastes could be sustainably produced. Moreover, the amount of sustainable biomass derived from agricultural land could be increased further by dedicating some land to the production of perennial grass and woody crops.

U.S. agriculture has changed considerably since the early part of the 20th century (USDA-NASS, 2003a). The key technological drivers of this change were mechanization and dramatically increased crop yields for major grain and fiber crops. Mechanization dramatically reduced the need for horses for "horsepower," and consequently oat production (for animal food) greatly decreased. In the same time frame, soybean production increased, but for different reasons.

Increased crop yields were a direct result of research, such as corn and wheat hybridization, and governmental price support policies. Agriculture also became more productive in the use of inputs to grow crops (Fig. 15). A substantial increase in livestock production, especially cattle and poultry, also occurred.

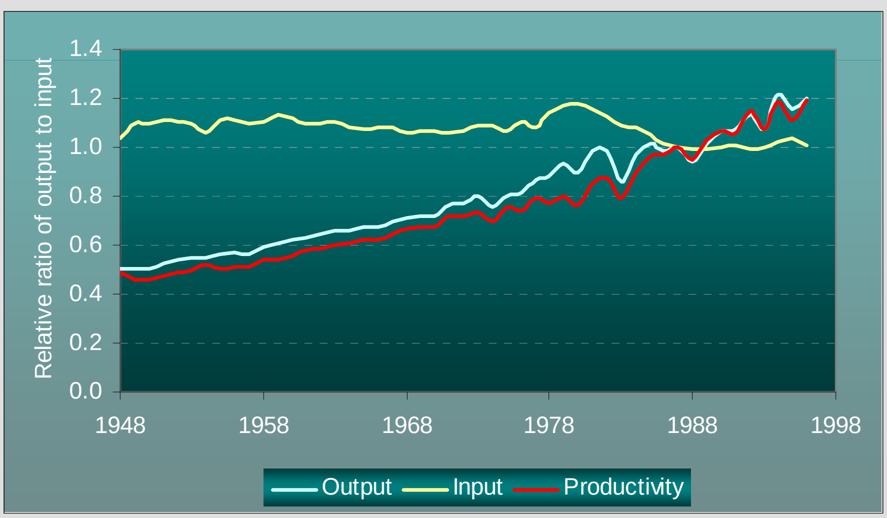


Fig. 15. Agricultural productivity, 1948–1996.

(Source: USDA-NASS, 2003a)

Agricultural productivity — a measure of output to input — has increased steadily over the last half century.

Driven by a need to reduce erosion, maintain soil structure and nutrients, and build soil carbon levels, agriculture adopted sounder environmental and conservation practices. For example, no-till cultivation, the most environmentally friendly production system, is now practiced on more than 62 million acres, and another 50 million acres are in some other conservation tillage system (CTIC, 2004). Crop rotation is also much more common. In the mid-1990s for instance, the practice of rotating corn with soybeans increased from nearly half to about two-thirds of planted corn acreage.

Agriculture is expected to continue to change and adapt to new technologies and circumstances. Crop use reallocation has occurred on a large scale (Fig. 16). Biotechnology, for example, is transforming agriculture by making available genetically altered varieties of corn and soybeans. Biotech hybrids of corn now account for 40% of total planted acreage (National Corn Growers Association, 2004).

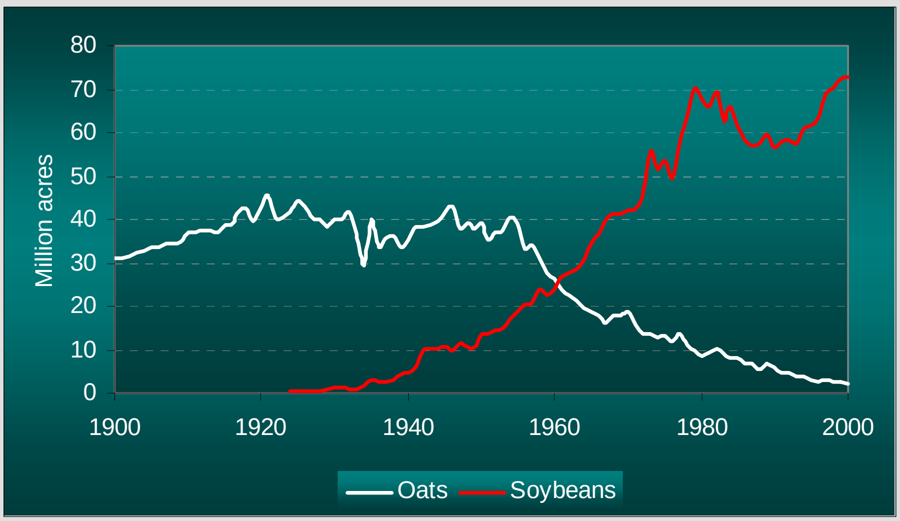


Fig. 16. Harvested acres of oats and soybeans, 1900–2000.

(Source: USDA-NASS, 2003a)

Major crop use allocations have occurred over the past 60 years.

The future could also see agriculture becoming a more important supplier of bioenergy and biobased products to the U.S. economy. The production of ethanol from corn and other grains is projected to continue to grow (USDA-OCE, 2003, 2004). Biodiesel production has also grown significantly, and could increase substantially in the future under an EPA mandate to reduce sulfur in diesel fuel (Stroup, 2004). The demand for new biobased products is also expanding. For example, innovative carbon-based technologies, such as the development of carbon-annotate fibers, could provide new markets for biomass.

4.3 Scenarios to Evaluate the Biomass Potential of Agriculture

To assess the potential biomass contribution from agriculture, we evaluated a number of scenarios. These scenarios include various combinations of changes in the following:

- yields of crops grown on active cropland,
- crop residue-to-grain or -seed ratios,
- annual crop residue collection technology and equipment,
- crop tillage practices,
- land use change to accommodate perennial crops (i.e., grasses and woody crops),
- demands for biofuels (i.e., ethanol and biodiesel), and
- secondary processing and other wastes.

Crop yields are of particular importance because they affect the amount of residue generated and the amount of land needed to meet food, feed, and fiber demands.

Three scenarios are summarized below: (1) current availability of biomass feedstocks from agricultural land; (2) biomass availability through a combination of technology changes (e.g., increased crop yields, more efficient harvest technology, and changes in tillage practices) without any changes in land use; and (3) biomass availability through technology changes (including residue-to-grain ratio changes) and, more significantly, changes in land use to accommodate perennial crops. The agricultural resources considered for each of these scenarios include residues from major crops, grains and oilseeds used for ethanol and biodiesel production, and residues and waste resources. Perennial crops, such as switchgrass and hybrid poplars, are included in the third scenario when land use changes are included.

4.3.1 Scenario 1: Current availability of biomass from agricultural lands

Current availability is the baseline that summarizes sustainable biomass resources under current crop yields, tillage practices (20–40% no-till for major crops), residue collection technology (~40% recovery), grain to ethanol and biodiesel production, and availability and use of secondary and tertiary residues and waste resources. In sum, the amount of biomass currently available for bioenergy and bioproducts is about 193 million dry tons annually. This is about 16% of the 1.2 billion dry tons of plant material produced on agricultural land. It includes 115 million dry tons of crop residues, 18 million dry tons of grain used for ethanol production, and 60 million dry tons of animal manures and wastes (e.g., MSW and landfill gas). The single largest source of this current potential is corn residues or corn stover (Fig. 17; Table B.2, Appendix B). These residues total 75 million dry tons.

4.3.2 Scenario 2: Technology change without land use change

Scenario 2 assumes an increase in crop yields for corn, wheat, and other small grains by 25–50%. Yields of other crops, such as soybeans, rice, cotton, alfalfa, hay, and silage, are assumed to increase only by 15–30% because there is less private-sector investment in those crops. Soybeans are assumed to contribute no crop residue under a moderate yield increase (15% yield increase) but to make a small contribution with a 30% yield increase. Collection equipment is assumed to be able to recover as much as 60% of the sustainably removable residue under the moderate yield increases and as much as 75% under the high yield increases. No-till cultivation is assumed to be practiced on approximately 200 million

Fig. 17. Current availability of biomass from agricultural lands.

The total current availability of biomass from cropland is approximately 193 million dry tons per year.
Slightly more than one-fifth of this biomass is currently used.
Corn stover is a major untapped source of agriculture-derived biomass.

acres under moderate yield increase and all of active cropland under high yields. This scenario also assumes a doubling of grain to ethanol under moderate yields and slightly less than a fourfold increase under the high yields. Soy oil used for biodiesel increases dramatically from the 2001 level under both moderate and high yield increases. Further, about 75 million dry tons of manure and other secondary and tertiary residues and wastes are assumed to be used for bioenergy production. Attaining this level of crop yield increase will require a continuation of research, deployment of new technologies, and incentives. However, such increases are certainly doable if past trends are indicative. This intensive scenario for use of crop residue results in the annual production of 379 million dry tons per year under moderate yields and 579 million dry tons under high yields (Fig. 18; Table B.3-4, Appendix B). In this scenario about two-thirds to three-fourths of total biomass is from crop residues.

4.3.3 Scenario 3: Technology change with land use change

Scenario 3 assumes land use changes and changes in soybean varieties as well as the technology changes assumed under the previous scenario. Soybean varieties are assumed to transition from an average residue-to-grain ratio of 1.5 to a ratio of 2.0. The land use changes include the conversion of either 40 or 60 million acres, associated, respectively, with moderate and high yield increases. Wood crops produced for fiber are expanded from 100,000 acres to 5 million acres, where they can produce an average annual yield of 8 dry tons per acre. Perennial crops grown primarily for energy expand to either 35 million acres at 5 dry tons per acre per year or to 55 million acres with average yields of 8 dry tons per acre per year. Twenty percent of the wood fiber crops are assumed to be used for energy and the remainder for other, higher-value conventional forest products. Ninety percent of the perennial crops are used for energy and 10% for other products. Finally, it is assumed that 90% of the biomass is harvested. This scenario results in the production of 563 to 933 million dry tons (Fig. 19; Table B.5-6, Appendix B). Crop residue increases even though conventional cropland is less because of the addition of more soybean residue together with increased yields. The single largest source of biomass is the crop residue, accounting for nearly 50% of the total. Perennial crops account for about 30 to 40% depending on crop yield increase (i.e., moderate or high yield).

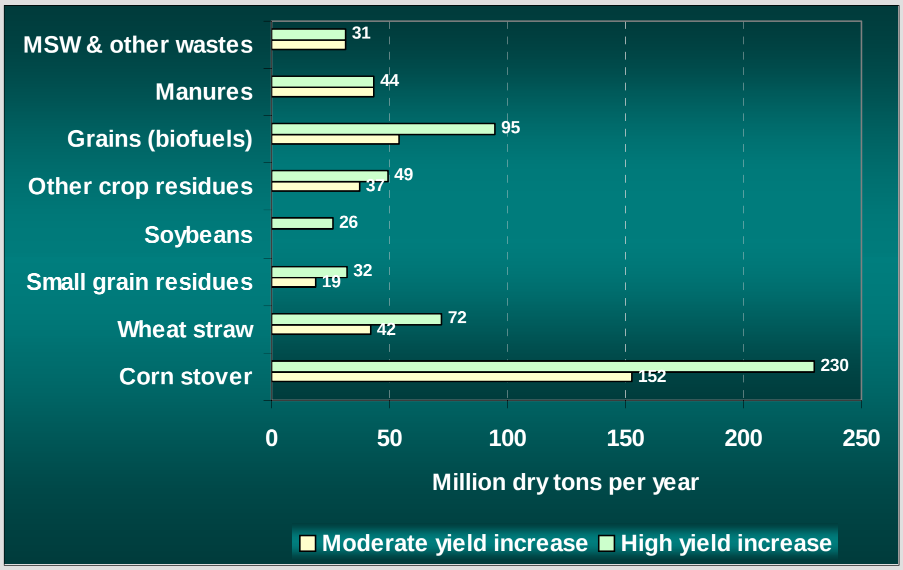


Fig. 18. Availability of biomass under increased crop yields and technology changes.

Total availability of biomass from cropland ranges from 379 to 579 million dry tons per year at crop yield increases of 25% (moderate) and 50% (high) for corn and other grains and 15% (moderate) and 30% (high) for other crops. Changes in tillage practices, residue to grain and seed ratios, and residue collection technology and equipment are required.

No changes in the current allocation of cropland are required to attain these levels biomass.

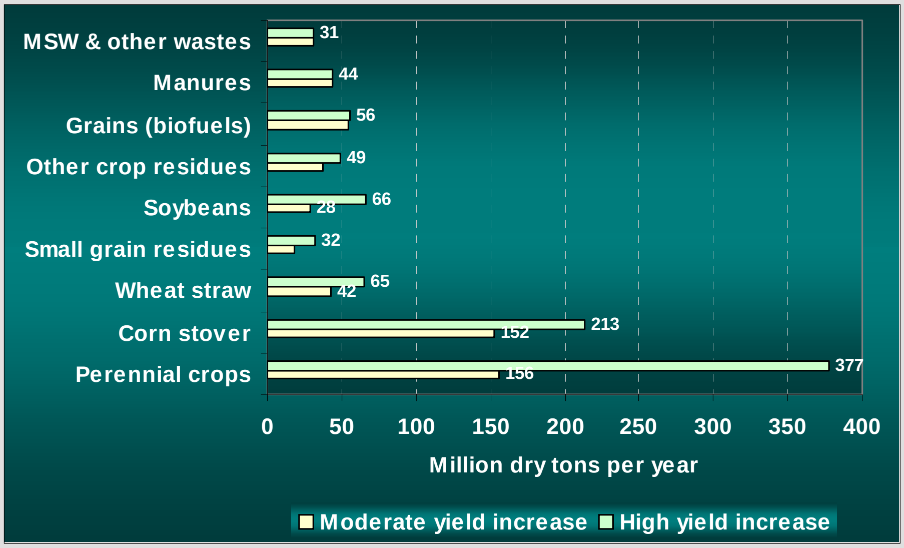


Fig. 19. Availability of biomass under increased crop yields, technology changes, and inclusion of perennial crops.

Total availability of biomass from cropland, idle cropland, and cropland pasture ranges from 563 to 933 million dry tons per year at crop yield increases of 25% (moderate) and 50% (high) for corn and other grains and 15% (moderate) and 30% (high) for other crops. Changes in tillage practices, residue to grain and seed ratios, and residue collection technology and equipment are also required.

The allocation of some active cropland, idle cropland, and cropland pasture is required to attain this level of annual production.

4.4 Increased Biomass Resources from Agriculture

4.4.1 Crop Yields

Corn grain yields have risen dramatically and steadily over the past 30 years at an average annual change of 1.7 bushels per acre even while fertilizer inputs have declined (Fig. 20) (Doberman et al., 2003). Continuing increases at this level will easily result in a 25% yield increase (173 bushels per acre) before 2025 and a 50% yield increase (207 bushels per acre) before 2045. This even assumes that the actual crop yield rate of increase is decreasing from a current level of nearly 1.2% per year to about 0.9% per year by 2030 — a prediction made by FAO (2003). Crop yields and acres for 2001 were obtained from published agricultural statistics (USDA-NASSa; USDA-NRCS, 2003a).

The high yield expectation of 207 bushels per acre is very reasonable (even conservative) given that average yields remain well below recent corn yield records, which range from 300 to 400 bushels per acre (Dobermann et al., 2003). Corn yield simulation models indicate that the actual yield potential of corn in the U.S. temperate climate is more than 300 bushels per acre (Arkebauer et al., 2004). This appears to be true in both irrigated and rainfed corn belt areas, where soil moisture is generally not a limiting factor. Doberman et al. (2003) points out that in recent years, record corn yields have been virtually the same between irrigated and rainfed acreage. This began to occur with the adoption of new varieties with many genetic improvements, including the Bt genetic modification.

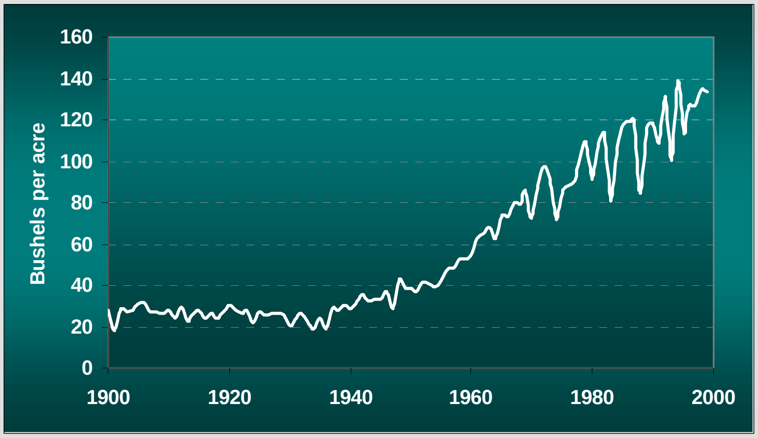


Fig. 20. Average corn yields, 1900–1999.

(Source: USDA-NASS, 2003a)

Corn grain yields have increased steadily throughout the latter half of the 20th century.

Recent corn selection techniques have optimized genotype/environment interactions leading to increased yield stability and stress tolerance (e.g., tolerance to higher planting densities) (Tollenaar and Lee, 2002). Research results and recommendations by Pioneer Hi-Bred Ltd. suggest that increasing the density of corn plantings is a trend that will continue, since it can increase profit in many situations (Paszkiewicz and Butzen, 2003).

Increasing wheat grain yields by 25 to 50% is also probable in the next 25 to 50 years. The most recent estimates from the Wheat Improvement Center in Mexico City (CIMMYT, 2002) show annual yield increasing by 1.7% in the United States for 1988–2000. These rates are lower than those of four or five decades ago, but are still very significant and higher than the average rate of 1.3% observed in the 1977–1988 period. However, a concern is that most genetic research on wheat in the United States currently focuses on developing dwarf varieties (which would reduce residue-to-grain ratios), and increasing disease resistance. Only a small amount of research is going toward improving tall wheat varieties.

The big unknown for wheat and other small grains is the effect of biotechnology. A technology being aggressively pursued that could affect wheat is asexual reproduction (Pollack, 2000). Asexual reproduction would allow seeds to be exact genetic copies, or clones, of the parent. If commercially successful, this technique would accelerate breeding, allow genetic adaptation of plants to specific micro-climates, and allow the ability to create and stabilize new genetic combinations. Major biotechnology and seed companies as well as the USDA, universities, and small private groups are all involved in research (GRAIN, 2001). An article by USDA Economic Research Service scientists (Riley and Hoffman, 1999) article suggested that wheat research has increased substantially in recently and that genetic transformation methods could have a big payoff in the next few years.

Of the plant growth factors that limit yield, soil moisture is the most limiting factor. Thus, continued selection for stress tolerance, including tolerance to moisture deficits, will be critically important to achieving a crop's yield potential. Climate changes could modify the U.S. potential for achieving expected future crop yields.

4.4.2 Residue-to-Grain or -Seed Ratios

The ratio of crop residues to grain is a key variable that has a significant effect on the availability of biomass. Since grain yields are reported annually, but "biomass" yields are not, an estimate of the relationship between the two is necessary for estimating biomass yields. A wide variation in residue-to-grain ratios exists in the literature. For this analysis, the baseline ratio of crop residues to grain is derived from the Soil Conditioning Index (SCI) of the USDA National Resource Conservation Service Soil (USDA-NRCS, 2003b). If different ratios are given for the same crop, the one associated with conditions that represented the largest crop acreage was used.

Clearly, the ratio of residue to grain (or its inverse, the harvest index) does vary within crops from year to year and according to time of harvest, variety, and density of planting. Prihar and Stewart (1990) indicate that harvest index increases with increasing total yields and decreasing crop stresses. This tendency was also shown in experiments in Minnesota reported by Linden et al. (2000). However, these results contrast with those published by Doberman et al. (2003), where harvest index was found to decrease slightly under the highest yield conditions in Nebraska experiment trials. The salient difference is that the highest yield conditions in Nebraska were associated with higher-density plantings. Tollenar and Lee (2002) report that the corn harvest index has not shown a clear trend in the past seven decades except where plants are grown at higher densities, in which case it decreases. The lowest harvest index measured in the Nebraska experiments, even at the highest density, was 0.49 (Yang et al., 2004). In this analysis, it is assumed that corn stover-to-grain ratios remain at 1:1 on a dry weight basis under all scenarios. It was necessary to adjust the weights published for crops in agricultural statistics (USDA-NASS, 2003a) to a dry weight based on assumed moisture content at harvest (Gupta, 1979). Information on moisture contents were found in Hellevang (1995).

A change in the residue-to-grain ratio is a possible technology change that could occur for any crop. In this assessment, however, a ratio change was assumed only for soybeans. They presently contribute nothing to the removable residue estimates because most, if not all, soybean residue needs to be left on the ground to meet conservation practice requirements. USDA genetic improvement research in soybeans has focused on developing varieties that grow taller, have improved lodging resistance, have a higher ratio of straw to beans, have a

Fig. 21. Comparison between conventional soybeans and large biomass soybeans.

(Source: Wu et al., 2004)

better over-winter residue persistence, and are able to attain these traits without genetic transformation (Fig 21 and 22). A recently released variety, Tara, has these characteristics (Devine and McMurtrey, 2004). Several similar varieties of soybean are being developed and tested for combined forage and grain production and to provide soil conservation benefits (Wu et al., 2004). It cannot be predicted whether farmers will adopt these new varieties, but clearly the technology will be available. Potentially, with such varieties soybean acreage could contribute to the availability of residues for bioenergy and bioproducts.

Fig. 22. Soybean residues from large biomass (top) and conventional soybeans (bottom)

(Source: Wu et al., 2004)

4.4.3 Residue Collection Technology for Annual Crops

Most residue recovery operations today pick up residue left on the ground after primary crops have been harvested. Collection of residues from these crops involves multiple passes of equipment over fields and results in no more than 40% removal of stover or straw on average. This recovery amount is due to a combination of collection equipment limitations, contour ridge farming, economics, and conservation requirements. It is possible under some conditions to remove as much as 60–70% of corn stover with currently available equipment. However, this level of residue collection is economically or environmentally viable only where land is under no-till cultivation and crop yields are very high. This analysis assumes that harvest technology and the percentage of cropland under no-till management are increased simultaneously.

Future residue collection technology with the potential of collecting up to 75% of the residue is envisioned (DOE, 2003). These systems are likely to be single-pass systems that would reduce costs by collecting the grain and residue together. Single-pass systems would also address concerns about soil compaction from residue collection equipment. Future one-pass systems for corn and grain will also need to have selective harvesting capability so that some portions of the residue stream can be reapplied to the field to meet conservation requirements.

4.4.4 Cropland Tillage

No-till planting systems are now used on more than 60 million acres in the United States, surpassing mulch till as the favored form of conservation tillage (Fig. 23) (CTIC, 2004). With the concerted effort by USDA to educate farmers and conservation advisors, it is anticipated that acres in no-till cultivation and other types of conservation tillage will increase in the future. One example of the USDA effort is the CORE4 Conservation Training Practices Guide (USDA-NRCS, 1999).

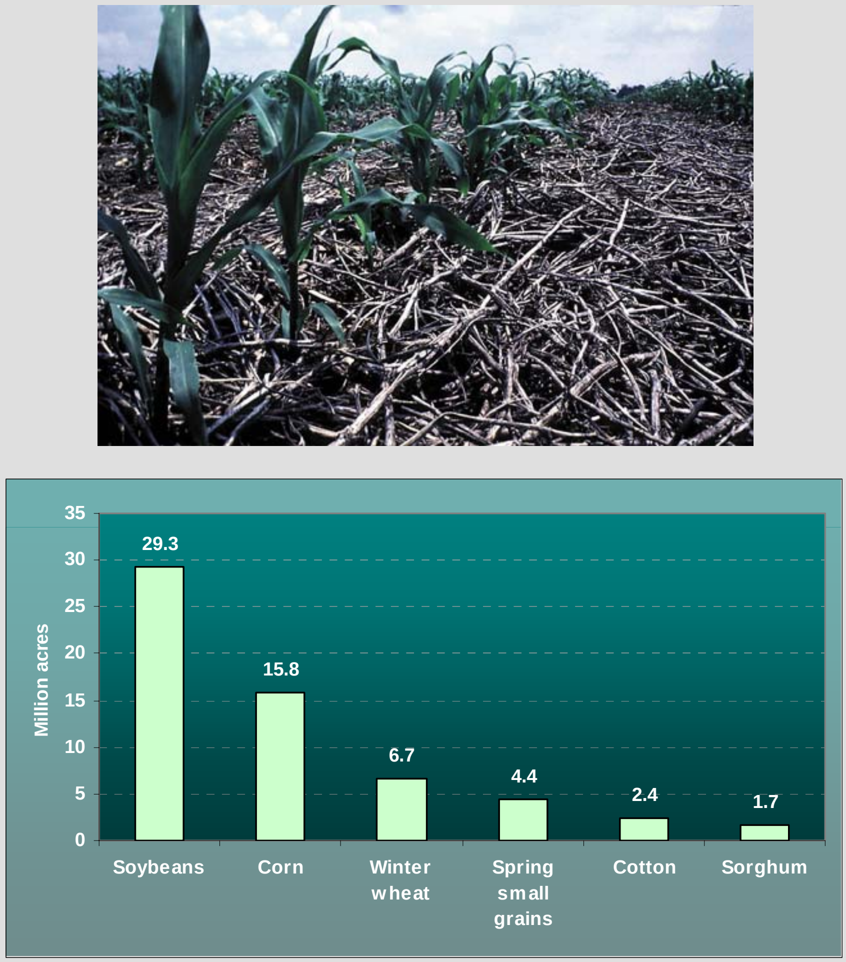


Fig. 23. Crops under no-till cultivation.

Source: Conservation Technology Information Center (www.ctic.purdue.edu).

Developing a single national estimate of the amount of residue that must remain on the ground to maintain soil sustainability for any given set of conditions is a challenge. Residue maintenance requirements (RMRs) are most properly estimated at the individual field level with models such as RUSLE (Revised Universal Soil Loss Equation), used together with the SCI tool as described in the National Agronomy Manual (USDA-NRCS, 2002). However, using this approach to provide a national estimate would require actual data from hundreds of thousands of specific locations. Nelson (2002) developed a methodology for making a national estimate that reflected the RUSLE/SCI modeling approach in that it considered soils, rainfall, crop and rotation choices, and tillage choices in determining the amount of residue required to minimize erosion to T (tolerance) levels recommended by USDA. Nelson is a co-author on the Graham et al., (2004) analysis that produced estimates of residue maintenance requirements on land with corn as a rotation crop (using 1995–2000 data). Walsh (2004) also relied on Nelson's approach in developing updated estimates of corn and wheat residue. Both of those efforts were used to derive national estimates of average RMRs for corn and wheat land.

Estimating national-level RMRs under various scenarios for corn land was done by creating factors using the Graham et al., (2004). Thus, the calculation

(Available Residue/Total Residue) ⁄ Acres Harvested

gave an average national RMR factor for minimizing erosion on corn land in dry tons per acre for current till and all no-till cases. The current-till RMR factor was used in the 2001 base case; the all-no-till RMR factor was used in the land change–high yield scenario; and an RMR factor halfway between was used in the land change–moderate yield scenario. For wheat, a similar development of RMR factors was done using results from the updated 2004 analysis by Walsh. Development of the soybean RMR factors relied on first calculating an average of the residue maintenance requirements found in the SCIVER25 worksheet from the top five soybean-producing states, adjusting that value based on the soybean residue equivalency value (to corn), and finally, further adjusting the value downward by the same amount that the corn values differed from SCIVER25 averages. This approach produced an artificial factor that was probably low for the 2001 baseline but high for the moderate-yield and high-yield scenarios, which also included an assumed change to large biomass soybean (LBS) varieties with higher residue-to-grain ratios. The low RMR factor in the 2001 baseline had no effect on results, since there was still not enough residue to make any contribution to biomass. The large RMRs used in the moderate-yield and high-yield scenarios means that the estimate of soybean contribution is conservative. McMurtrey et al. (in press) found that LBS varieties provided 40–100% more residue cover than conventional soybeans, not only because of higher biomass but also because the decomposition of the LBS varieties is slower.

The current goal of soil conservation is not just to manage for minimizing erosion but also to increase soil carbon (Puckett, 2003). Practices that enhance soil carbon include high biomass yields, cover crops, reduced or no tillage, rotational grazing, and establishment of perennial crops. All practices but grazing also have the potential of increasing sustainably removable biomass. With annual crop production, the largest increases in soil organic matter will result from continuous no-till cultivation. Leaving the root structure of plants undisturbed is vitally important to the success of no-till in increasing soil carbon, more so than leaving crop residues on the surface (USDA-NRCS, 1999). While some residue will nearly always need to be left on the soil to maintain soil moisture and quality (i.e., nutrients and organic matter), limit rainfall and wind erosion, and maintain or increase soil carbon levels, the amount that can be taken off sustainably is expected to increase as crop yields and total residue produced increase.

4.4.5 Allocation of Cropland Acres to Perennial Crops

It is assumed that significant amounts of land could shift to the production of perennial crops if a large market for bioenergy and biobased products emerges. Studies by de la Torre Ugarte et al. (2003) and McLaughlin et al. (2002) indicate that this could happen today if the price for energy crops were high enough to attract the interest of farmers. These authors report that if a farmgate price of about $40 per dry ton were offered to farmers, perennial grass crops producing an average of 4.2 dry tons per acre (a level attainable today) would be competitive with current crops on about 42 million acres of cropland and CRP land.

The high-yield scenario for perennial crops in this assessment assumes an average crop yield of 8 dry tons per acre, an amount considered feasible by grass researchers provided there is a concomitant increase in R&D. Current average annual yields from switchgrass clones tested in small plots over multiple years at 23 locations in the United States range from a low of 4.2 dry tons per acre to a high of 10.2 dry tons per acre, with most locations having an average between 5.5 and 8 dry tons per acre (McLaughlin and Kszos, in press). Yields from the best clones were generally 8 dry tons per acre or higher. The highest observed yield at any location or year was 15.4 dry tons per acre. The best-performing clones were often the same at a majority of the 23 sites spread over the Great Plains, the Midwest, and the South. None of the test plots were irrigated. Assuming an intensive genetic selection and research program on grasses, the feasibility of attaining average yields of 8 dry tons per acre over millions of acres is supported by modeling (McLaughlin and Kszos, in press). For woody crops, annual yields have been generally 5 dry tons per acre in most locations and are currently achieving more than 8 dry tons per acre in commercial plantings in the Pacific Northwest. These test data alone suggest that future yields estimated for perennial crops are well within reason, if not conservative. Yields from small plots are not likely to be representative of average yields across the millions of acres assumed in the perennial crop scenarios. However, with the genetic variability existing in switchgrass and woody crops, the potential for continued yield increases and attainment of 8 dry tons per acre averaged over millions of acres is very high.

The technology change with land use change scenario (scenario 3 as described in Sect. 4.3) assumes that as many as 60 million acres of cropland, cropland pasture, and CRP is shifted to perennial crop production. Forest Service projections of possible expansion of short-rotation woody crop technology were used as the basis for assuming that 5 million acres are shifted to woody crops (Ince, 2001). It was assumed, however, that 80% of the harvested wood goes to fiber and only 20% is available for energy. On the remaining 55 million acres, it is assumed that at least 80% of the perennial crops are used for energy. Whether the perennial crops are primarily wood or grass may depend on whether the bioenergy emphasis is on fuels or power. Figure 24 summarizes the change in land use among the three broad categories of agricultural land (i.e., active cropland, idle cropland, and cropland pasture) between scenario 1 and scenario 3 under moderate and high crop yield increases. In all cases, USDA baseline projections for food and feed demands continue to be met (Table B.1, Appendix B).

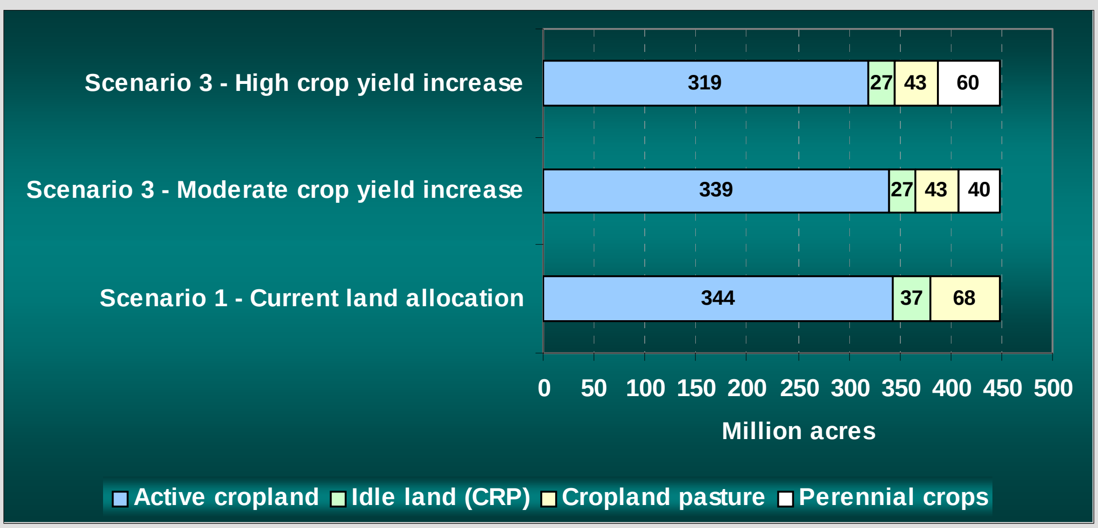


Fig. 24. Summary of the allocation of agricultural land under alternative scenarios.

4.4.6 Grain to Ethanol and Soybeans to Biodiesel

The USDA Office of the Chief Economist projects that under business-as-usual conditions, acreage planted for the eight major crops grown in the United States will decrease by 1 million acres between 2003 and 2013 but harvested acres will increase by 9 million acres (USDA-OCE, 2004). This would suggest that fewer crop failures are expected. All crop use categories increase, with grain to ethanol showing the largest relative increase and exports also significantly increasing. To create scenarios beyond 2013, we considered world population and crop yield trends published by the United Nations Food and Agricultural Organization (UN, 2003 and FAO, 2003). Projections suggest that the North American population will increase by 23% between 2013 and 2050 while the world population increase will be only slightly higher. Thus, in our highest-yield scenarios, corn required for food in the United States is assumed to increase by 23% over the 2013 value.

The FAO (2003) predicts that export demands from industrial countries will continue to increase through 2030 but at a slowing rate. The USDA-OCE (2004) predicts that export demand for corn through 2013 will rise, primarily because of increasing demand for animal feed. This evaluation assumes that corn exports rise by another 10% in the high-corn-yield scenarios. The USDA-OCE (2004) also predicts that exports of wheat and soybeans will remain level through 2013 because of increasing foreign competition. This evaluation assumes level demand in all scenarios.

The USDA-OCE (2004) projects that demand for corn grain for ethanol will increase from 714 million bushels in 2001 to 1360 million bushels in 2013, or from 7.5% (16.9 million dry tons) to about 11.7% (32 million dry tons) of total corn grain production. This evaluation assumes that food, feed, and exports demands are met first and then ethanol (or other bioproducts) is produced from the remaining grain. The results show that with a 50% increase in corn yield and no land change, over 62 million dry tons of grain would be available for bioproducts or ethanol. Urbancheck (2001) projected that ethanol use could increase to 8.8 billion gallons in the future; this amount would require 2464 million bushels or 58.3 million dry tons of corn grain. When corn acres are reduced by 5 million acres, then grain available for ethanol or other bioproducts is reduced to 38 million dry tons.

The USDA-OCE (2004) projections to 2013 show domestic use of soybeans increasing due to more demand for pork and poultry, but planted and harvest acres of soybeans are projected to decline slightly because of increasing yields. No projections of soybean use for biodiesel are made.

Biodiesel production from soybeans has already more than doubled from 12.5 million gallons in since 2001 to more than 25 million gallons today. Expectations are that demand will continue to rise. Stroup (2004) noted that a “big looming potential for biodiesel is the use of biodiesel blends for transportation fuel.” This could result from a proposed EPA mandate to reduce sulfur in diesel fuel. This assessment assumes that all soybeans not needed for food, feed, or export could be used to make biodiesel or other industrial products. The maximum amount available is 21 million dry tons under the high-yield, no land use change scenario. That is reduced to only 7 million dry tons when 10 million acres of soybeans are assumed to be converted to perennial crops. However, 7 million dry tons could produce about 350 million gallons of biodiesel if all were used for that purpose. This assessment assumes 4–8 million dry tons of other oilseed crops and 2 million tons of inedible tallow and grease will be available for biodiesel fuels in future scenario alternatives.

4.4.7 Secondary Processing and Other Wastes

The largest potential single source of biomass from food/feed processing and post consumer wastes is animal manure. Manure can be readily collected from confined animal feeding operations (CAFOs), which continue to increase in number and size. In the recent past, CAFOs for cattle and hogs have increased slightly while those for poultry increased considerably.

Data published by USDA on manure production in CAFOs (USDA-ERS, 2001) and studies estimating the amounts of recoverable nitrogen and phosphorus (Kellog et al., 2000; Gollehon, 2002) are used to determine collectable and recoverable dry weights of manure. All future scenarios assume some increase in manure collected. While one option might have been to assume that all collectable manure is available for bioenergy, it is assumed that only the portion in excess of the amounts that can be applied on-farm without exceeding EPA mandated criteria, is available. Estimates of that excess amount are also derived Kellog et al. (2000) and Gollehon (2001). Of course, manure will need to be handled differently than most other biomass resources. Its use is dependent on development of appropriate technologies. It would be best utilized on-farm or very close to the source.

The utilization of other secondary sources of wastes from food and feed processing and tertiary wastes, such as MSW and gas, may be important at a few locations but were not large enough overall to include in a significant way in this evaluation.

4.5 Agricultural Resources Summary

The amount of biomass sustainably removable from agricultural lands is currently about 193 million dry tons annually. This amount can be increased nearly fivefold through a combination of technology changes (principally technologies to give higher yields and improved residue collection technology), adoption of no-till cultivation, and changes in land use to accommodate large-scale production of perennial crops. The amount of biomass under these assumptions is 933 million dry tons. By comparison, the total amount of biomass grown on this acreage is 2.1 billion dry tons. There is a large increase both in total amount of plant matter produced due to higher crop yields and in the estimated biomass amounts due to changes in tillage practices and harvest technology. Without changes in land use the amount of sustainably removable biomass would be 579 million dry tons of biomass under the high- yield assumption. Approximately the same amount of biomass could be produced on agricultural lands by assuming more moderate changes in future yields (e.g., 25% for corn and small grains), less residue recovery, and less no-till cultivation, provided there is some change in land use to accommodate about 40 million acres of perennial energy crops where most of the product is utilized for bioenergy and biobased products. Most of this land could come from idle land (summer fallow and CRP) and cropland pasture. Use of active cropland would be required. These results are graphically summarized in Fig. 25.

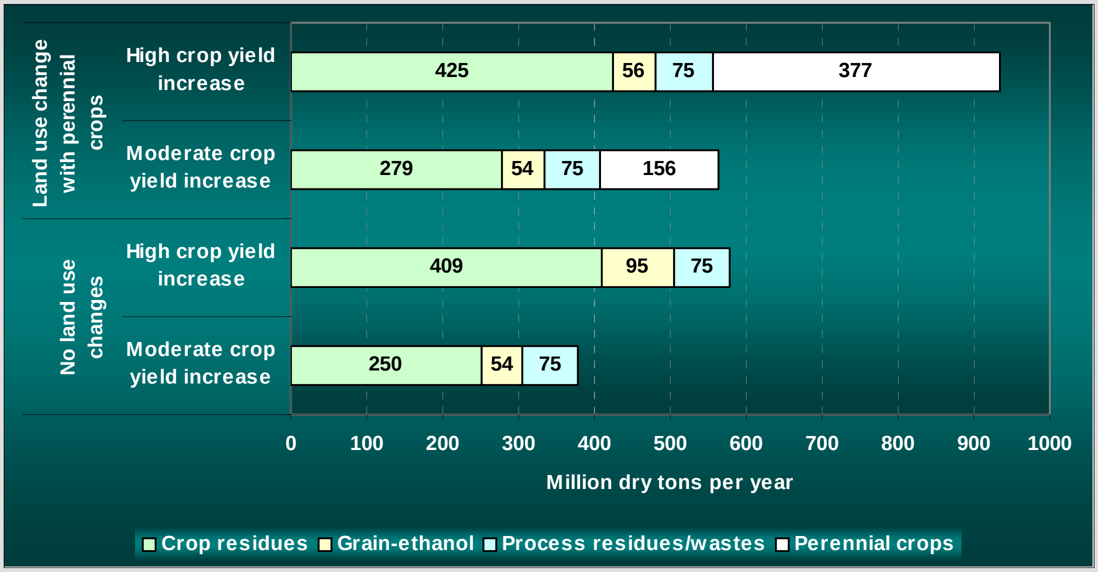


Fig. 25. Summary of potentially available agricultural resources.

Some factors not considered could limit the maximum amount of biomass estimated to be available. First, if demand for meat production increases (rather than remaining level) it will be more difficult to convert conventional cropland into perennial crop production. Of course, greater animal production would result in more by-products from the animals (manures and oils and grease from animal rendering). Second, higher export demands for wheat and soybeans could limit conversion of cropland to perennials. Third, if the total cropland base becomes less due to encroachment of urban populations, cropland conversion will also be less likely to occur. Fourth, the process used for adjusting residue availability as a function of tillage may not fully account for amounts needed to maintain or increase carbon in soils. This assessment also did not account for the use of residues by cattle for forage, which was estimated to equal about 12 million dry tons based on 1997 cattle populations (Gallagher et al., 2003). With the trend toward increasing the proportion of cattle reared in CAFOs, the demand for forage is likely to be decreasing.

Other rational scenario assumptions could increase the maximum amounts of biomass estimated to be available. For instance, the crop yield increases assumed are essentially business-as-usual expectations. None of the scenarios consider the possibility that technology could overcome yield limitations caused by drought and pests or increase nutrient use efficiency. Also, adoption of new cropping technologies in developing countries could further reduce export demands on the United States. Second, it is just as logical to assume that future meat demands will decline rather than increase. Populations will be aging, thus requiring less protein for sustenance. Further, trends towards healthier eating practices may cause reduced meat demand, at least in industrialized countries.

These results are believed to be a reasonable, if not conservative, estimates of future biomass potential in the United States.

5. POTENTIAL IMPACTS

Forestland and cropland resources have the potential to provide for a six-fold increase in the amount of biomass energy currently consumed. This annual potential exceeds 1.3 billion dry tons — the equivalent of more than one-third of the current demand for transportation fuels. About 30% of this potential would come from extensively managed forestlands and about 70% from intensively managed croplands. The major primary resources would be logging residues and fuel treatments from forestland and crop residues and perennial crops from agricultural land. Some additional quantities of biomass would be available from secondary sources; however, most of this biomass would be expected to be used by the forest products industry and food processing industries. Tertiary or waste sources of biomass are small relative to the primary sources. A sizeable fraction of this potential would be captive to existing uses. Examples are most of the biomass resource generated by the forest products industry, fuelwood extracted from forestlands, some urban wood wastes, grains used in the production of biofuels, and some agricultural wastes. Excluding these captive uses of biomass from the total resource potential still shows 220 million dry tons of forestland biomass (logging residue, fuel treatments, urban wood wastes) and, depending on crop yield improvements, 450 to nearly 850 million dry tons of cropland biomass (agricultural residues, perennial crops, and most process wastes) as potentially available for new bioenergy and biobased product uses (Fig. 26).

Producing one billion tons of feedstock annually will require technologies that can increase the utilization of currently available and underutilized feedstocks, such as agricultural residues and forest residues. It will require the development of perennial crops as an energy resource on a relatively large scale. It will require changes in agricultural and silvicultural crop management systems. Production yields from these systems will need to be increased and costs lowered. Changes in the way biomass feedstocks are collected or harvested, stored and transported, and pre-processed will also have to be made. Accomplishing these changes will obviously require R&D investments and policy initiatives as well as the coordinated involvement of numerous stakeholder groups to gain broad public acceptance. Much more program coordination among the Departments of Energy and Agriculture and other federal, state, and local agencies will be necessary to attain the billion-ton feedstock goal.

The utilization of a significant amount of these biomass resources would also require a concerted R&D effort to develop technologies to overcome a host of technical, market, and cost barriers. Demonstration projects and incentives (e.g., tax credits, price supports, and subsidies) would be required. Additional analyses would be required to discern the potential impact that large-scale forest and crop residue collection and production of perennial crops could have on traditional markets for agricultural and forest products. These policy considerations are very important but are certainly well beyond the limited technical scope of this resource assessment. The remainder of this assessment focuses on utilization issues and analysis limitations.

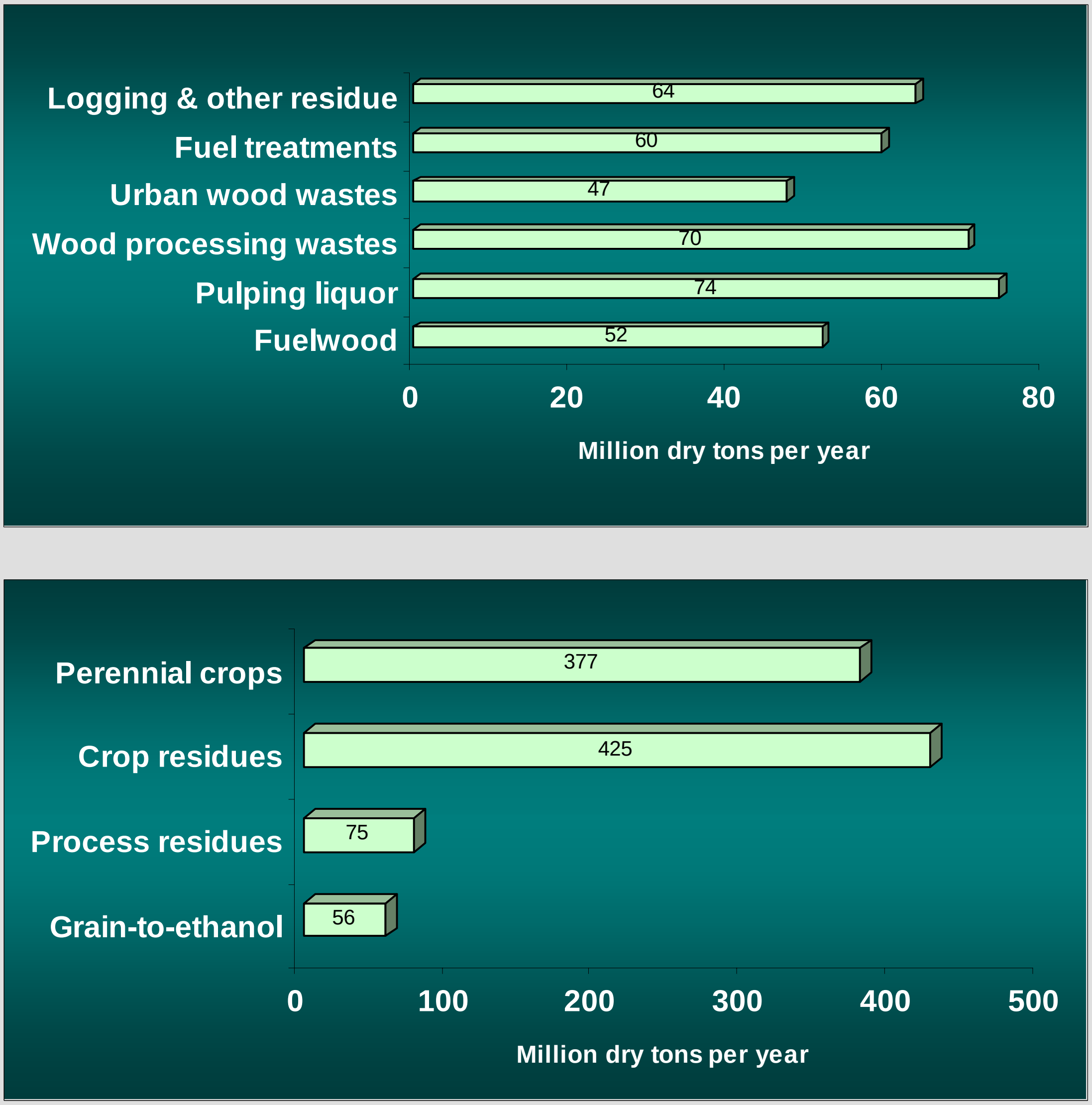


Fig. 26. Summary of potential forest and agricultural resources.

5.1 Forest-Derived Biomass Resources

The three key forest resources identified for this assessment are residues from logging and other removals, fuel treatments, and urban wood wastes. There are particular issues associated with the utilization of each of these resources.

- Accessibility, terrain (e.g., steep slopes), and environmentally sensitive areas limit fuel treatment operations. Where treatment operations are appropriate, costs associated with the removal of the excess biomass may be prohibitive. Separating and marketing larger-diameter trees for conventional (higher-valued) forest products would be necessary to help defray the costs of dealing with large numbers of small-diameter material (USDA-

FS, 2003). Removing large trees, however, can create unfavorable public opinion and opposition to fuel treatment operations.

- Transportation costs, usually in the range of $0.20 to $0.60 per dry ton-mile could severely limit the haul distances, if based solely of bioenergy and biobased product values. The availability of markets within viable transport distances may limit the practicality of removing fuel treatment biomass for bioenergy and biobased products.

- Labor availability may be a key constraint in fuel treatment operations. The strategic fuel treatment assessment for the western states notes that there is a disparity between the distribution of skilled forestry workers and the forestlands requiring fuel treatments (USDA-FS, 2003). Mobilizing forestry workers and equipment across large distances can increase costs and reduce competition for contracted projects.

- Fuel treatment operations have the potential to create environmental impacts, especially if sites are severely disturbed. The impact of erosion and consequent movement of sediments into surface waters is a particular concern. However, studies suggest that there is often a much higher flow of sediments into surface waters as a consequence of wildfires than as a consequence of fuel treatment thinning operations (USDA-FS, 2003).

- More cost-effective fuel treatment operations and recovery of logging and other removal residue will require the development of more efficient and specialized equipment that can accommodate small-diameter trees. The availability of more efficient equipment will make the recovery of biomass for bioenergy and biobased products much more cost-effective.

- Federal funding for forestry programs for such activities as private tree planting, forest stand management, and technical assistance are a small fraction (<0.5%) of direct agricultural payments to farmers (Alig et al., 2003). Given the size of private forestland ownership, well-crafted policies aimed at providing incentives for landowners to manage their holdings could attract large quantities of biomass. Of course, any policies must be based on good science and require that all requirements of sustainability are met.

- The availability of urban wood wastes is largely governed by the size of tipping fees. Where such fees are high (due in part to the lack of land for landfills), recycling is often higher. Also, high tipping fees provide economic incentives to utilize these resources.

- Some urban wood wastes are highly dispersed, making economical recovery potentially costly. Seasonality of the generated residue can also affect the viability of this source.

- Contamination and commingling of urban wood wastes with non-wood products, especially demolition wastes and some construction wastes, can limit uses. Contamination with dirt and rocks is also a potential issue with yard and tree trimmings.

5.2 Agriculture-Derived Biomass Resources

Annual crop residues, perennial crops, and, to a lesser extent, processing residues and wastes (e.g., animal manures) have the potential to sustainably contribute up to 850 million dry tons of biomass annually. This number is in addition to biomass that is currently used and likely to be used in the future, such as biofuel production from grains. Issues associated with these resources are as follows.

- Utilizing crop residues and growing perennial crops on a large scale would require significant changes in current crop yields, tillage practices, harvest/collection technologies, and transportation. The required technological changes are plausible, however, based on an extrapolation of current trends and experimental research. Without major technological breakthroughs, significant changes in the way land is allocated among crops and in food, feed, and fiber productions systems may be required.

- Potential environmental impacts are key concerns associated with the removal of large quantities of residues from cropland. Removing residues in excess of recommended or sustainable amounts could lower crop productivity, reduce soil quality, promote erosion, and lead to a loss of soil carbon.

- Annual crops are quite variable in yield, particularly at a local level. A key requirement to attaining targeted crop yields is the availability of sufficient water and nutrients. Genetic selection continues to move toward crops that are more stable in yield and more efficient in their use of water and nutrients. However, for specific bioenergy facilities, it will be necessary to incorporate strategies of excess production, storage, and ability to utilize multiple feedstocks in order to assure adequate supplies in any given year.

- Any practices that increase yields without reducing nitrogen releases into waterways will have serious negative impacts that could lead to government regulations on farmers (Raloff, 2004a). The transition of large amounts of land to perennial crops could be a partial solution both to the nitrogen release problem and to the need to find additional sources of biomass (Raloff, 2004b).

- There are significant environmental benefits in the planting of perennial crops relative to conventional planting of annual crops. Perennial crops require fewer applications of pesticides and fertilizers. Runoff of pesticides and nutrients will therefore be less. Perennial crops are much less erosive than annual crops because once they are established there is no soil disturbance. Perennial crops also provide better habitat for many birds, such as migratory song birds, and for several types of mammals.

- Redirecting large quantities of animal manure to bioenergy uses can lessen nutrient runoff and reduce contamination of surface water and groundwater resources.

- The use of biomass has considerable potential to reduce emissions of greenhouse gases, especially if perennial crops are a large component of the resource mix. Depending how the biomass resources are utilized, there could also be reductions in regional and locally significant air emissions. The expanded use of forest- and agriculture-derived biomass resources could result in improvements in water quality (at least relative to wildfires and annual crops) and reduced soil erosion.

- With increased production of ethanol from corn and small grains, the amount of distillers dried grains, gluten feed and gluten meal will increase. Also, soybean meal will increase as more soybeans are crushed for biodiesel. These co-products of biofuels production can be used as a protein supplement for livestock in place of corn grain. It is also assumed in this evaluation that perennial grasses are processed to remove proteins prior to their utilization as a low-cost ethanol feedstock. With all of these protein sources, there is sufficient feed material for livestock under all scenarios.

- This evaluation of the technical feasibility of changes in agricultural systems cannot determine whether markets would respond in a way that would support the biomass potential outlined.

6. SUMMARY FINDINGS

The U.S. Department of Energy and the U.S. Department of Agriculture are both strongly committed to expanding the role of biomass as an energy source. In particular, they support biomass fuels and products as a way to reduce the need for oil and gas imports; as a way of supporting the growth of agriculture, forestry, and rural economies; and as a way to foster major new domestic industries in the form of biorefineries that manufacture a variety of fuels, chemicals, and other products. The purpose of this analysis was to determine if the land resources of the United States are sufficient to support a large-scale biorefinery industry capable of displacing a significant fraction of our nation's petroleum consumption. This study found that the combined forest and agriculture land resources have the potential of sustainably supplying much more than one-third of the nation's current petroleum consumption.

Forest lands, and in particular, timberlands, have the potential to sustainably produce close to 370 million dry tons of biomass annually. This estimate includes the use of residues generated in the manufacture of various forest products and the use of residues generated in the use of manufactured forest products. It also includes the harvest of wood for various residential and commercial space-heating applications. With the exception of urban wood wastes, most of these sources of forest biomass are currently being utilized and there are significant efforts under way to use these resources much more efficiently. Two potentially large sources of forest biomass not currently being used are logging and other removal residues and fuel treatment thinnings. These sources can sustainably contribute over 120 million dry tons annually. The logging and other removal residues can easily be recovered following commercial harvest and land clearing operations. Fuel treatment thinnings can also be recovered concomitantly with efforts to reduce forest fire hazards and otherwise improve the health of our nation's forests.

Agricultural lands can provide more than 900 million dry tons of sustainably collectable biomass and continue to meet food, feed and export demands. This estimate includes 425 million dry tons of crop residues, 377 million dry tons of perennial crops, 56 million dry tons of grains used for biofuels, and 75 million dry tons of animal manures, process residues, and other residues generated in the consumption food products. The perennial crops are crops dedicated primarily for bioenergy and biobased products and will likely include a combination of grasses and woody crops. Providing this level of biomass will require increasing yields of corn, wheat, and other small grains by 50%; doubling residue-to-grain ratios for soybeans; developing much more efficient residue harvesting equipment; managing active cropland with no-till cultivation; growing perennial crops whose output is primarily dedicated for bioenergy purposes on 55 million acres of cropland, idle cropland, and cropland pasture; using animal manure in excess of what can be applied on-farm for soil improvement for bioenergy; and using a larger fraction of other secondary and tertiary residues for bioenergy.

In the context of the time required to scale-up to a large-scale biorefinery industry, the annual biomass potential of 1.3 billion dry tons can be produced with relatively modest changes in land use and agricultural and forestry practices. Moreover, this estimated potential is not an upper limit. It is just one scenario and scientists in the Departments of Energy and Agriculture will continue to explore more advanced scenarios that could increase the amount of biomass available for bioenergy and biobased products further.

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GLOSSARY

Annual removals – The net volume of growing stock trees removed from the inventory during a specified year by harvesting, cultural operations such as timber stand improvement, or land clearing.

Asexual reproduction – The naturally occurring ability of some plant species to reproduce asexually through seeds, meaning the embryos develop without a male gamete. This ensures the seeds will produce plants identical to the mother plant.

Biobased product – The term 'biobased product' as defined by Farm Security and Rural Investment Act (FSRIA), means a product determined by the U.S. Secretary of Agriculture to be a commercial or industrial product (other than food or feed), that is composed in whole or in significant part, of biological products or renewable domestic agricultural materials (including plant, animal, and marine materials) or forestry materials.

Bioenergy – Useful, renewable energy produced from organic matter – the conversion of the complex carbohydrates in organic matter to energy. Organic matter may either be used directly as a fuel, processed into liquids and gasses, or be a residual of processing and conversion.

Biodiesel – Fuel derived from vegetable oils or animal fats. It is produced by when a vegetable oil or animal fat is chemically reacted with an alcohol.

Biorefinery – A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can be based on a number of processing platforms using mechanical, thermal, chemical, and biochemical processes.

Biofuels – Fuels made from biomass resources, or their processing and conversion derivatives. Biofuels include ethanol, biodiesel, and methanol.

Biomass – Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood wastes and residues, plants (including aquatic plants), grasses, residues, fibers, and animal wastes, municipal wastes, and other waste materials. Biomass is generally produced in a sustainable manner from water and carbon dioxide by photosynthesis. There are three main categories of biomass – primary, secondary, and tertiary.

Biopower – The use of biomass feedstock to produce electric power or heat through direct combustion of the feedstock, through gasification and then combustion of the resultant gas, or through other thermal conversion processes. Power is generated with engines, turbines, fuel cells, or other equipment.

Black Liquor – Solution of lignin-residue and the pulping chemicals used to extract lignin during the manufacture of paper.

Coarse materials – Wood residues suitable for chipping, such as slabs, edgings, and trimmings.

Commercial species – Tree species suitable for industrial wood products.

Conservation Reserve Program – CRP provides farm owners or operators with an annual per-acre rental payment and half the cost of establishing a permanent land cover, in exchange for retiring environmentally sensitive cropland from production for 10- to 15-years. In 1996, Congress reauthorized CRP for an additional round of contracts, limiting enrollment to 36.4 million acres at any time. The 2002 Farm Act increased the enrollment limit to 39 million acres. Producers can offer land for competitive bidding based on an Environmental Benefits Index (EBI) during periodic signups, or can automatically enroll more limited acreages in practices such as riparian buffers, field windbreaks, and grass strips on a continuous basis. CRP is funded through the Commodity Credit Corporation (CCC).

Cropland – Total cropland includes five components: cropland harvested, crop failure, cultivated summer fallow, cropland used only for pasture, and idle cropland.

Cropland used for crops – Cropland used for crops includes cropland harvested, crop failure, and cultivated summer fallow. **Cropland harvested** includes row crops and closely sown crops; hay and silage crops; tree fruits, small fruits, berries, and tree nuts; vegetables and melons; and miscellaneous other minor crops. In recent years, farmers have double-cropped about 4 percent of this acreage. **Crop failure** consists mainly of the acreage on which crops failed because of weather, insects, and diseases, but includes some land not harvested due to lack of labor, low market prices, or other factors. The acreage planted to cover and soil improvement crops not intended for harvest is excluded from crop failure and is considered idle. **Cultivated summer fallow** refers to cropland in sub-humid regions of the West cultivated for one or more seasons to control weeds and accumulate moisture before small grains are planted. This practice is optional in some areas, but it is a requirement for crop production in the drier cropland areas of the West. Other types of fallow, such as cropland planted to soil improvement crops but not harvested and cropland left idle all year, are not included in cultivated summer fallow but are included as idle cropland.

Cropland pasture – Land used for long-term crop rotation. However, some cropland pasture is marginal for crop uses and may remain in pasture indefinitely. This category also includes land that was used for pasture before crops reached maturity and some land used for pasture that could have been cropped without additional improvement.

Cull tree – A live tree, 5.0 inches in diameter at breast height (d.b.h.) or larger that is non-merchantable for saw logs now or prospectively because of rot, roughness, or species. (See definitions for rotten and rough trees.)

d.b.h. – The diameter measured at approximately breast high from the gorund.

Feedstock – A product used as the basis for manufacture of another product.

Fiber products – Products derived from fibers of herbaceous and woody plant materials. Examples include pulp, composition board products, and wood chips for export.

Fine materials – Wood residues not suitable for chipping, such as planer shavings and sawdust.

Forest land – Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10 percent stocked with forest trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet wide.

Fuel Treatment Evaluator (FTE) – A strategic assessment tool capable of aiding the identification, evaluation, and prioritization of fuel treatment opportunities.

Fuelwood – Wood used for conversion to some form of energy, primarily in residential use.

Grassland pasture and range – Grassland pasture and range comprises all open land used primarily for pasture and grazing, including shrub and brush land types of pasture; grazing land with sagebrush and scattered mesquite; and all tame and native grasses, legumes, and other forage used for pasture or grazing. Because of the diversity in vegetative composition, grassland pasture and range are not always clearly distinguishable from other types of pasture and range. At one extreme, permanent grassland may merge with cropland pasture, or grassland may often be found in transitional areas with forested grazing land.

Growing stock – A classification of timber inventory that includes live trees of commercial species meeting specified standards of quality or vigor. Cull trees are excluded. When associated with volume, includes only trees 5.0 inches d.b.h. and larger.

Idle cropland – Land in cover and soil improvement crops and cropland on which no crops were planted. Some cropland is idle each year for various physical and economic reasons. Acreage diverted from crops to soil-conserving uses (if not eligible for and used as cropland pasture) under Federal farm programs is included in this component. Cropland enrolled in the Federal Conservation Reserve Program (CRP) is included in idle cropland.

Industrial wood – All commercial roundwood products except fuelwood.

Live cull – A classification that includes live cull trees. When associated with volume, it is the net volume in live cull trees that are 5.0 inches d.b.h. and larger.

Logging residues – The unused portions of growing-stock and non-growing-stock trees cut or killed by logging and left in the woods.

Nonforest land – Land that has never supported forests and lands formerly forested where use of timber management is precluded by development for other uses. (Note: Includes area used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 4.5-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide, and clearings, etc., must be more than 1 acre in area, to qualify as nonforest land.)

Nonindustrial private – An ownership class of private lands where the owner does not operate wood-using processing plants.

Other forest land – Forest land other than timberland and reserved forest land. It includes available forest land, which is incapable of annually producing 20 cubic feet per acre of industrial wood under natural conditions because of adverse site conditions such as sterile soils, dry climate, poor drainage, high elevation, steepness, or rockiness.

Other removals – Unutilized wood volume from cut or otherwise killed growing stock, from cultural operations such as precommercial thinnings, or from timberland clearing. Does not include volume removed from inventory through reclassification of timberland to productive reserved forest land.

Other sources – Sources of roundwood products that are not growing stock. These include salvable dead, rough and rotten trees, trees of noncommercial species, trees less than 5.0 inches d.b.h., tops, and roundwood harvested from nonforest land (for example, fence rows).

Poletimber trees – Live trees at least 5.0 inches in d.b.h. but smaller than sawtimber trees.

Primary wood-using mill – A mill that converts roundwood products into other wood products. Common examples are sawmills that convert saw logs into lumber and pulp mills that convert pulpwood roundwood into wood pulp.

Pulpwood – Roundwood, whole-tree chips, or wood residues that are used for the production of wood pulp.

Residues – Bark and woody materials that are generated in primary wood-using mills when roundwood products are converted to other products. Examples are slabs, edgings, trimmings, sawdust, shavings, veneer cores and clippings, and pulp screenings. Includes bark residues and wood residues (both coarse and fine materials) but excludes logging residues.

Rotten tree – A live tree of commercial species that does not contain a saw log now or prospectively primarily because of rot (that is, when rot accounts for more than 50 percent of the total cull volume).

Rough tree – (a) A live tree of commercial species that does not contain a saw log now or prospectively primarily because of roughness (that is, when sound cull due to such factors as poor form, splits, or cracks accounts for more than 50 percent of the total cull volume) or (b) a live tree of noncommercial species.

Roundwood products – Logs and other round timber generated from harvesting trees for industrial or consumer use.

Salvable dead tree – A downed or standing dead tree that is considered currently or potentially merchantable by regional standards.

Saplings – Live trees 1.0 inch through 4.9 inches d.b.h.

Secondary wood processing mills – A mill that uses primary wood products in the manufacture of finished wood products, such as cabinets, moldings, and furniture.

Sound dead – The net volume in salvable dead trees.

Timberland – Forest land that is producing or is capable of producing crops of industrial wood, and that is not withdrawn from timber utilization by statute or administrative regulation. Areas qualifying as timberland are capable of producing more than 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.

Timber Product Output Database Retrieval System (TPO) – Developed in Support of the 1997 Resources Planning Act (RPA) Assessment. This system acts as an interface to a standard set of consistently coded TPO data for each State and county in the Country. This national set of TPO data consists of 11 data variables that describe for each county the roundwood products harvested, the logging residues left behind, the timber otherwise removed, and the wood and bark residues generated by its primary wood-using mills.

Appendix A: Forest Resource Analysis

Table A.1 – Current availability of logging residue and other removals

Forest resource	National forest	Other public	Private lands	Total
		Million dry tons		
Logging residues	1.1	3.2	44.4	48.8
Other removals	0.5	0.7	17.1	18.3
Total	1.6	3.9	61.5	67.1

Source: Timber Product Output database (USDA-FS, 2004).
Note: Conversion of volumetric from the Forest Inventory Analysis and Timber Product Output databases an average density of 30 dry lbs/ft^3.

Table A.2 – Availability factors for logging residue and other removals under current recovery conditions

Forest resource	Portion of forest resource available				Harvest frequency
	Accessible fraction	Recovery fraction	Biomass fraction	Total availability	
Logging residue					
Public	1	0.65	1	0.65	Annually
Private	1	0.65	1	0.65	Annually
Other removals					
Public	1	0.5	1	0.5	Annually
Private	1	0.5	1	0.5	Annually

Notes: Logging residue and residue from other removals are assumed to be 100% accessible provided these materials are removed concurrently with harvest and/or land clearing operations. Recovery fractions are based on field studies and average site conditions. The lower recovery fraction for other removals is because of generally smaller parcel size making collection more difficult. Generally, the small and scattered piece-size limits the recovery of this material. All recovered material is assumed to be available as a feedstock for bioenergy and biobased products.

Table A.3 – Availability of logging residue and other removals under current recovery conditions

Forest resource	National forest	Other public	Private lands	Total
	Million dry tons			
Logging residues	0.7	2.1	28.9	31.7
Other removals	0.3	0.4	8.5	9.2
Total	1.0	2.5	37.4	40.9

Notes: Availability of logging and other removal residue is based on the product of the total resource size (Table A.1) and availability factor (Table A.2).

Table A.4 – Availability of logging residue and other removals under future growth and recovery conditions

Forest resource	National forest	Other public	Private lands	Total
	Million dry tons			
Logging residues	1.0	3.1	42.3	46.4
Other removals	0.5	0.7	16.3	17.4
Total	1.5	3.8	58.5	63.8

Notes: Under future conditions (mid-century), harvested roundwood products are assumed to increase by 35% and 47% for softwoods and hardwoods, respectively. The amount of logging residue generated is assumed to decline from 6.7% to 6% for softwoods and from 12.4% to 9% for hardwoods. These assumptions are derived from Haynes (2003). The fraction of recoverable logging and other removal residue is assumed to increase by 20%.

Table A.5 – Total fuel treatment thinnings resource

Forest resource	National forest	Other public	Private lands	Total
		Million dry tons		
Timberland	1,849	770	5,175	7,794
Other forest land	147	158	310	616
Total	1996	928	5486	8410

Note: Conversion of volumetric Forest Inventory Analysis data assumes 30 dry lbs/ft^3.
Tree volumes were partitioned into two utilization groups – trees greater than 7 inches taken to a 4 inch minimum top diameter and the remaining smaller material (tops, limbs, small diameter trees). The larger-sized material was assumed merchantable for higher-valued products and the smaller-sized material suitable for bioenergy and biobased products.

Table A.6 – Assumed availability factors for fuel treatment thinnings

Forest resource	Portion of forest resource available				Harvest frequency
	Accessible Fraction	Recovery fraction	Biomass fraction	Total availability	
Timberland					
Public	0.6	0.85	0.3	0.15	30 years
Private	0.8	0.85	0.3	0.20	30 years
Other forest land					
Public	0.6	0.85	0.9	0.46	30 years
Private	0.8	0.85	0.9	0.61	30 years

Notes: These assumptions are based in part on from USDA-FS (2003) and from Stokes et al. (2004).

Table A.7 – Availability of fuel treatment thinnings

Forest resource	National forest	Other public	Private lands	Total
	Million dry tons			
Timberland	9.4	3.9	35.2	48.6
Other forest land	2.2	2.4	6.3	11.0
Total	11.7	6.3	41.5	59.6

Notes: Availability of fuel treatment thinnings is based on the product of the total resource size (Table A.5) and availability factors (Table A.6) divided by the harvest frequency (Table A.6).

Table A.8 – Forest products industry processing residues

	Mill residue byproducts (tons)			
Source	Energy	Product and other uses	Unused	Total
Primary wood processing mills	39.4	50.3	1.7	93.1
Secondary wood processing mills	--	9.5	6.1	15.6
Pulp and paper mills	52.1	--	--	52.1

Source: Timber Product Output database (USDA-FS, 2004).
Notes: Primary wood processing mills account for 91.3 million dry tons split among bark, coarse wood, and fine wood in the following proportions – 26.5%, 42.9%, and 30.7%, respectively.
Mill residues are projected to increase by about 30% and somewhat less for black liquor generated at pulp and paper mills.

Table A.9 – Summary availability of urban wood wastes

Urban wood waste source	Disposition of waste		
	Generated	Recovered, combusted for energy & unusable	Available
	Million dry tons		
Construction waste	11.6	3.0	8.6
Demolition debris	27.7	16.1	11.7
Woody yard trimmings (MSW)	9.8	8.0	1.7
Wood (MSW)	13.2	7.3	6.0
Total	62.3	34.4	28.0

Source: McKeever (2004).
Notes: Woody yard trimmings were converted to dry tons based on 40% moisture content.
The amount of urban wood waste generated is estimated to increase by about 30%. This estimate is based on trends associated with residential and nonresidential construction, demolition, and remodeling, as well as in the disposal of durables and packaging wastes.

Appendix B: Agriculture Resource Analysis

Table B.1 – Comparison of USDA Baseline for Major Crops with Change Scenarios

Major crop	USDA Baseline		Technology changes without land use change, no perennial crops		Technology changes with land use change to accommodate perennial crops	
	2001	**2013**	**Moderate**	**High**	**Moderate**	**High**
Corn						
Harvested acres (millions)	68.8	73.8	68.8	68.8	68.8	63.8
Yield (bushels/acre)	138.2	158.5	172.8	207.3	172.8	207.3
Production (thousand bushels)	9,506,840	11,695,000	11,886,582	14,263,898	11,886,582	13,225,740
Total grain supply (000's bushels)	11,416,000	12,949,000				
Use (000's bushels)						
Food, Seed, Res. (000's bushels)	1,340,000	1,480,000	1,480,000	1,820,400	1,480,000	1,820,400
Animal Feed (000's bushels)	5,874,000	6,025,000	6,025,000	6,627,500	6,025,000	6,627,500
Export (000's bushels)	1,889,000	2,875,000	2,875,000	3,162,500	2,875,000	3,162,500
Industry/fuel (000's bushels)	714,000	1,360,000	1,506,582	2,653,498	1,506,582	1,615,340
Stocks (000's bushels)	1,599,000	1,209,000				
Total grain Use (000's bushels)	11,416,000	12,949,000	11,886,582	14,263,898	11,886,582	13,225,740
Wheat						
Harvested acres (millions)	48.8	51.0	48.8	48.8	48.8	43.8
Yield (bushels/acre)	40.1	44.9	50.2	60.2	50.2	60.4
Production (thousand bushels)	1,957,043	2,290,000	2,445,813	2,934,975	2,445,813	2,643,975
Total grain supply (000's bushels)	2,941,000	3,141,000				
Use (000's bushels)						
Food, Seed, Res. (000's bushels)	1,010,000	1,010,000	1,010,000	1,242,300	1,010,000	1,242,300
Animal Feed (000's bushels)	193,000	295,000	295,000	295,000	295,000	295,000
Export (000's bushels)	961,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000
Industry/fuel (000's bushels)			40,813	297,675	40,813	6,675
Stocks (000's bushels)	777,000	736,000				
Total grain Use (000's bushels)	2,941,000	3,141,000	2,445,813	2,934,975	2,445,813	2,643,975
Soybeans						
Harvested acres (millions)	73.0	71.2	73.0	73.0	73.0	63.0
Yield (bushels/acre)	39.6	43.7	45.5	51.5	45.5	51.5
Production (thousand bushels)	2,890,682	3,110,000	3,324,420	3,758,040	3,324,420	3,243,240
Total grain supply (000's bushels)	3,140,749	3,331,000				
Use (000's bushels)						
Food, Seed, Res. (000's bushels)	440,621	321,905	321,905	395,943	321,905	395,943
Animal Feed (000's bushels)	1,102,333	1,285,000	1,285,000	1,285,000	1,285,000	1,285,000
Export (000's bushels)	1,356,250	1,290,833	1,290,833	1,290,833	1,290,833	1,290,833
Industry/fuel (000's bushels)	8,929	178,571	426,682	786,264	426,682	271,464
Stocks (000's bushels)	255,317	252,583				
Total grain Use (000's bushels)	3,163,450	3,328,893	3,324,420	3,758,040	3,324,420	3,243,240

Table B.2 – Current availability of biomass from agricultural lands – baseline summary

Crop	Acres harvested or reserved	Product yield	Fiber yield	Residue yield	Total cropland plant mass	Harvested product production	Total residue produced	Residue logistically removable	Residue sustainably removable	Grains used for bioenergy	Secondary & tertiary residues available	Total sustainable biomass
	Million acres	------------------Dry tons/acre/year------------------			------------------Million dry tons/year------------------							
Corn grain	68.8	3.3	na	3.3	450.0	225.0	225.0	90.0	74.8	16.9		91.7
Sorghum	8.6	1.4	na	1.4	24.8	12.4	12.4	5.0	0.0	0.5		0.5
Barley	4.3	1.2	na	1.8	12.8	7.7	7.7	3.1	0.8	0.3		1.2
Oats	1.9	0.8	na	1.7	4.8	3.2	3.2	1.3	0.2	0.0		0.2
Wheat-winter	31.3	1.1	na	1.9	95.4	60.1	60.1	24.0	10.0	0.0		10.0
Wheat-spring	17.5	0.9	na	1.2	35.5	20.1	20.1	8.0	2.6	0.0		2.6
Soybeans	73.0	1.1	na	1.6	193.0	115.8	115.8	46.3	0.0	0.2		0.2
Rice	3.3	2.9	na	4.3	23.7	14.2	14.2	5.7	5.7	0.0		5.7
Cotton lint	13.8	0.3	na	1.0	17.7	13.3	13.3	2.7	2.7	0.0		2.7
Alfalfa	23.8	3.0	na	0.0	70.6	0.0	0.0	0.0	0.0	0.0		0.0
Other Hay	39.7	1.7	na	0.0	67.4	0.0	0.0	0.0	0.0	0.0		0.0
Silage corn	6.1	6.6	na	0.0	40.8	0.0	0.0	0.0	0.0	0.0		0.0
Silage sorghum	0.3	4.4	na	0.0	1.5	0.0	0.0	0.0	0.0	0.0		0.0
Other Crops	20.1	1.0	na	1.0	20.1	20.1	20.1	18.1	18.1	0.0		18.1
Double Crops								0.0	0.0	0.0		0.0
Crop failure	10.0	0.5	na	0.0	5.0	0.0	0.0	0.0	0.0	0.0		0.0
Summer fallow	21.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Grasses (CRP)	25.4	2.0	na	0.0	50.8	0.0	0.0	0.0	0.0	0.0		0.0
Trees (CRP)	2.2	2.0	na	0.0	4.4	0.0	0.0	0.0	0.0	0.0		0.0
Environment (CRP)	6.4	2.0	na	0.0	12.7	0.0	0.0	0.0	0.0	0.0		0.0
Unaccounted	3.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Pasture	67.5	1.5	na	0.0	101.3	0.0	0.0	0.0	0.0	0.0		0.0
Wood fiber	0.1	0.0	6.0	2.0	0.8	0.6	0.2	0.2	0.2	0.0		0.2
Perennials	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Manure			na	na	na	na	54.9				35.1	35.1
Fats & greases							3.5				0.9	0.9
MSW											23.7	23.7
Totals	448.1	37.7	6.0	21.1	1233.1	492.4	550.4	204.3	115.0	18.0	59.7	192.7

Table B.3 – Summary of biomass from agricultural lands under moderate crop yield increases without land use change

Crop	Acres harvested or reserved	Product yield	Fiber yield	Residue yield	Total cropland plant mass	Harvested product production	Total residue produced	Residue logistically removable	Residue sustainably removable	Grains used for bioenergy	Secondary & tertiary residues available	Total sustainable biomass
	Million acres	------------------Dry tons/acre/year------------------			----------Million dry tons/year----------							
Corn grain	68.8	4.1	na	4.1	562.5	281.2	281.2	168.7	152.5	35.6		188.1
Sorghum	8.6	1.8	na	1.8	31.0	15.5	15.5	9.3	3.7	1.1		4.8
Barley	4.3	1.5	na	2.2	16.0	6.4	9.6	5.8	3.7	0.7		4.4
Oats	1.9	1.1	na	2.1	6.0	2.0	4.0	2.4	1.4	0.0		1.4
Wheat-winter	31.3	1.4	na	2.4	119.2	44.2	75.1	45.0	32.1	0.0		32.1
Wheat-spring	17.5	1.1	na	1.4	44.4	19.3	25.1	15.1	10.1	0.0		10.1
Soybeans	73.0	1.2	na	1.8	221.9	88.8	133.1	79.9	0.0	11.4		11.4
Rice	3.3	3.3	na	4.9	27.2	9.5	16.3	9.8	9.8	0.0		9.8
Cotton lint	13.8	0.4	na	1.1	20.4	5.1	15.3	6.1	6.1	0.0		6.1
Alfalfa	23.8	3.4	na	0.0	81.2	81.2	0.0	0.0	0.0	1.1		1.1
Other Hay	39.7	2.0	na	0.0	77.5	77.5	0.0	0.0	0.0	0.0		0.0
Silage corn	6.1	7.6	na	0.0	46.9	46.9	0.0	0.0	0.0	0.0		0.0
Silage sorghum	0.3	5.1	na	0.0	1.7	1.7	0.0	0.0	0.0	0.0		0.0
Other Crops	20.1	1.2	na	1.2	23.1	23.1	23.1	20.8	20.8	2.0		22.8
Double Crops								10.0	10.0	2.0		12.0
Crop failure	10.0	0.5	na	0.0	5.0	0.0	0.0	0.0	0.0	0.0		0.0
Summer fallow	21.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Grasses (CRP)	25.4	2.0	na	0.0	50.8	0.0	0.0	0.0	0.0	0.0		0.0
Trees (CRP)	2.2	2.0	na	0.0	4.4	0.0	0.0	0.0	0.0	0.0		0.0
Environment (CRP)	6.4	2.0	na	0.0	12.7	0.0	0.0	0.0	0.0	0.0		0.0
Unaccounted	3.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Pasture	67.5	1.5	na	0.0	101.3	0.0	0.0	0.0	0.0	0.0		0.0
Wood fiber	0.1	0.0	6.0	2.0	0.8	0.6	0.2	0.2	0.2	0.0		0.2
Perennials	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Manure			na	na	na	na	68.0				43.5	43.5
Fats & greases							5.0				2.0	2.0
MSW											29.4	29.4
Totals	448.1	43.1	6.0	25.1	1454.1	703.1	671.6	373.1	250.5	53.9	74.9	379.3

Table B.4 – Summary of biomass from agricultural lands under high crop yield increase without land use change

Crop	Acres harvested or reserved	Product yield	Fiber yield	Residue yield	Total cropland plant mass	Harvested product production	Total residue produced	Residue logistically removable	Residue sustainably removable	Grains used for bioenergy	Secondary & tertiary residues available	Total sustainable biomass
	Million acres	------------------Dry tons/acre/year------------------			--Million dry tons/year--							
Corn grain	68.8	4.9	na	4.9	675.0	337.5	337.5	253.1	230.1	62.8		292.9
Sorghum	8.6	2.2	na	2.2	37.1	18.6	18.6	13.9	8.8	1.9		10.6
Barley	4.3	1.8	na	2.7	19.2	7.7	11.5	8.6	6.6	1.3		7.9
Oats	1.9	1.3	na	2.5	7.2	2.4	4.8	3.6	2.6	0.0		2.6
Wheat-winter	31.3	1.7	na	2.9	143.1	53.0	90.1	67.6	54.3	0.0		54.3
Wheat-spring	17.5	1.3	na	1.7	53.3	23.2	30.1	22.6	17.6	0.0		17.6
Soybeans	73.0	1.4	na	2.1	250.8	100.3	150.5	112.9	26.2	21.0		47.2
Rice	3.3	3.7	na	5.6	30.8	9.5	18.5	13.9	13.9	0.0		13.9
Cotton lint	13.8	0.4	na	1.3	23.1	5.8	17.3	10.4	10.4	0.0		10.4
Alfalfa	23.8	3.9	na	0.0	91.8	91.8	0.0	0.0	0.0	0.0		0.0
Other Hay	39.7	2.2	na	0.0	87.7	87.7	0.0	0.0	0.0	0.0		0.0
Silage corn	6.1	8.6	na	0.0	53.1	53.1	0.0	0.0	0.0	0.0		0.0
Silage sorghum	0.3	5.8	na	0.0	1.9	1.9	0.0	0.0	0.0	0.0		0.0
Other Crops	20.1	1.3	na	1.3	26.1	26.1	26.1	23.5	23.5	4.0		27.5
Double Crops									15.0	4.0		19.0
Crop failure	10.0	0.5	na	0.0	5.0	0.0	0.0	0.0	0.0	0.0		0.0
Summer fallow	21.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Grasses (CRP)	25.4	2.0	na	0.0	50.8	0.0	0.0	0.0	0.0	0.0		0.0
Trees (CRP)	2.2	2.0	na	0.0	4.4	0.0	0.0	0.0	0.0	0.0		0.0
Environment (CRP)	6.4	2.0	na	0.0	12.7	0.0	0.0	0.0	0.0	0.0		0.0
Unaccounted	3.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Pasture	67.5	1.5	na	0.0	101.3	0.0	0.0	0.0	0.0	0.0		0.0
Wood fiber	0.1	0.0	6.0	2.0	0.8	0.6	0.2	0.2	0.2	0.0		0.2
Perennials	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Manure			na	na	na	na	68.0				43.5	43.5
Fats & greases							5.0				2.0	2.0
MSW											29.4	29.4
Totals	448.1	48.4	6.0	29.1	1675.2	819.1	778.2	530.3	409.1	94.9	74.9	579.0

Table B.5 – Summary of biomass from agricultural lands under moderate crop yield increase with land use change

Crop	Acres harvested or reserved	Product yield	Fiber yield	Residue yield	Total cropland plant mass	Harvested product production	Total residue produced	Residue logistically removable	Residue sustainably removable	Grains used for bioenergy	Secondary & tertiary residues available	Total sustainable biomass
	Million acres	------------------Dry tons/acre/year------------------			---------------------------------Million dry tons/year---------------------------------							
Corn grain	68.8	4.1	na	4.1	562.5	281.2	281.2	168.7	152.5	35.6		188.1
Sorghum	8.6	1.8	na	1.8	31.0	15.5	15.5	9.3	3.7	1.1		4.8
Barley	4.3	1.5	na	2.2	16.0	6.4	9.6	5.8	3.7	0.7		4.4
Oats	1.9	1.1	na	2.1	6.0	2.0	4.0	2.4	1.4	0.0		1.4
Wheat-winter	31.3	1.4	na	2.4	119.2	44.2	75.1	45.0	32.1	1.1		33.2
Wheat-spring	17.5	1.1	na	1.4	44.4	19.3	25.1	15.1	10.1	0.0		11.2
Soybeans	73.0	1.2	na	2.4	266.3	88.8	177.5	106.5	28.4	11.4		39.8
Rice	3.3	3.3	na	4.9	27.2	9.5	16.3	9.8	9.8	0.0		9.8
Cotton lint	13.8	0.4	na	1.1	20.4	5.1	15.3	6.1	6.1	0.0		6.1
Alfalfa	23.8	3.4	na	0.0	81.2	81.2	0.0	0.0	0.0	0.0		0.0
Other Hay	39.7	2.0	na	0.0	77.5	77.5	0.0	0.0	0.0	0.0		0.0
Silage corn	6.1	7.6	na	0.0	46.9	46.9	0.0	0.0	0.0	0.0		0.0
Silage sorghum	0.3	5.1	na	0.0	1.7	1.7	0.0	0.0	0.0	0.0		0.0
Other Crops	20.1	1.2	na	1.2	23.1	23.1	23.1	20.8	20.8	2.0		22.8
Double Crops									10.0	2.0		12.0
Crop failure	10.0	0.5	na	0.0	5.0	0.0	0.0	0.0	0.0	0.0		0.0
Summer fallow	16.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Grasses (CRP)	15.4	2.0	na	0.0	30.8	0.0	0.0	0.0	0.0	0.0		0.0
Trees (CRP)	2.2	2.0	na	0.0	4.4	0.0	0.0	0.0	0.0	0.0		0.0
Environment (CRP)	6.4	2.0	na	0.0	12.7	0.0	0.0	0.0	0.0	0.0		0.0
Unaccounted	3.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Pasture	42.5	1.5	na	0.0	63.8	0.0	0.0	0.0	0.0	0.0		0.0
Wood fiber	5.1	0.0	6.0	2.0	40.8	30.6	10.2	9.2	9.2	0.0		9.2
Perennials	35.0	0.4	0.0	4.7	175.0	12.3	162.8	146.5	146.5	0.0		146.5
Manure			na	na	na	na	68.0				43.5	43.5
Fats & greases							5.0				2.0	2.0
MSW											29.4	29.4
Totals	448.1	43.4	6.0	30.3	1656.0	745.3	888.7	545.2	434.4	53.9	74.9	563.2

Table B.6 – Summary of biomass from agricultural lands under high crop yield increase with land use change

Crop	Acres harvested or reserved	Product yield	Fiber yield	Residue yield	Total cropland plant mass	Harvested product production	Total residue produced	Residue logistically removable	Residue sustainably removable	Grains used for bioenergy	Secondary & tertiary residues available	Total sustainable biomass
	Million acres	------------------Dry tons/acre/year------------------			------------------Million dry tons/year------------------							
Corn grain	63.8	4.9	na	4.9	625.8	312.9	312.9	234.7	213.3	38.2		251.6
Sorghum	8.6	2.2	na	2.2	37.1	18.6	18.6	13.9	8.8	1.1		9.9
Barley	4.3	1.8	na	2.7	19.2	7.7	11.5	8.6	6.6	0.8		7.4
Oats	1.9	1.3	na	2.5	7.2	2.4	4.8	3.6	2.6	0.0		2.6
Wheat-winter	28.8	1.7	na	2.9	131.6	48.8	82.9	62.2	49.9	0.2		50.1
Wheat-spring	15.0	1.3	na	1.7	45.7	19.9	25.8	19.4	15.1	0.0		15.1
Soybeans	63.0	1.4	na	2.7	259.8	86.6	173.2	129.9	65.9	7.2		73.1
Rice	3.3	3.7	na	5.6	30.8	9.5	18.5	13.9	13.9	0.0		13.9
Cotton lint	13.8	0.4	na	1.3	23.1	5.8	17.3	10.4	10.4	0.0		10.4
Alfalfa	23.8	3.9	na	0.0	91.8	91.8	0.0	0.0	0.0	0.0		0.0
Other Hay	39.7	2.2	na	0.0	87.7	87.7	0.0	0.0	0.0	0.0		0.0
Silage corn	6.1	8.6	na	0.0	53.1	53.1	0.0	0.0	0.0	0.0		0.0
Silage sorghum	0.3	5.8	na	0.0	1.9	1.9	0.0	0.0	0.0	0.0		0.0
Other Crops	20.1	1.3	na	1.3	26.1	26.1	26.1	23.5	23.5	4.0		27.5
Double Crops									15.0	4.0		19.0
Crop failure	10.0	0.5	na	0.0	5.0	0.0	0.0	0.0	0.0	0.0		0.0
Summer fallow	16.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Grasses (CRP)	15.4	2.0	na	0.0	30.8	0.0	0.0	0.0	0.0	0.0		0.0
Trees (CRP)	2.2	2.0	na	0.0	4.4	0.0	0.0	0.0	0.0	0.0		0.0
Environment (CRP)	6.4	2.0	na	0.0	12.7	0.0	0.0	0.0	0.0	0.0		0.0
Unaccounted	3.0	0.0	na	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Pasture	42.5	1.5	na	0.0	63.8	0.0	0.0	0.0	0.0	0.0		0.0
Wood fiber	5.1	0.0	6.0	2.0	40.8	30.6	10.2	9.2	9.2	0.0		9.2
Perennials	55.0	0.6	0.0	7.4	440.0	30.8	409.2	368.3	368.3	0.0		368.3
Manure			na	na	na	na	68.0				43.5	43.5
Fats & greases							5.0				2.0	2.0
MSW											29.4	29.4
Totals	448.1	49.0	6.0	37.2	2038.4	834.0	1184.0	897.5	802.5	55.6	74.9	933.0